Urban Meteorology and Integrated Air Quality Modeling:

applications and new directions using ENVIRO-HIRLAM

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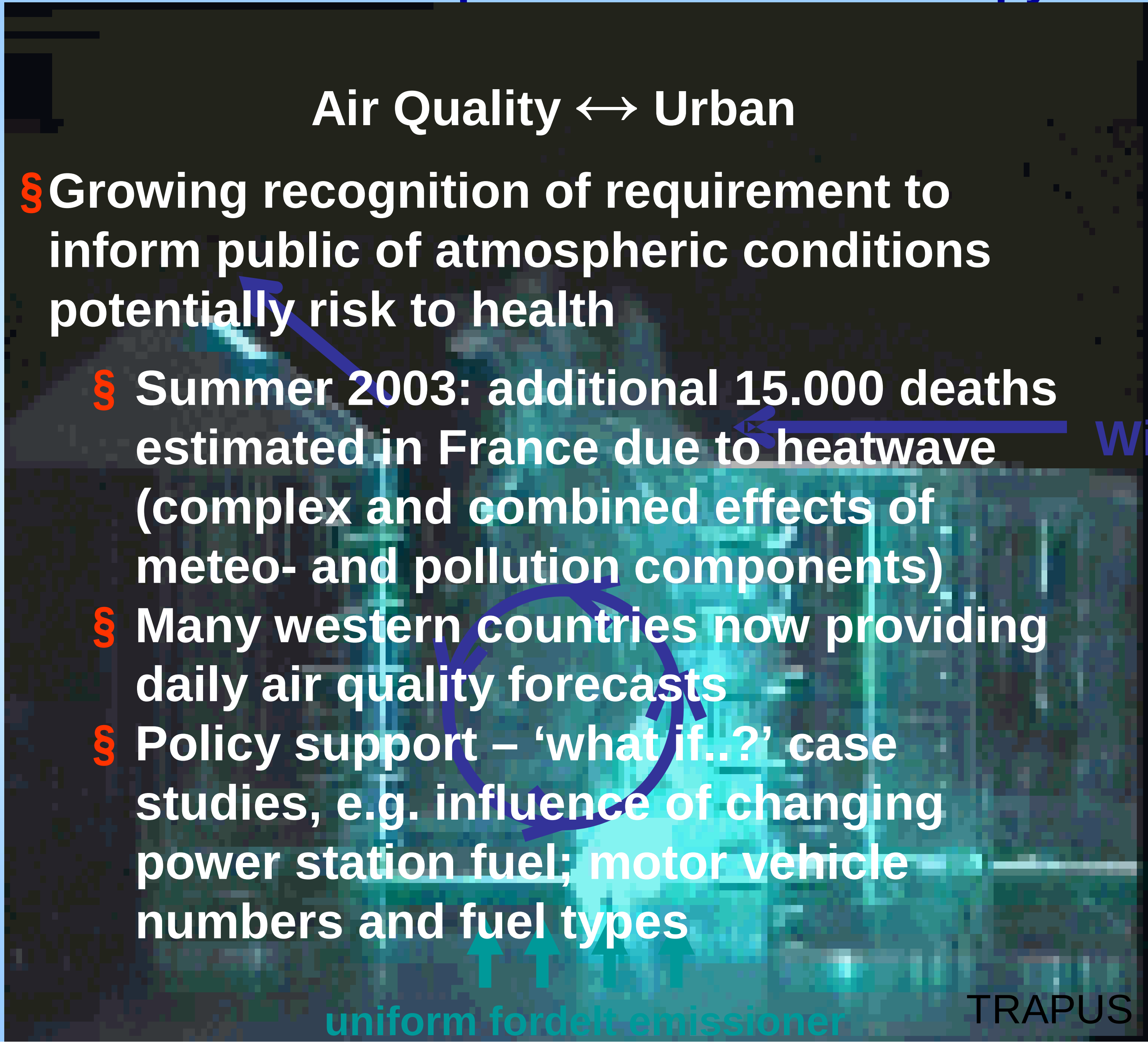
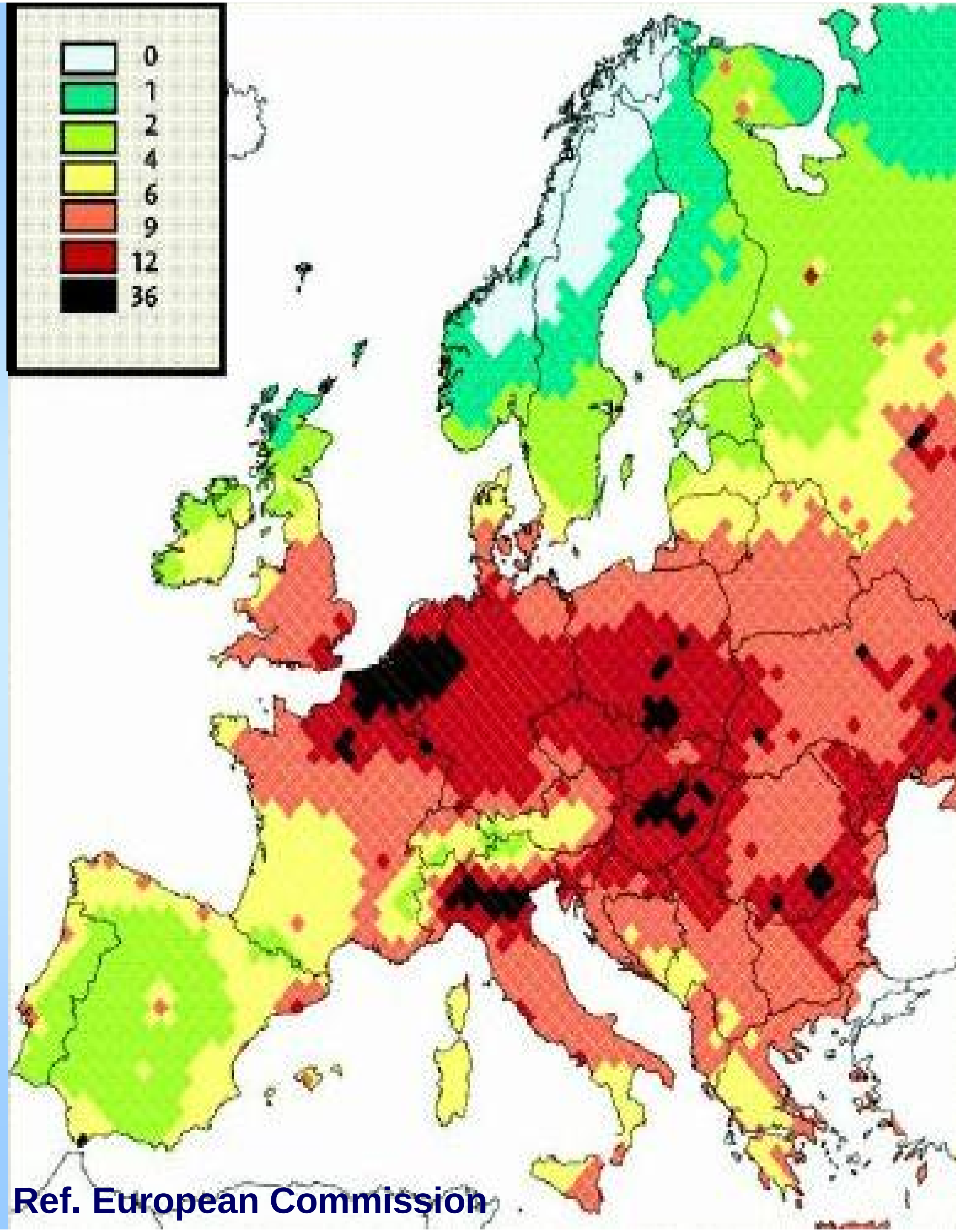
Wind tunnel dispersion for urban canopy

Air Quality ↔ Urban

- Growing recognition of requirement to inform public of atmospheric conditions potentially risk to health
  - Summer 2003: additional 15.000 deaths estimated in France due to heatwave (complex and combined effects of meteo- and pollution components)
  - Many western countries now providing daily air quality forecasts
  - Policy support – 'what if..?' case studies, e.g. influence of changing power station fuel; motor vehicle numbers and fuel types



Number of months air pollutants reduce the life of an European on the average →

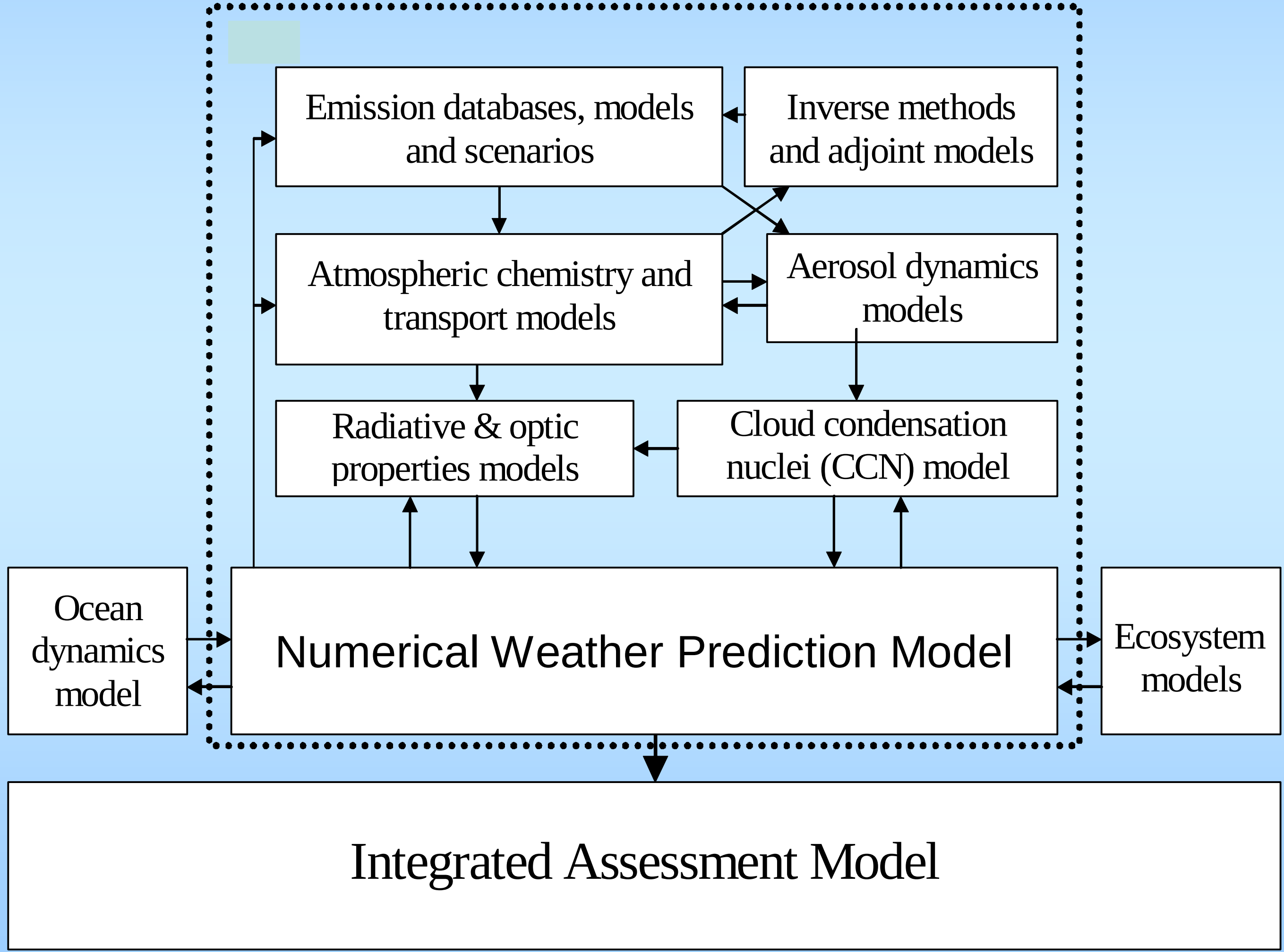


Ref. European Commission

On the average air pollutants reduce nine months of an Europe-an's life.

DMI-Enviro-HIRLAM

New integrated (on-line coupled) modeling system structure for predicting the atmospheric composition



Why develop an on-line coupled modelling system?

Climate modelling:

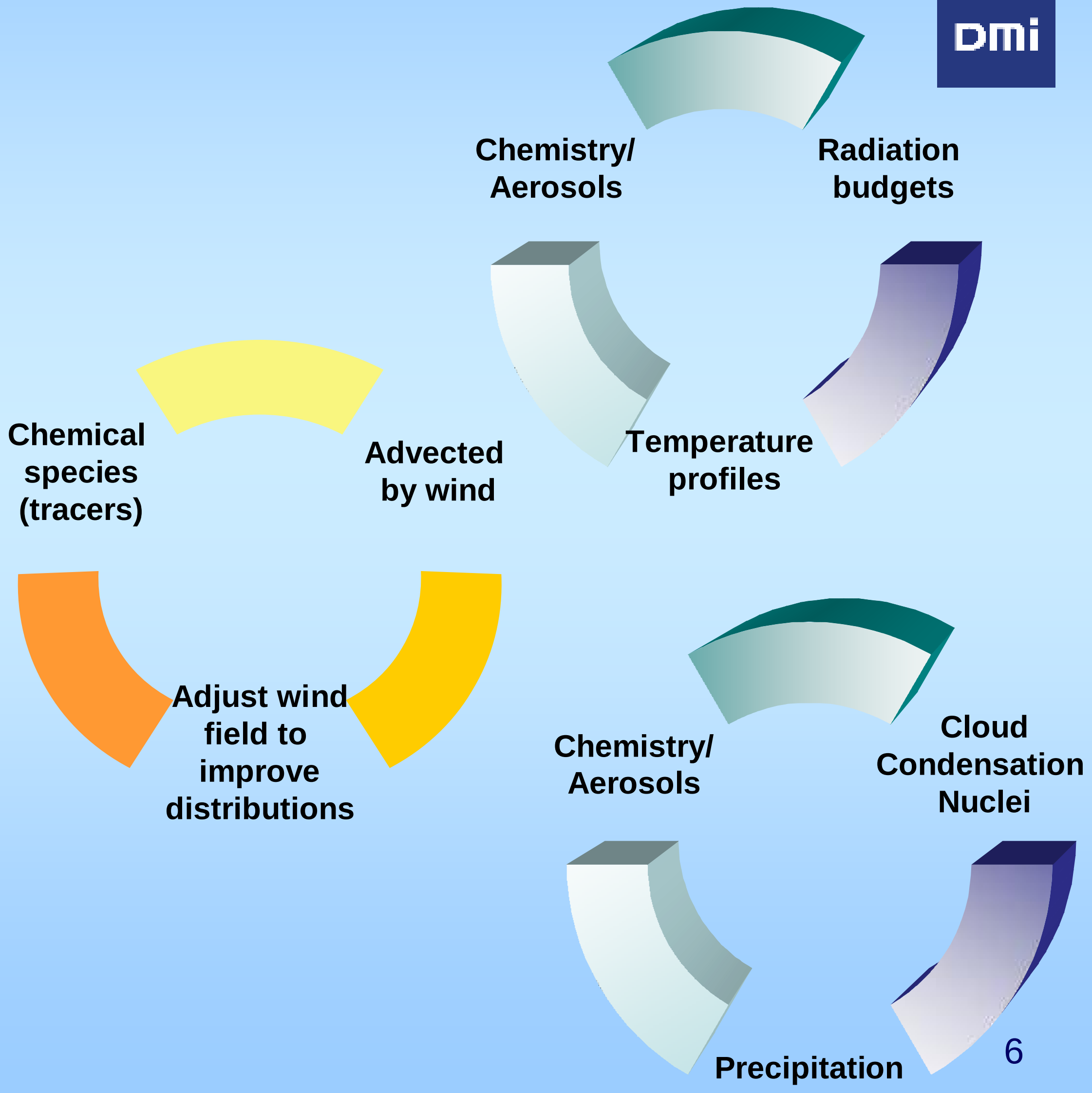
- well established influence of atmospheric composition on long term energy flux budgets, e.g.
  - aerosol radiative properties
  - absorption of short wave radiation by ozone
  - effect of ozone on vegetation yields
- essential to include chemical evolution of atmosphere in long term climate modelling

Why develop an on-line coupled modelling system?

Improvements in NWP models:

Atmospheric composition feedback on NWP forecasts, e.g.

- **Influence of aerosols on radiation budget**
- **Wind increments**
- **Precipitation**



Plan for DMI-ENVIRO-HIRLAM development and applications (2005 -2010)

1st part of presentation: Description of the problems related to using NWP in urban areas.

1. DMI-HIRLAM related continued (2005 – 2007):

- **URBANIZATION**
  - Ø **DMI URBAN MODULE** (cont. cooperation with S. Zilitinkevich, HU, Finland)
  - Ø **SM2_U MODULE** (cont. cooperation with ECN, France)
  - Ø **BEP MODULE** (cont. cooperation with EPFL, Switzerland)
- § **ISBA LAND SURFACE SHEME AND PHYSICS PARAMETRIZATIONS**
- § **LAND USE CLASSIFICATION AND CLIMATE GENERATION FOR HIGH RESOLUTION MODELLING**
- § **ATMOSPHERIC BOUNDARY LAYER HEIGHT PARAMETRIZATIONS**

2nd part of presentation.

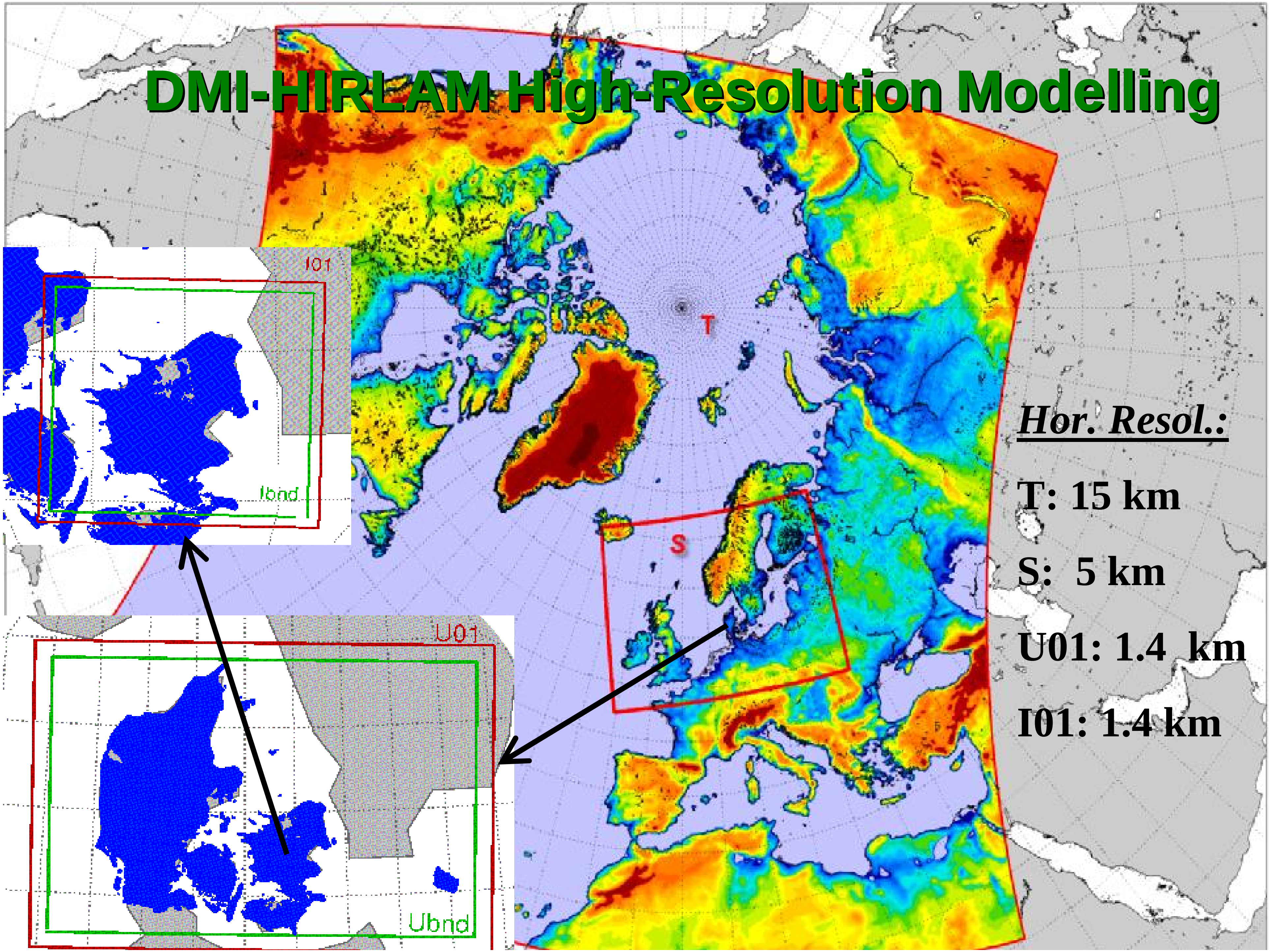
2. Environment Integrated Modelling related:

- **TRACER ADVECTION** (2005-2006)
- **DEPOSITION** (2005-2006)
- **AEROSOLS** (2005 – 2007)
- **POLLEN** (2005 – 2007)
- **CHEMISTRY** (2006 – 2008)
- **FEEDBACKS** (2007 – 2009)

3nd part of presentation, first test of the model.

3. Data assimilation

DMI-HIRLAM High-Resolution Modelling



Hor. Resol.:

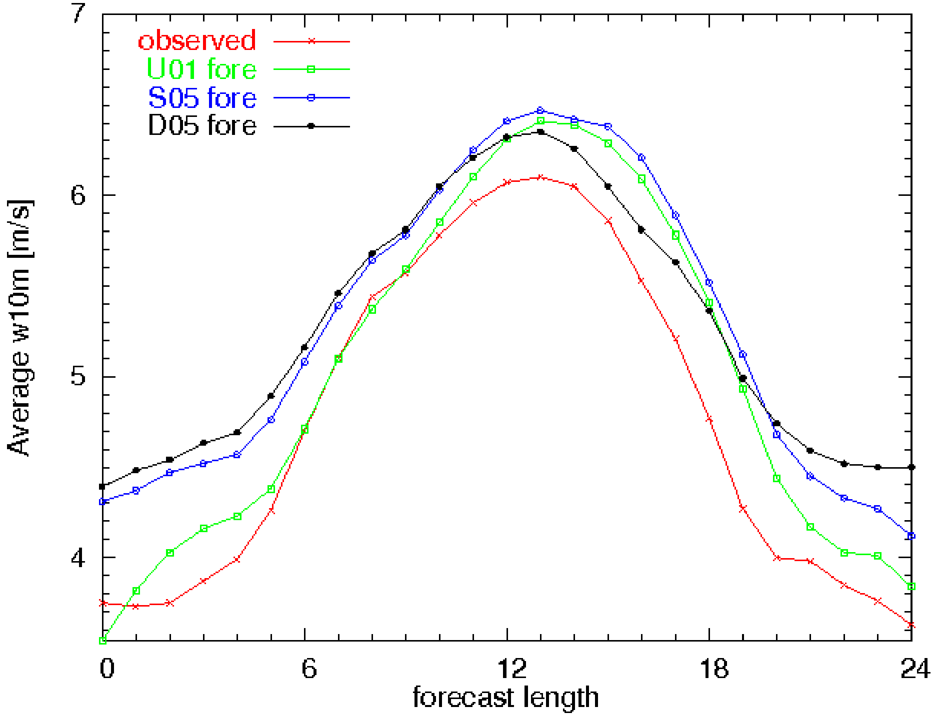
T: 15 km

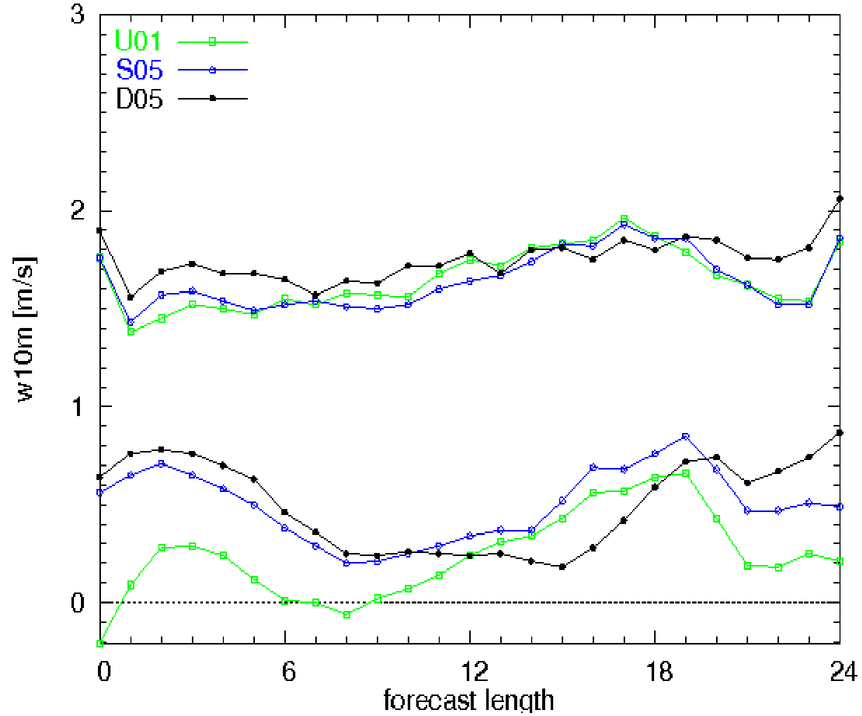
S: 5 km

U01: 1.4 km

I01: 1.4 km

High-Resolution DMI-HIRLAM Verification





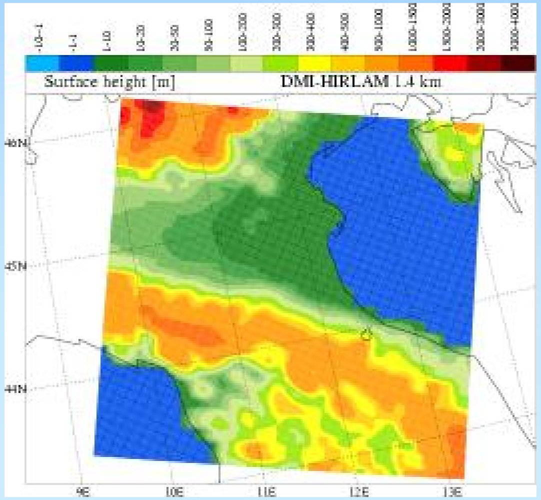
Comparison of the diurnal variation of average wind velocity (in m/s) at 10 m between observational data and three DMI-HILRAM-S05, -U01, and -D05 model versions for 00 UTC forecasts during May of 2005:

(left) comparison with observations,

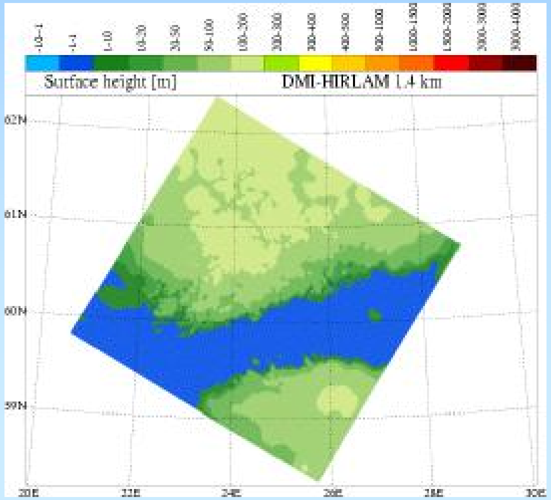
(right) at top - bias, bottom - rms error.

Urban Episode Studies by DMI-HIRLAM

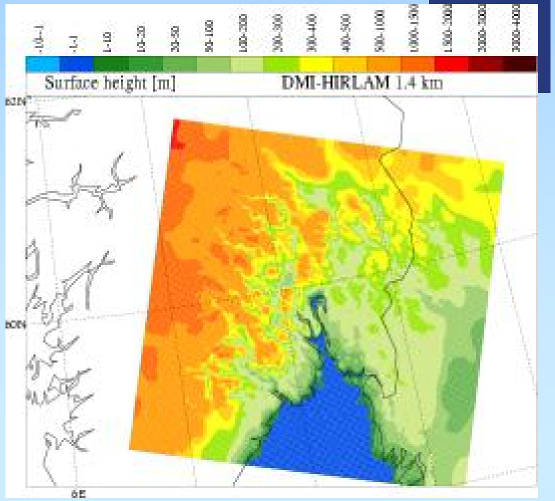
Bologna area



Helsinki area

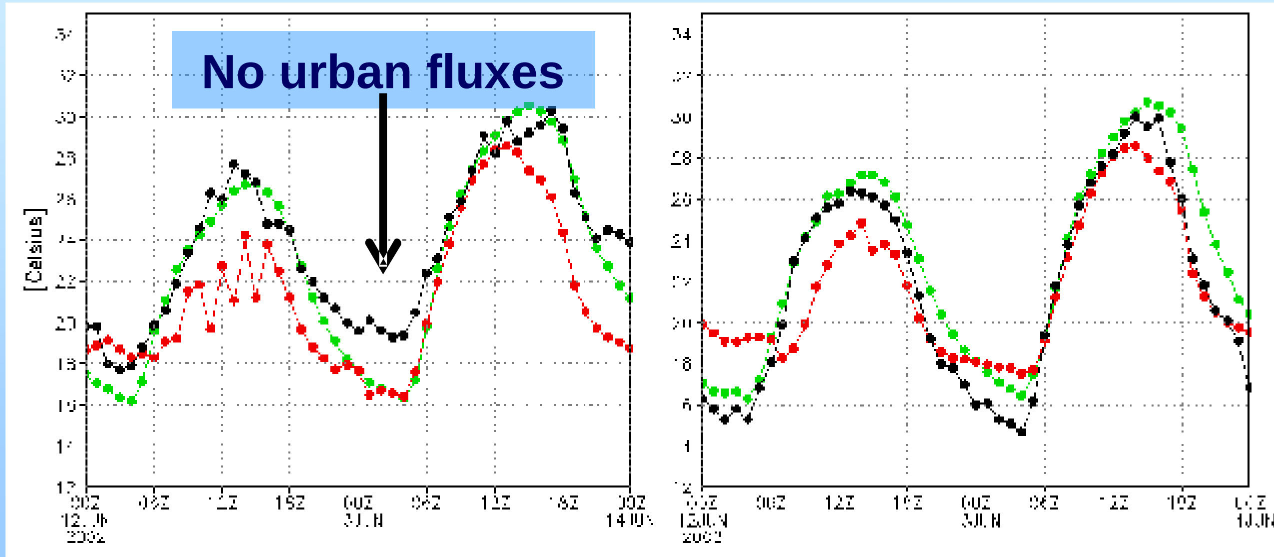


Oslo area



Urban

Rural/Po valley



Time series of 2m temperature for DMI-HIRLAM 1.4km (green), ARPA-LAMI 1.1km (red) and observations (black), 12 Jun 2002.

Left: Bologna Piazza VIII Agosto.

Right: San Pietro Capofiume.

(Deserti et al., 2004)

General Conclusion

- The DMI-HIRLAM shows very good skills in predicting the daily 2m temperature cycles and maximum values of warm episodes, i.e., the Helsinki April 2002 and the Bologna June 2002 episode.

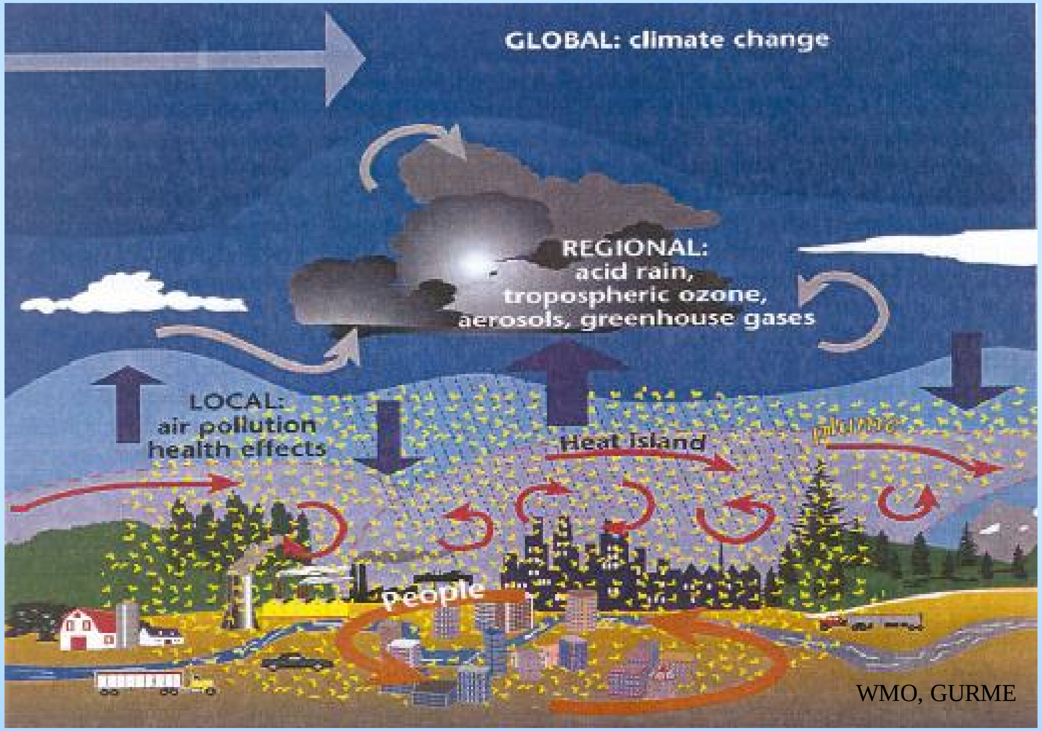
- However, the observed very low 2m temperatures of strong inversion episodes (Helsinki December 1995, Oslo January 2003 and Bologna January 2003) are generally overpredicted like in most other models.

- The effect of increased model grid resolution on the investigated parameters is visible.

- NWP’s need to be ‘urbanized’ for forecasting in urban areas.

Urban Boundary Layer Features

- Local-scale inhomogeneties, sharp changes of roughness and heat fluxes,
- Wind velocity reduce effect due to buildings,
- Redistribution of eddies due to buildings, large => small,
- Trapping of radiation in street canyons,
- Effect of urban soil structure, diffusivities heat and water vapour,
- Anthropogenic heat fluxes, urban heat island,
- Internal urban boundary layers (IBL), urban Mixing Height,
- Effects of pollutants (aerosols) on urban meteorology and climate,
- Urban effects on clouds, precipitation and thunderstorms.



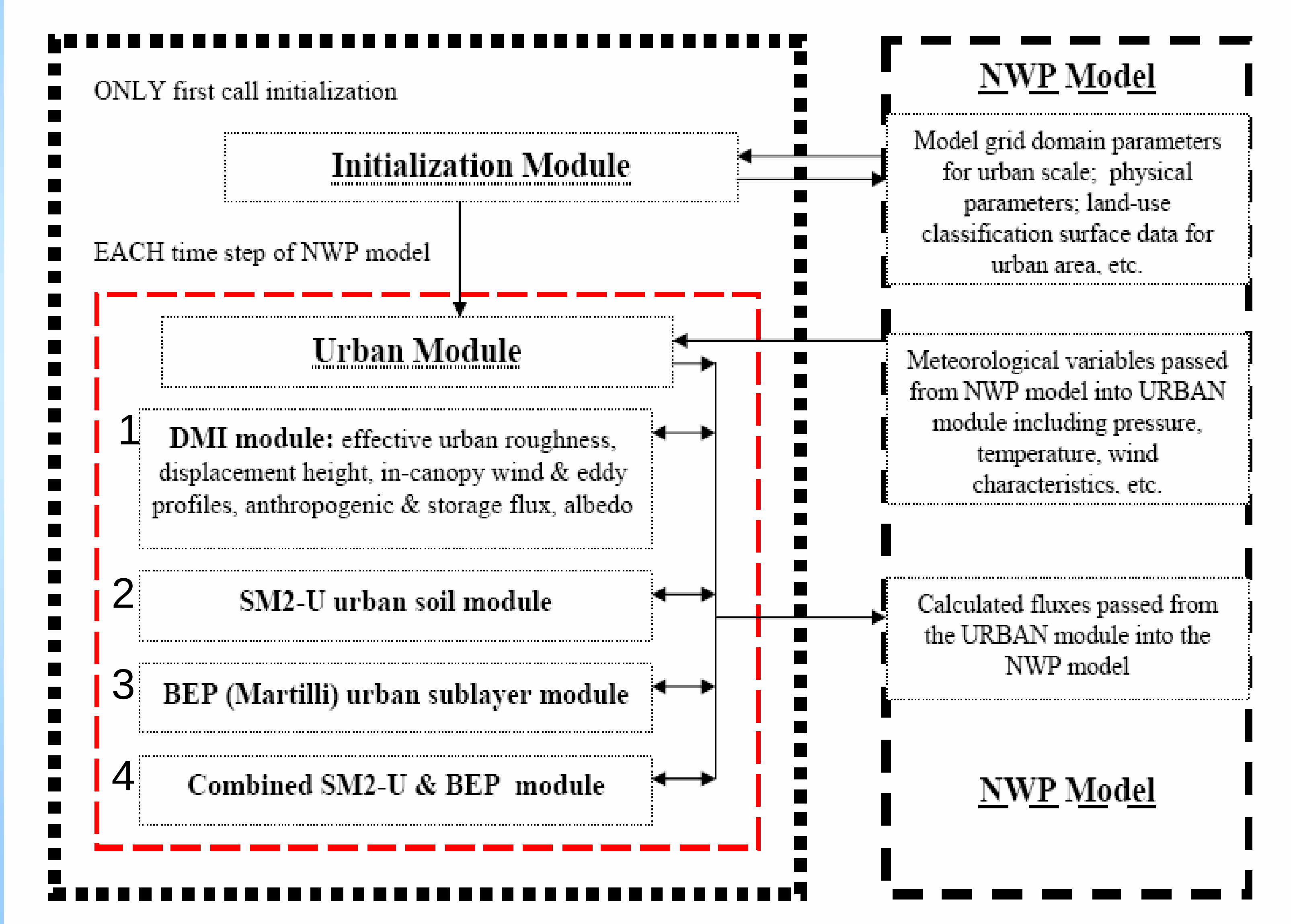
Key parameters for urban models of different scales

Mesoscale models	**Sub-meso scale models**	**Street canyon scale models**
z_0, z_{0T}	$z_0(x)$, d(x)	
h_{UBL}	L_c, L_a, z_*	Detailed geometry
'Surface' fluxes (effective)	u_*^{IS}, H^{IS}, general: x_*^{IS}	$\bar{u}(h)$ second velocity scale for **horizontal** transport
Anthropogenic heat flux (non-surface) at some representative height	Dispersive fluxes	Heat exchange at vertical and horizontal building surfaces
Profiles of turbulent fluxes	Profiles of turbulent fluxes	Characteristic velocity variance in street canyon
Higher order moments?	Higher order moments (skewness, ...)	Higher order moments?
Synoptic forcing, average albedo	Mesoscale stability, albedo(x)	

(COST715)

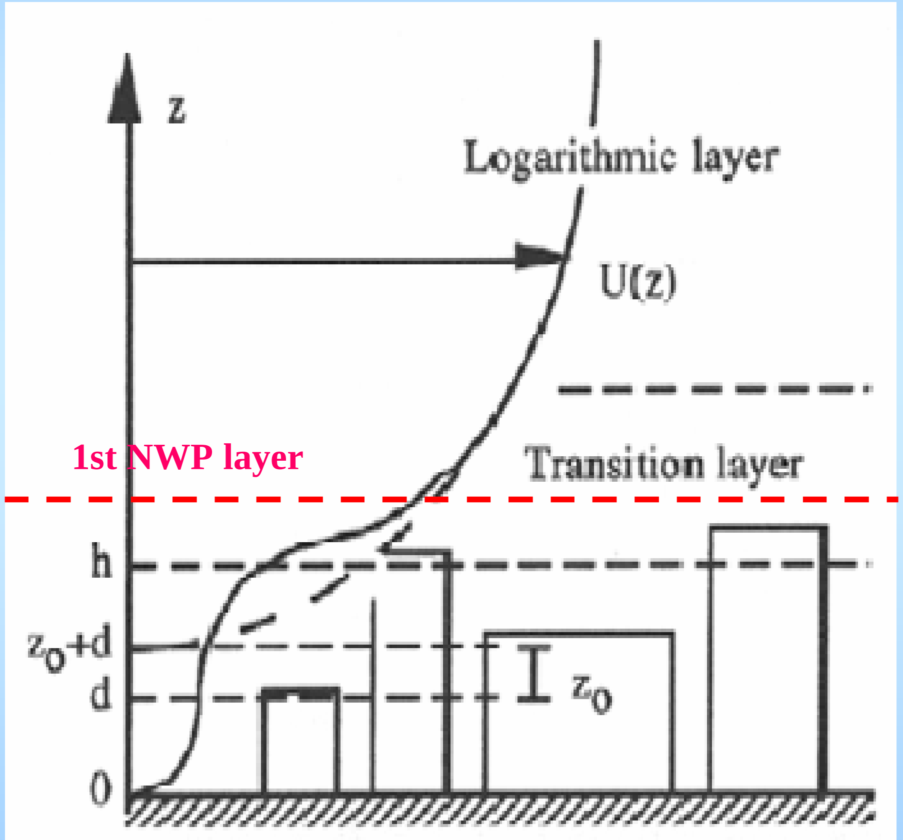
Examples of integrated urban module for NWP models

4 levels of complexity of the NWP 'urbanization'



1 DMI urban module: Analytical urban parameterisations

- **Displacement height,**
- **Effective roughness and flux aggregation,**
- **Effects of stratification on the roughness (*Zilitinkevich et al, 2004*),**
- **Different roughness for momentum, heat, and moisture;**
- **Calculation of anthropogenic and *storage* urban heat fluxes;**
- **Prognostic MH parameterisations for SBL;**
- **Parameterisations of wind profile in canopy layer (*Coceal and Belcher, 2004*; *Zilitinkevich and Baklanov, 2004*).**

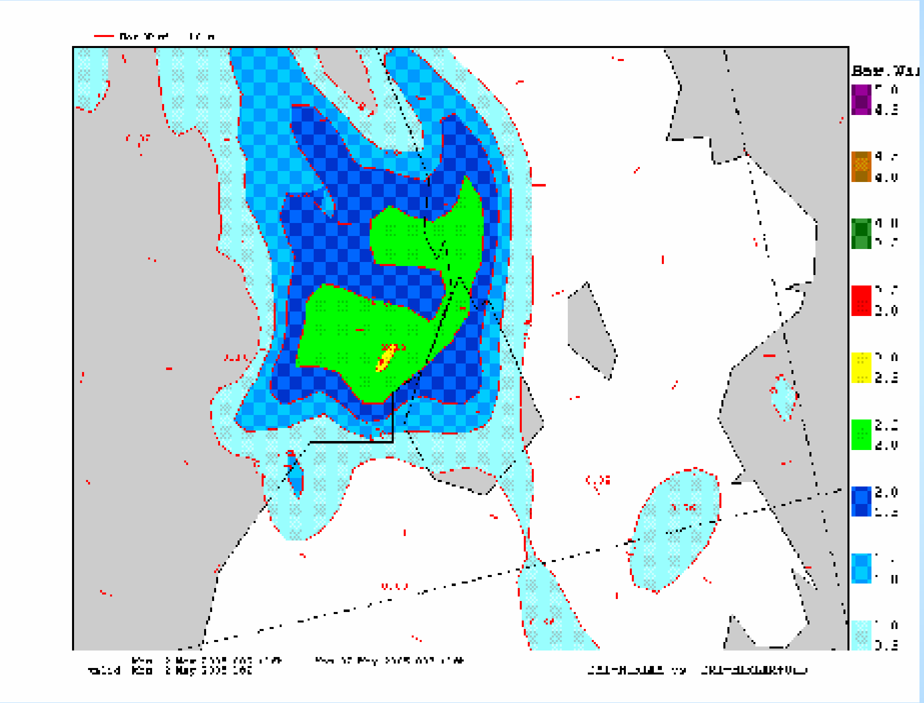


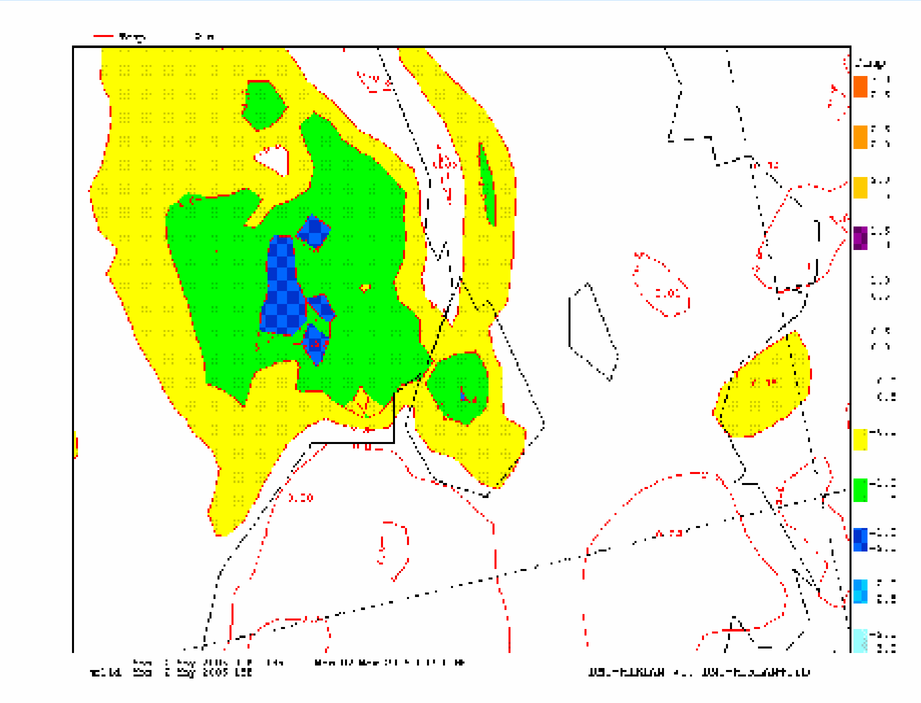
$$U_h(z_s) = \frac{u_{*s}}{\kappa} \cdot \ln\left(\frac{z_s - z_d}{z_0} - \psi_m(z_s / L)\right)$$

$$u = \frac{2}{3C_M} \frac{u_*}{1} \frac{}{\delta}\left\{\left[\delta + (1-\delta)\frac{z}{h_0}\right]^{3/2} - \delta^{3/2}\right\}$$

DMI urban module

Tests for Copenhagen using DMI-HIRLAM



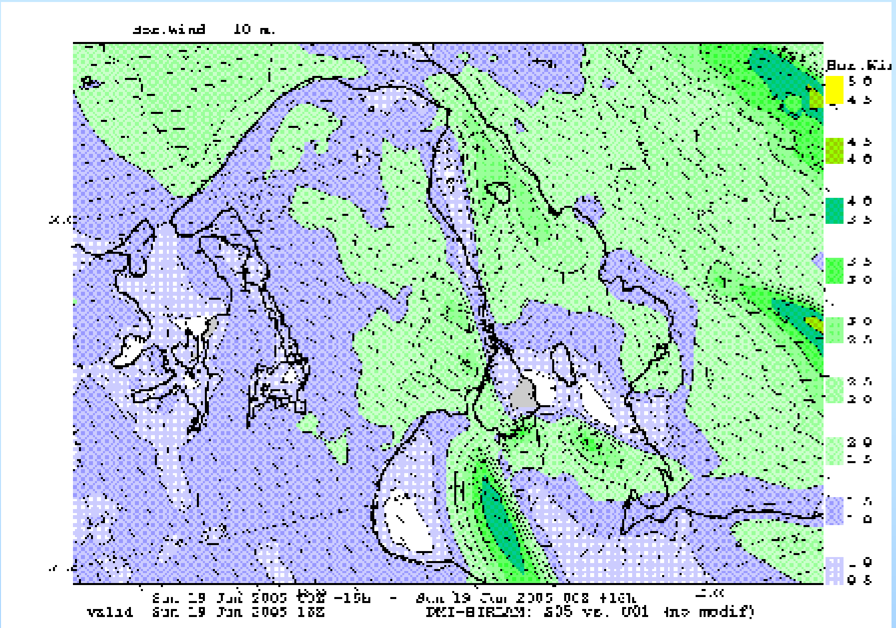


(a) **(b)**

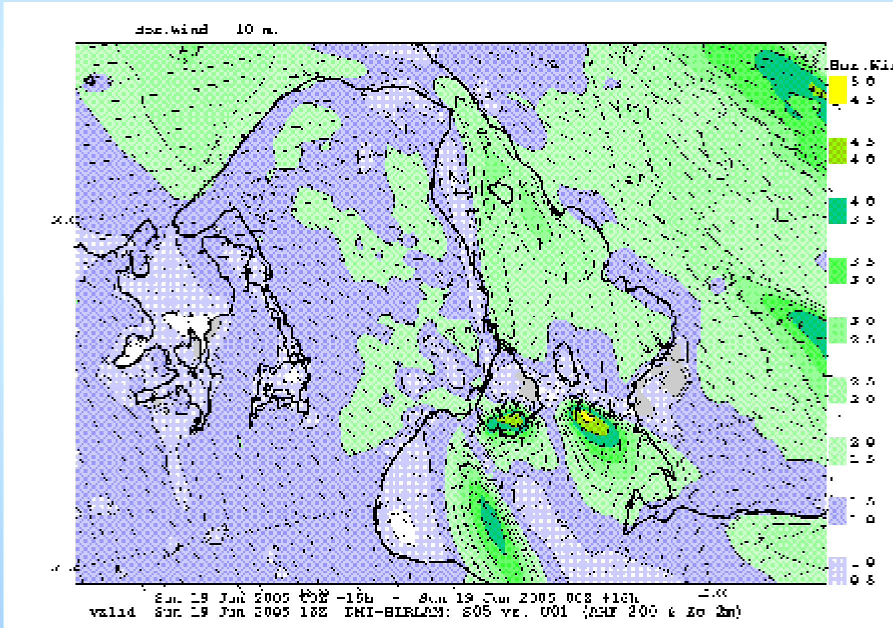
Difference plots (between outputs of the DMI-HIRLAM control vs. DMI-HIRLAM+Urb) for (a) wind velocity at 10 m and (b) air temperature at 2 m for forecasts at 18 UTC, 2 May, 2005.

DMI-HIRLAM S05 vs. U01

Difference fields for the wind at 10 m simulated
by the DMI-HIRLAM-S05 vs. U01 (urbanized) models
at 16 UTC on 19 June 2005 for the ISBA land surface scheme with:

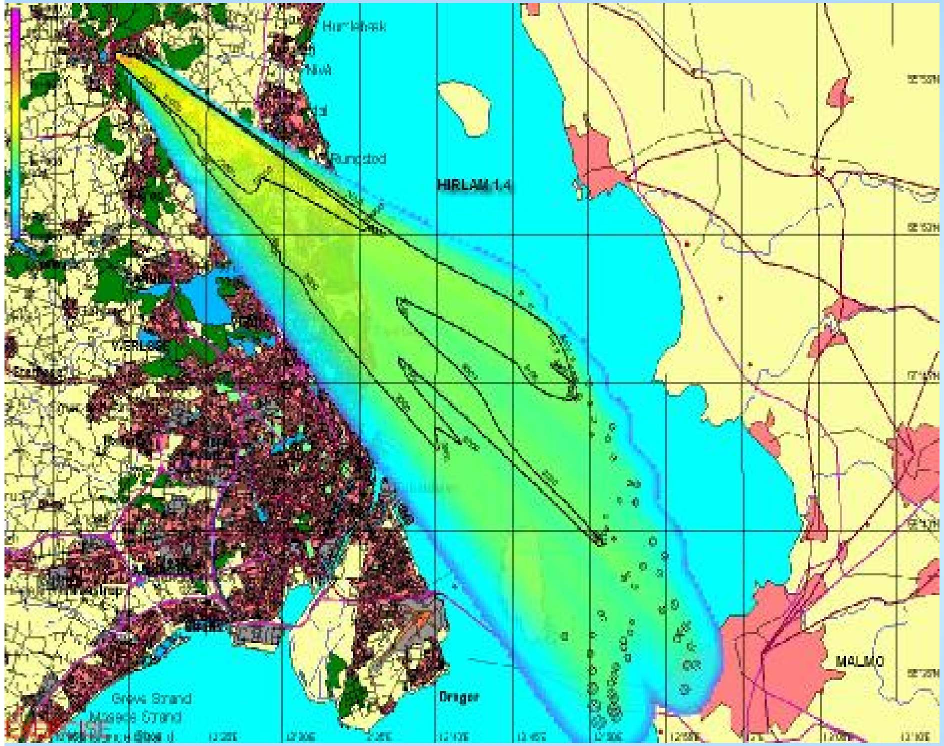


no modifications

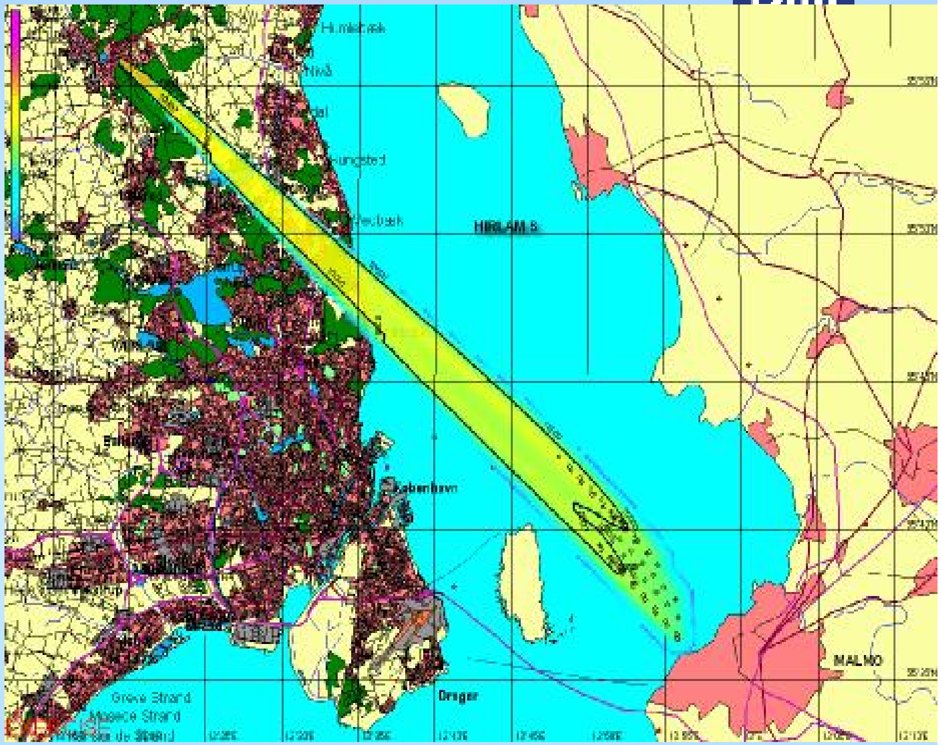


combined effects of roughness and anthropogenic heat flux

Sensitivity of ARGOS dispersion simulations to urbanized DMI-HIRLAM NWP data



urbanised U01, 1.4 km resolution

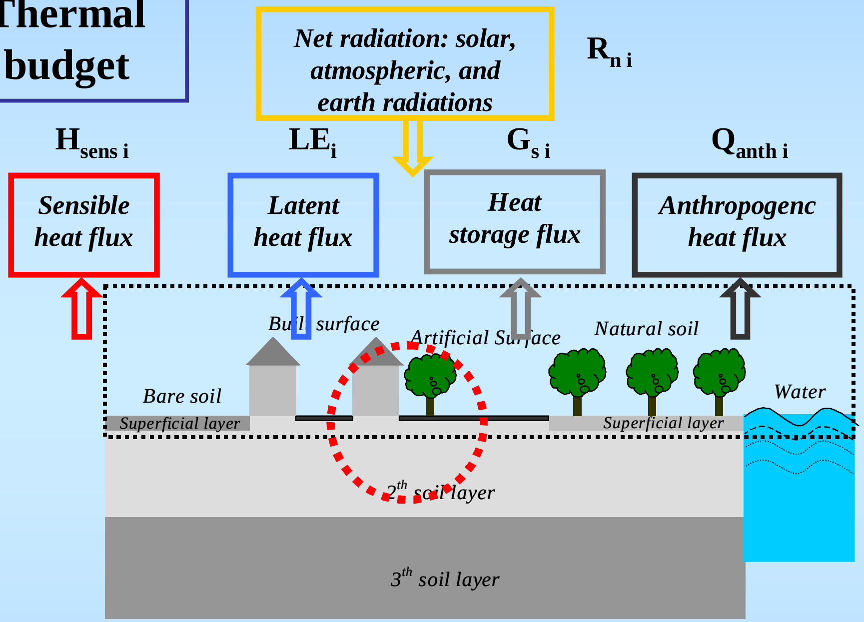


operational S05, 5 km resolution

Cs-137 air concentration for different DMI-HIRLAM data
A local-scale plume from the ^{137}Cs hypothetical atmospheric release in Hillerød at 00 UTC, 19 June 2005 as calculated with RIMPUFF using DMI-HIRLAM and visualised in ARGOS for the Copenhagen Metropolitan Area.

Module 2: SM2-U
(Soil Model for Sub-Meso Scales Urbanized Version)

Thermal budget



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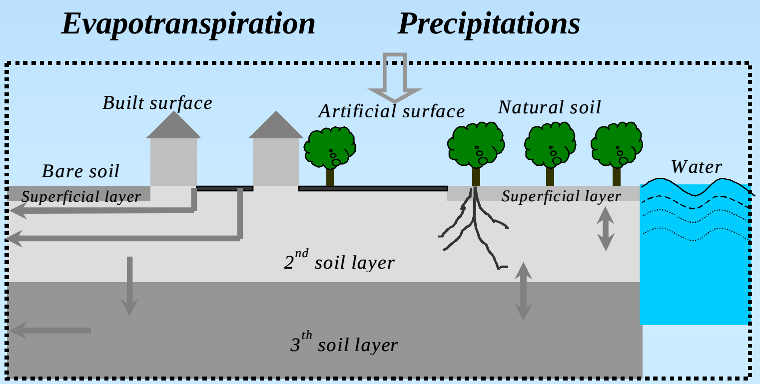
Water budget



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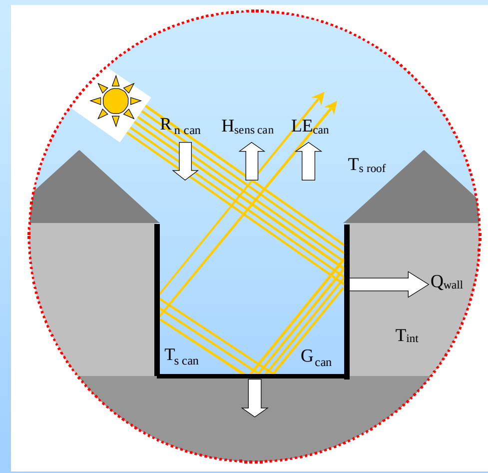
Canopy



$$Q_H + Q_E + Q_G = Q^* = K^{-} - K- + L^{-} - L-$$

$$dT_s/dt = C_T Q_G - (2p/t)(T_s - T_{soil})$$

Q_G = Ground flux ; t = 24 h

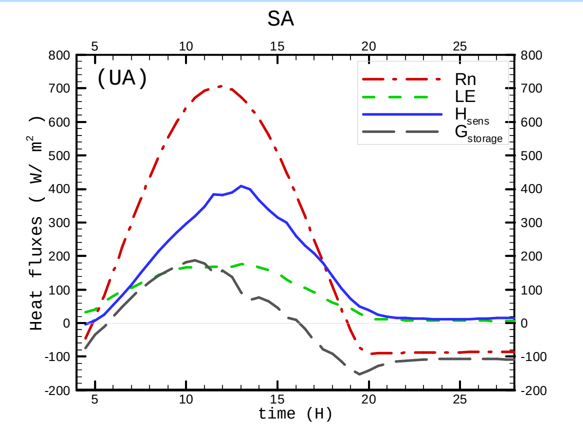
(Mestayer et al., 2004; Dupont et al., 2005ab)

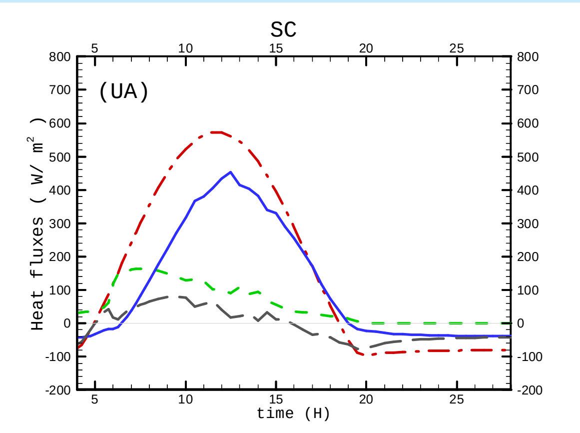
SM2-U Sensitivity Study on City Representation

SA : Detailed city (CC – city center, HBD – high buildings district, ICD – industrial commercial district, RD – residential district)

SC : Mineral city (used in land surface model, no buildings, dry bare soil)

Mean fluxes (whole urban area)



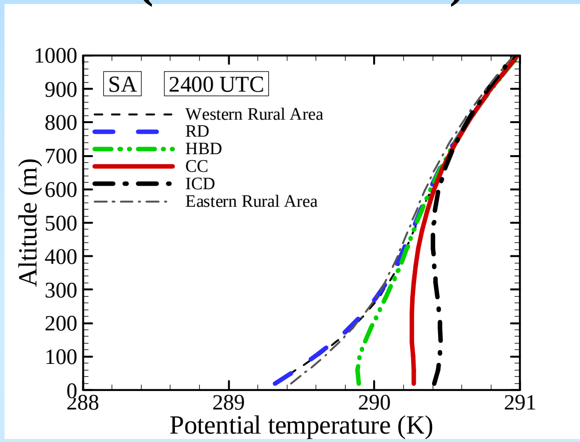


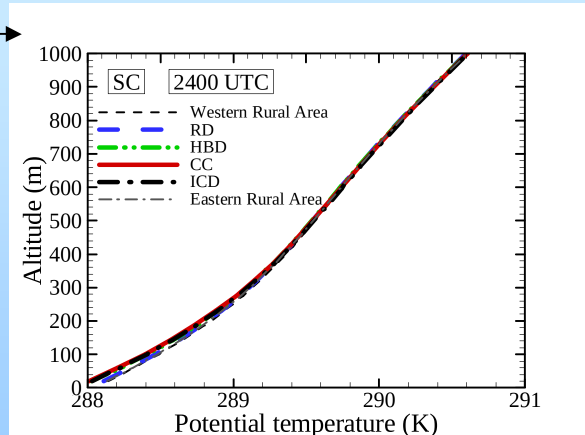
AL: Different behaviour
SC vs SA :
stores & releases less energy (no radiative trapping) ;
Rn is weaker (higher albedo)

SA: at 00h neutral stratification above CC & HBD, stable - others. Urban Heat Island is seen (Surface air temperature above the city higher than on the rural area).
SC: Stable stratification & temperature homogeneity for all.

Importance of urban surface characteristics description

Temperature profiles (above districts)

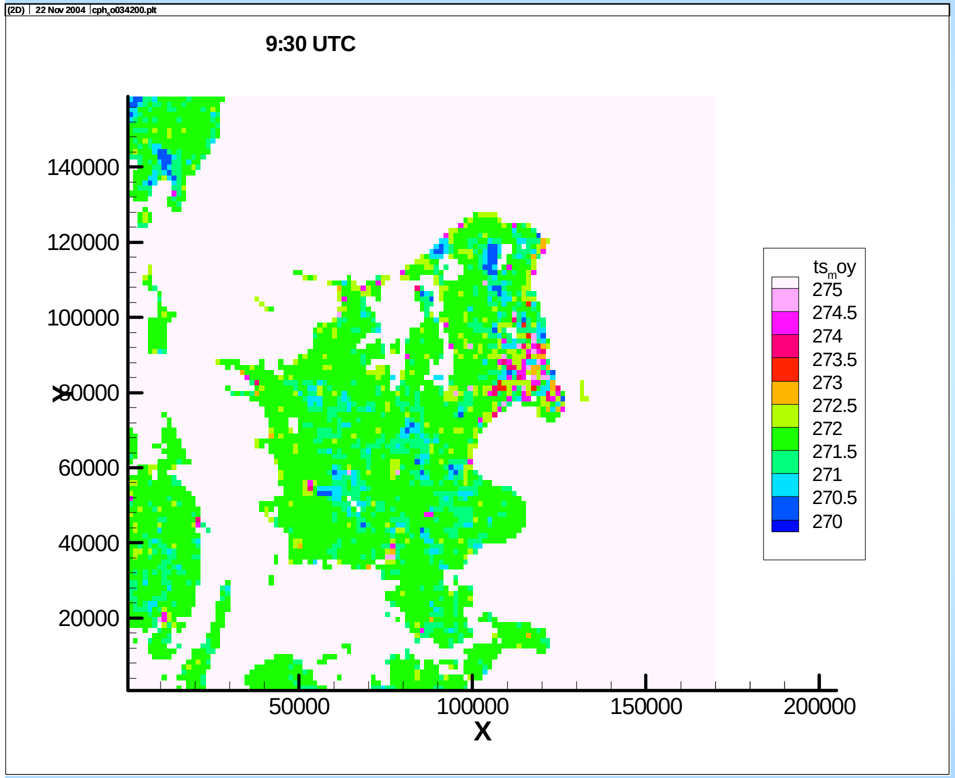


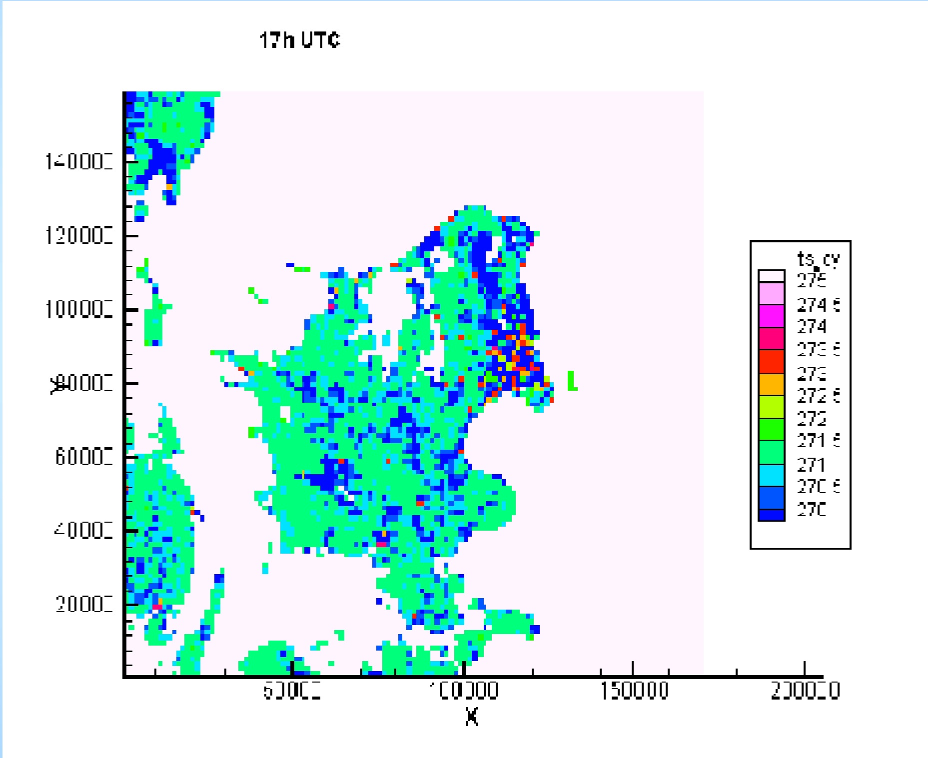


(With ECN contribution of Calmet, Leroyer, Long)

SUBMESO + SM2-U CLIMA RUNS FOR COPENHAGEN

TEMPERATURE OF THE SURFACE

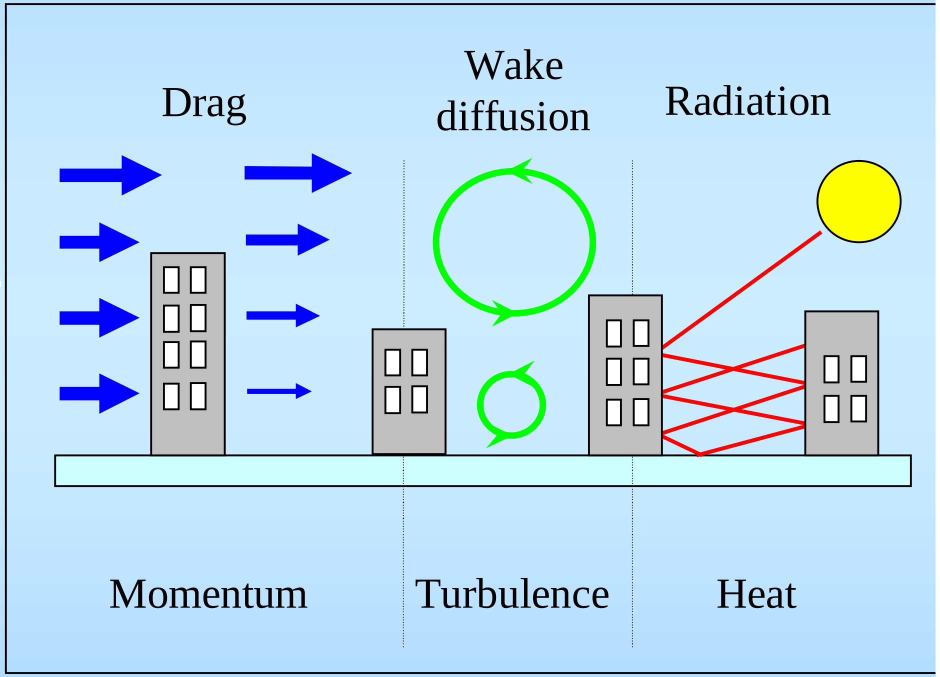




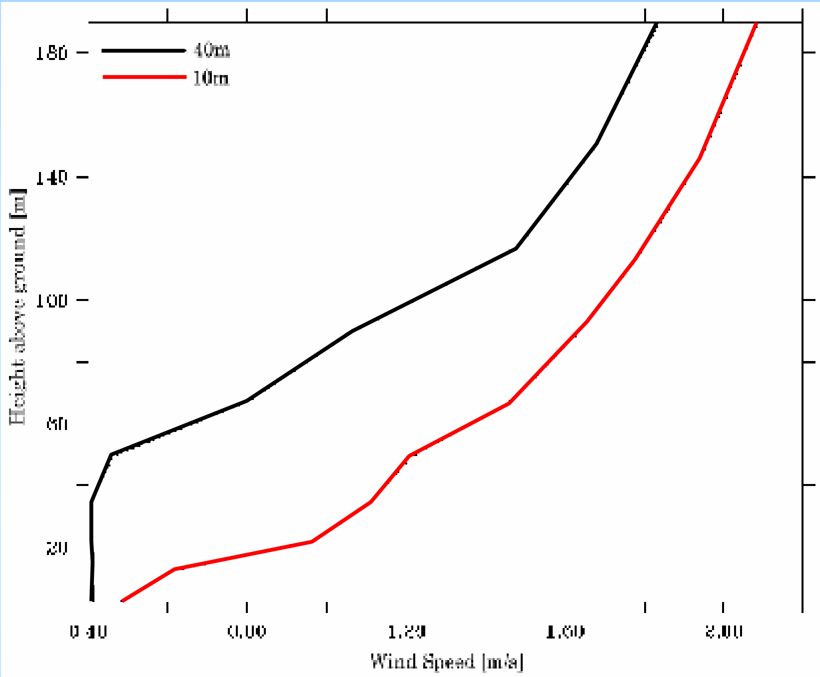
(Leroyer et al., 2005)

Module 3: BEP (Building Effect Parameterization) urban sub-layer module in DMI-HIRLAM:

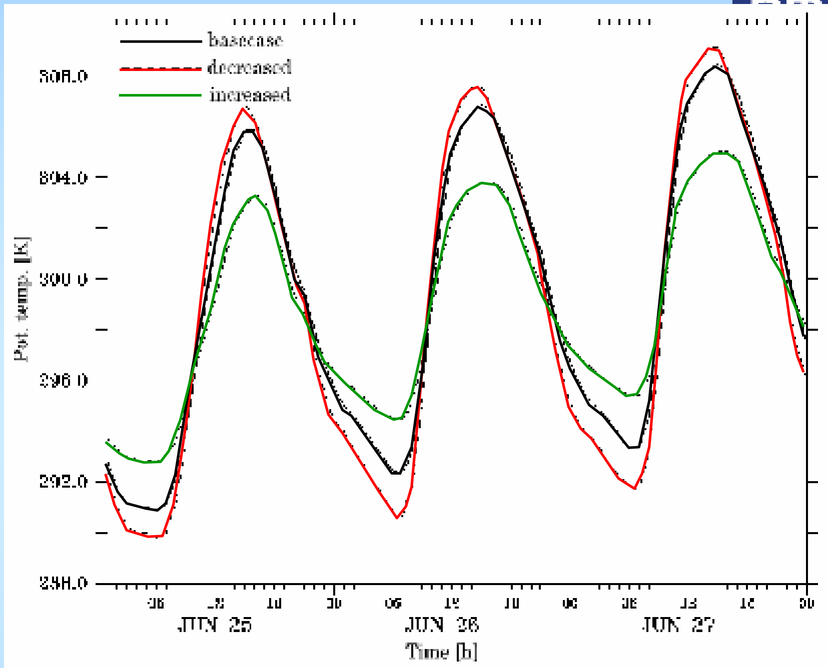
- Modification of the original version (Martilli et al., 2002) for NWP
- Implementation of additional anthropogenic heat flux
- Improvements by UCL (Hamdi and Schayes, 2004) due to:
  - new drag formulation (cumulated surface)
  - introduction of the fraction of vegetation
  - Introduction of a new lateral friction
- Realization of BEP as a post-processor
- Implementation and tests in TVM, FVM, HIRLAM, aLMo
- Verification vs. urban experiments BUBBLE, ESCOMPTE
- Combination with the analytical profile into the urban canopy
- Improved formulation for different turbulence closure models



BEP sensitivity to urban parameters



Wind profile simulated with 40 m (black line) and 10 m (red line) building height

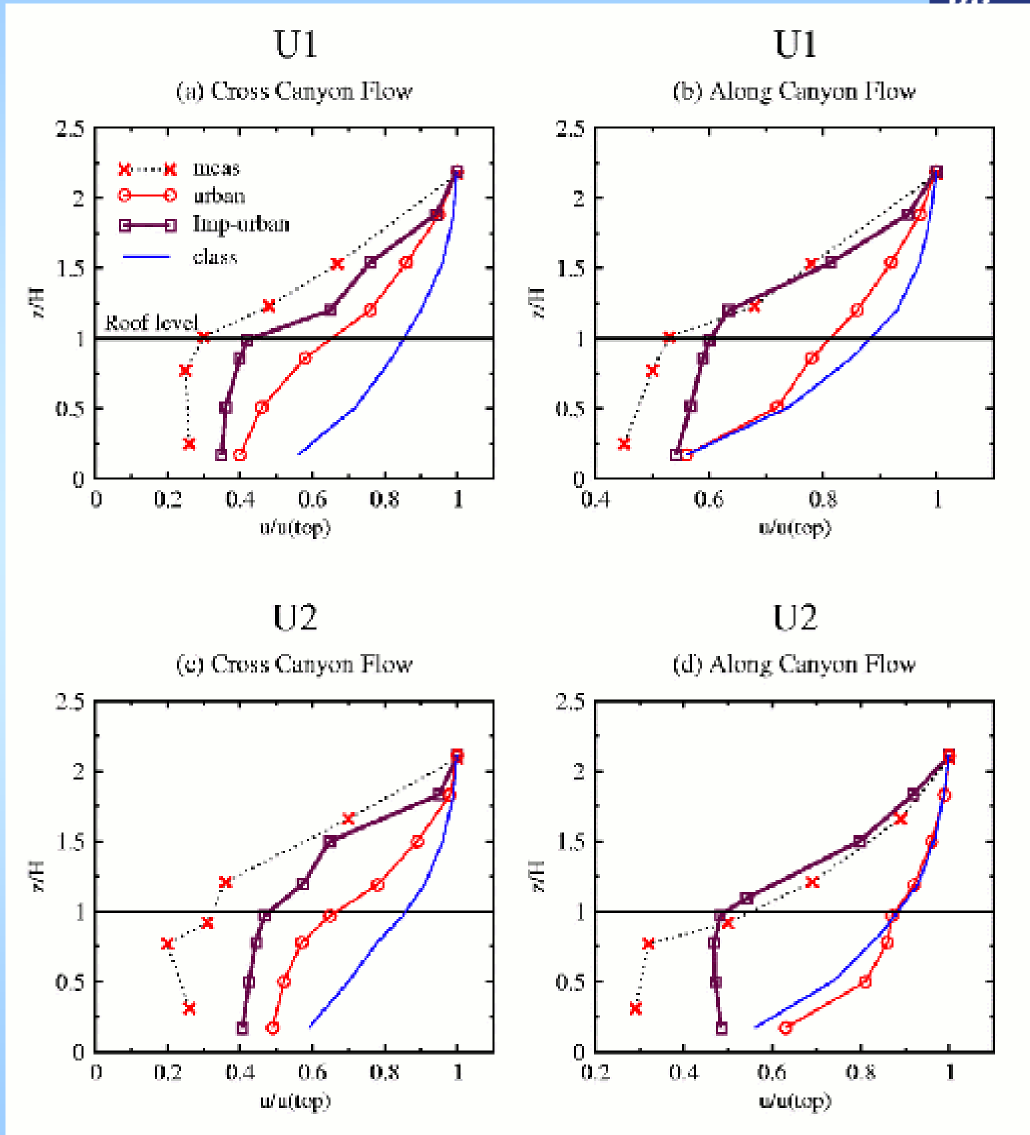


Temperature evolution inside the urban canopy for three different street heat capacities: 1.4 (black line), 14 (red line), 0.14 (green line) MJm-3K-1.

Clappier er al., 2004

Verification of the improved BEP model

The wind speed profile normalized by u (top) at the tower for cross canyon (left) and along canyon flow (right) for the two sites U1 and U2 in Basel.

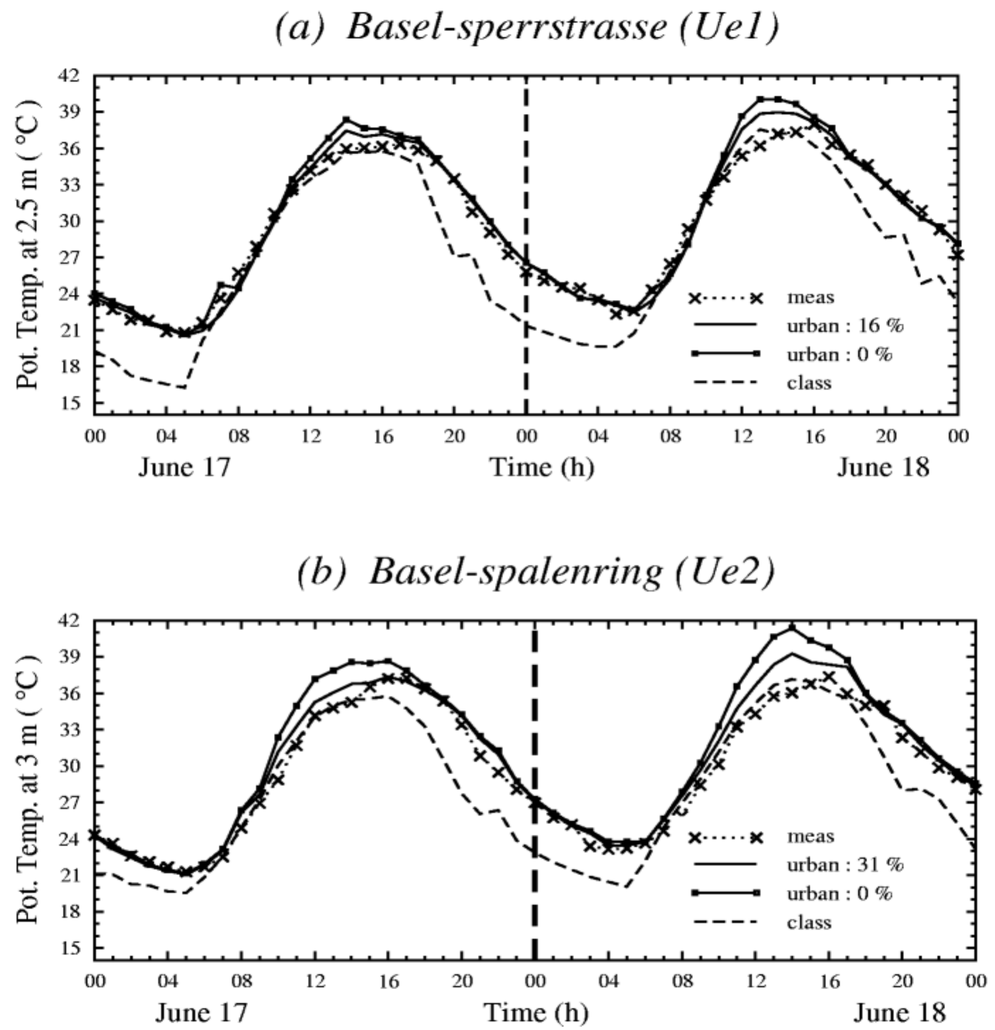


Hamdi et al., 2005

Verification of the improved BEP model

Accounting for vegetation fraction in the urban module improves the daily temperature wave simulation.

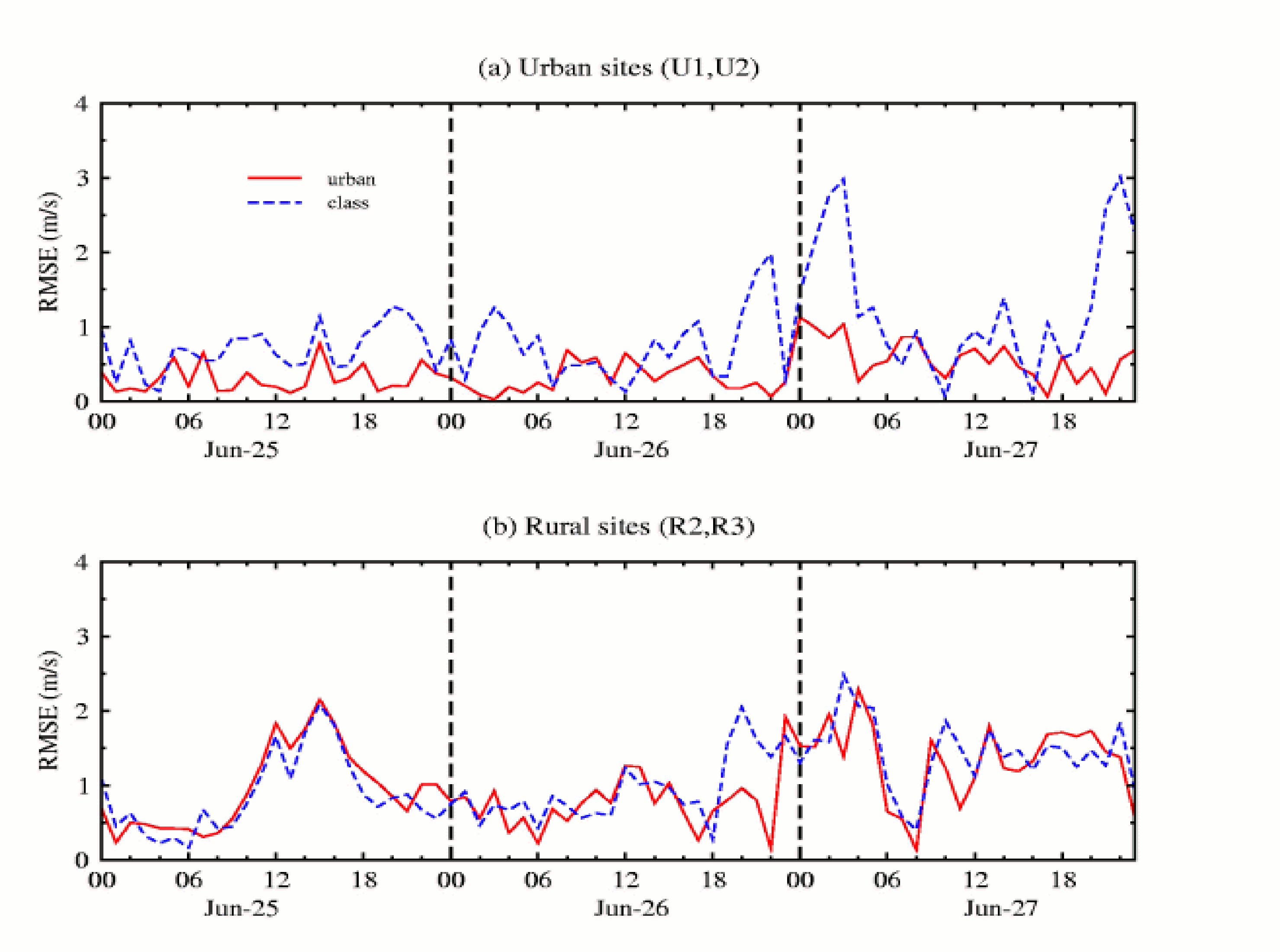
Graphs show results for two experimental sites.



Urban= present formulation with vegetation=; class=MOST

(Hamdi and Schayes, 2005)

Verification of the improved BEP model



The RMSE of the difference in wind speeds between observations with classical simulation (blue) and urban ones (red).

(Hamdi and Schayes, 2005)

Results of BEP and SM2-U tests in NWP HIRLAM

BEP module:

- too low vertical resolution of HIRLAM => low sensitivity to urban features,
- no moisture and latent fluxes included into BEP,
- not complete anthropogenic heat fluxes in BEP,
- recalculation of fields on lowest sub-layer is necessary.

SM2-U module:

- much more sensitive in urban areas,
- needs to be further developed (SM2-U & ISBA in HIRLAM) for urban cells run,
- snow and ice are not included in SM2-U,
- no anthropogenic heat fluxes parameterised in SM2-U, but storage heat fluxes are acceptable,
- doesn’t consider the building drag effect.

The Three Modules Applicability

- **DMI urban module is the cheapest way of “urbanising” the model and can be easily implemented into operational NWP and Regional Climate Models.**

- **BEP module is computationally 10 -30 % more expensive, but it gives a possibility to consider the energy budget components and fluxes inside the urban canopy. However, only effective if the first model level is lower than 30 meters.**

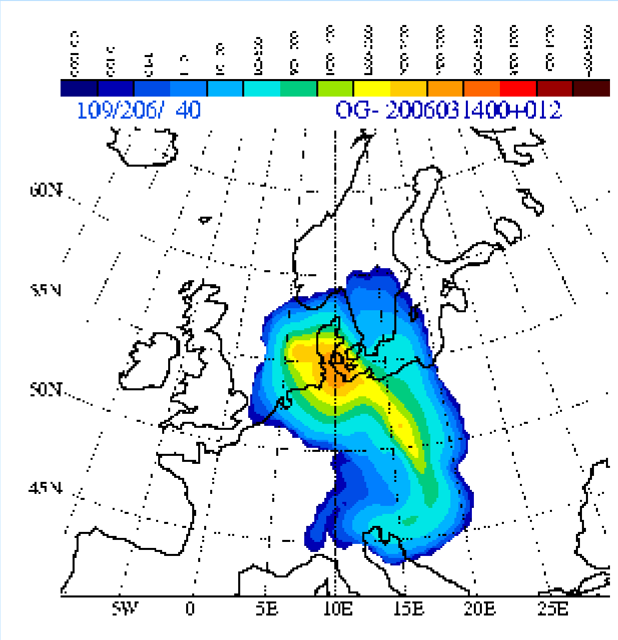
- **SM2-U module is up to 10 times more computationally expensive than the DMI urban and BEP Modules. However, it provides the possibility to accurately study the urban soil and canopy energy exchange including the water budget.**

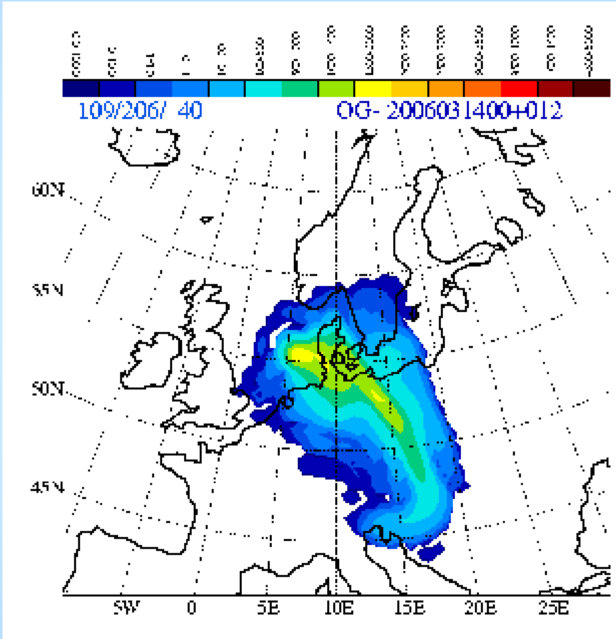
- **DMI urban and BEP modules are recommended for use in advanced urban-scale NWP and meso-meteorological research models.**

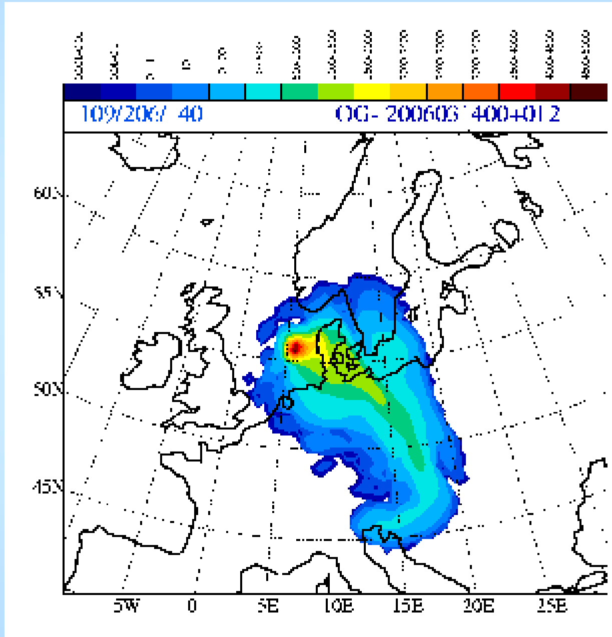
Application 1: Tracer Advection

Test of different advection schemes in Enviro-HIRLAM.

ETEX exp, after 48h, first release
Simulation model Enviro-HIRLAM



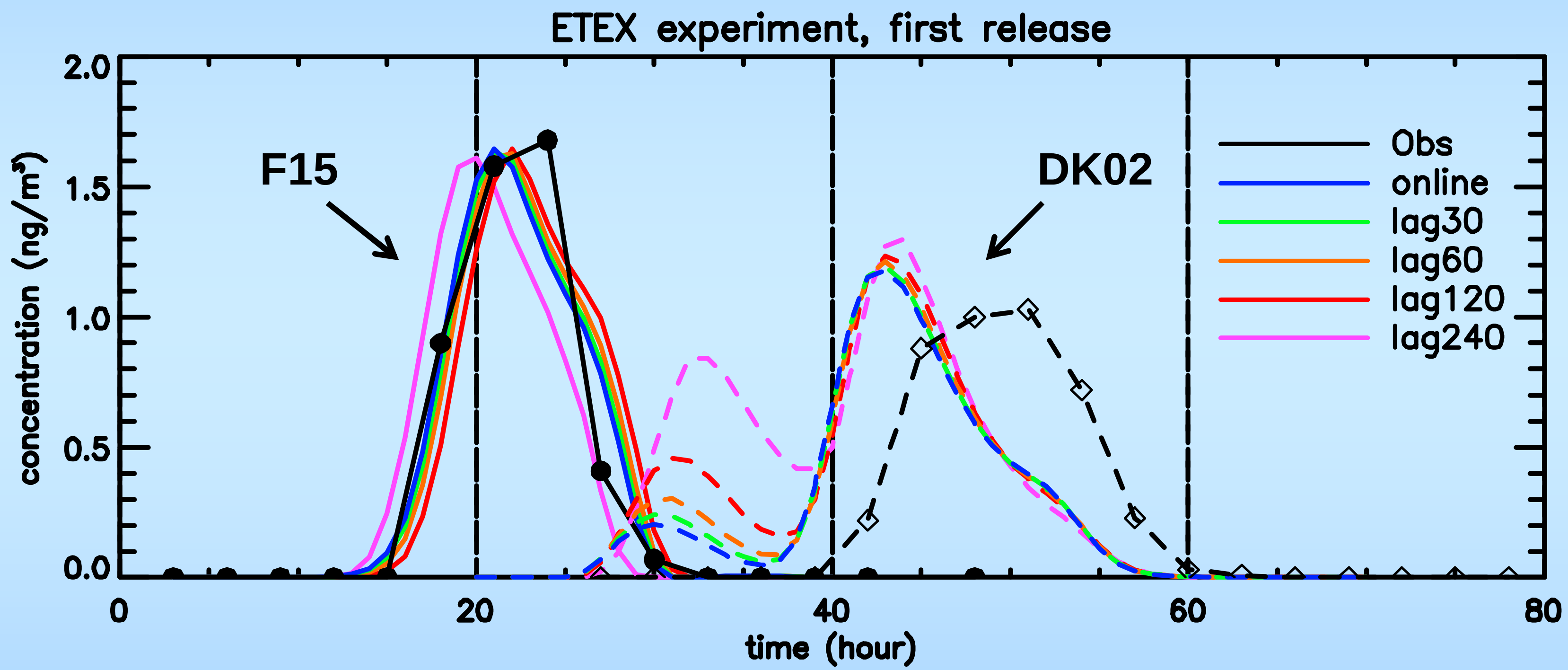




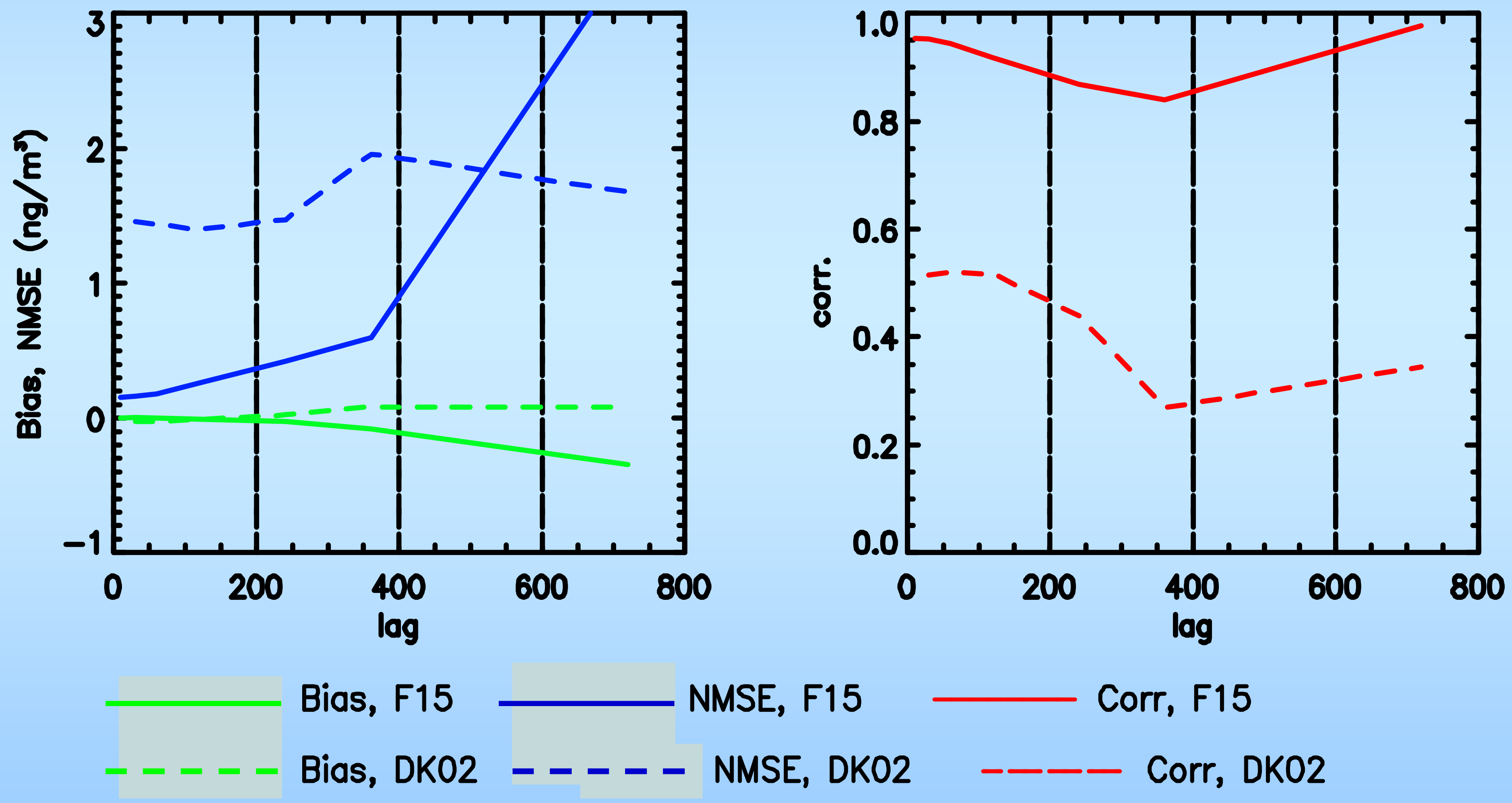
Semi-Langrangian in HIRLAM

Bott scheme (Bott, 1989)

Bott-Easter sheme (Bott, 1993)


ETEX experiment, first release
concentration (ng/m³)
time (hour)
F15
DK02
Obs
online
lag30
lag60
lag120
lag240
2.0
1.5
1.0
0.5
0.0
0
20
40
60
80

ETEX experiment, first release
Statistics

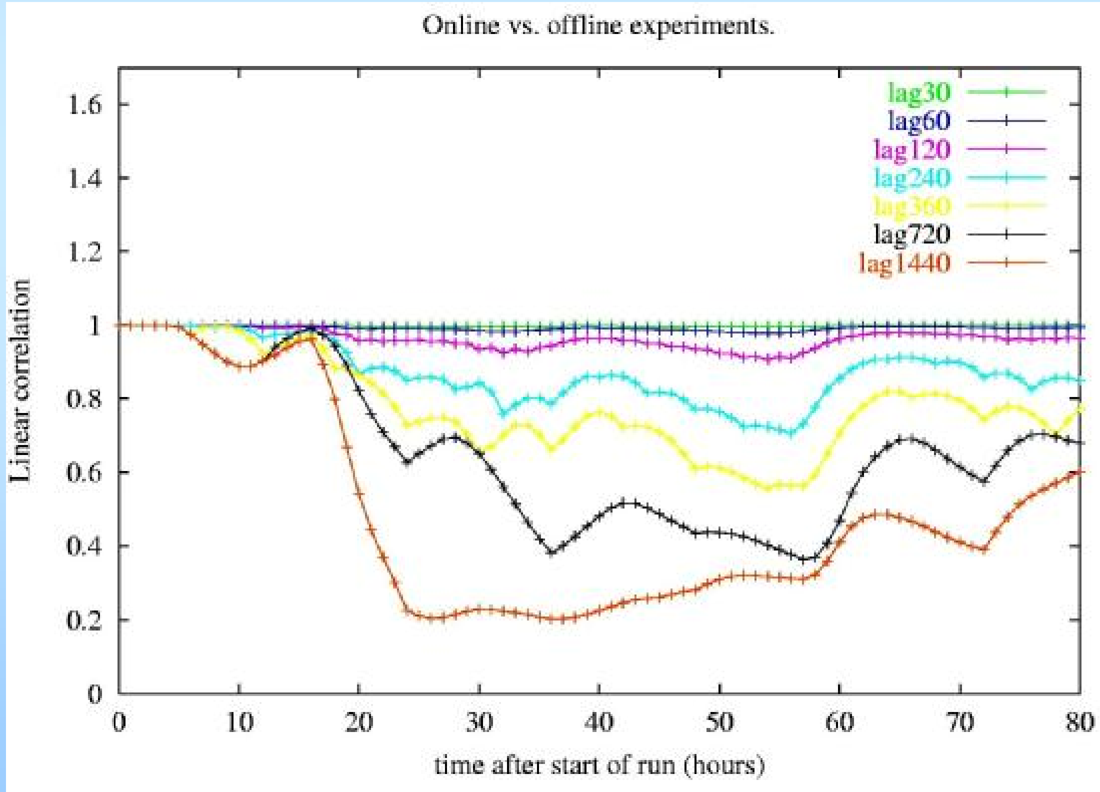


DMI-ENVIRO-HIRLAM: Online versus offline

First test: only Advection part is differently coupled

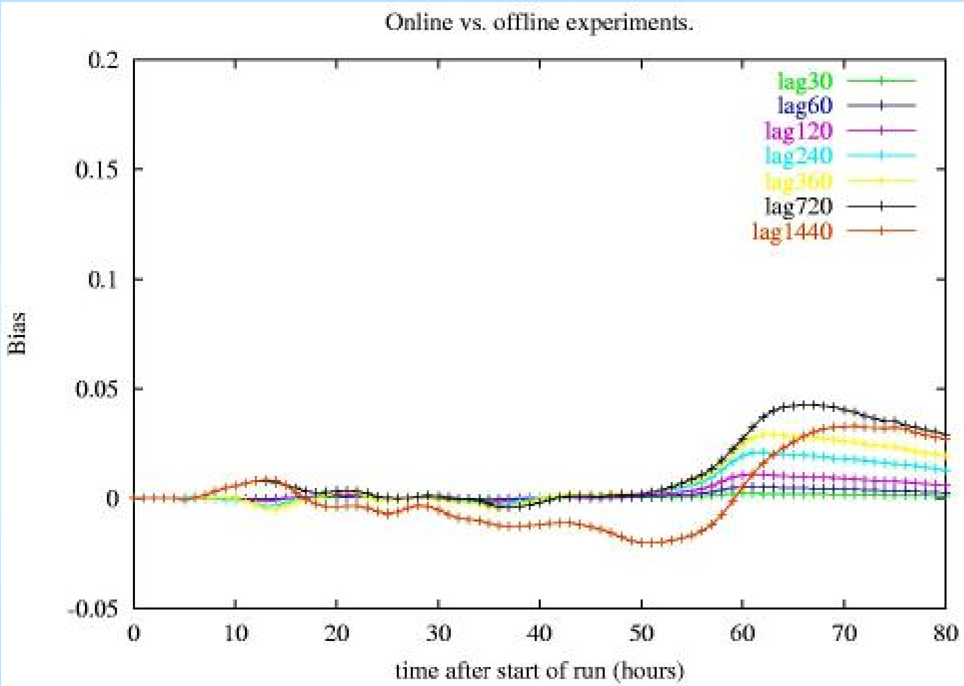
On-line: each time step, Off-line: 0.5, 1, 2, 4, 6, 12, 24 hours

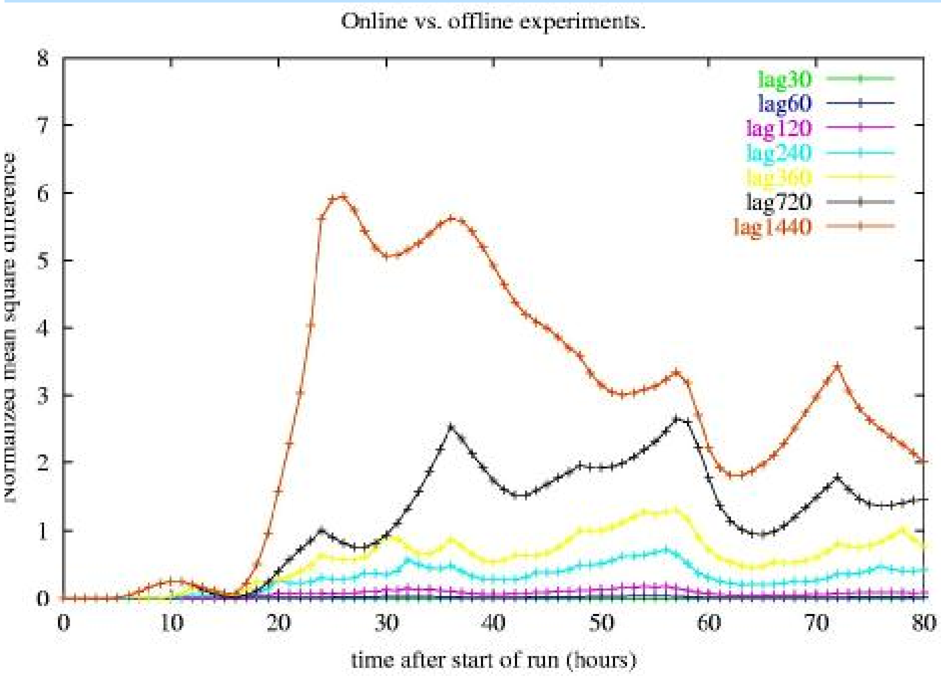
Typical meteorological conditions (ETEX1 case)



Linear correlation

DMI-ENVIRO-HIRLAM: On-line versus off-line



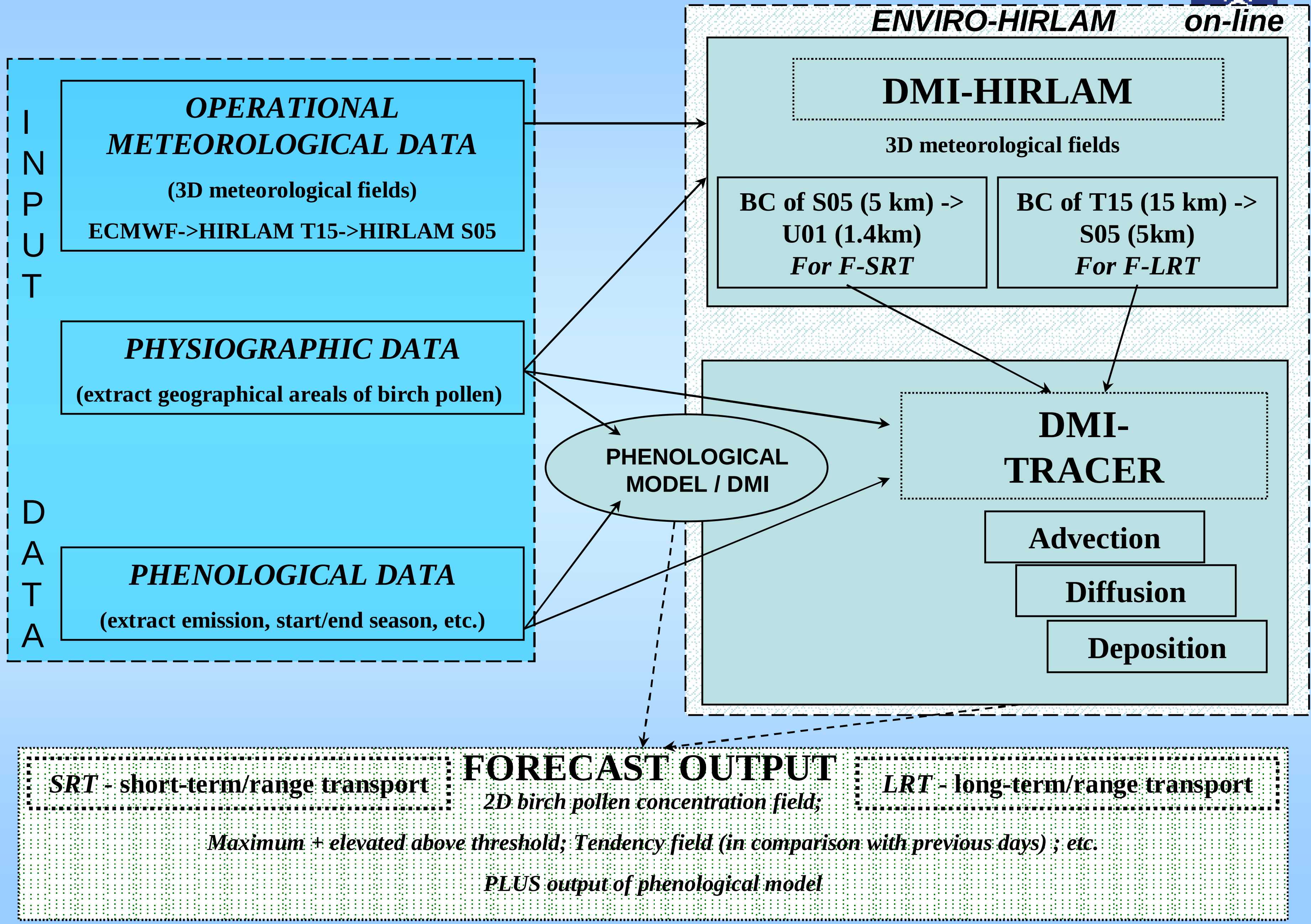


Bias **Normalized mean square difference**

Application 2: Pollen Forecasting

Develop and test the birch pollen forecasting module for domain of Denmark and surrounding territories.

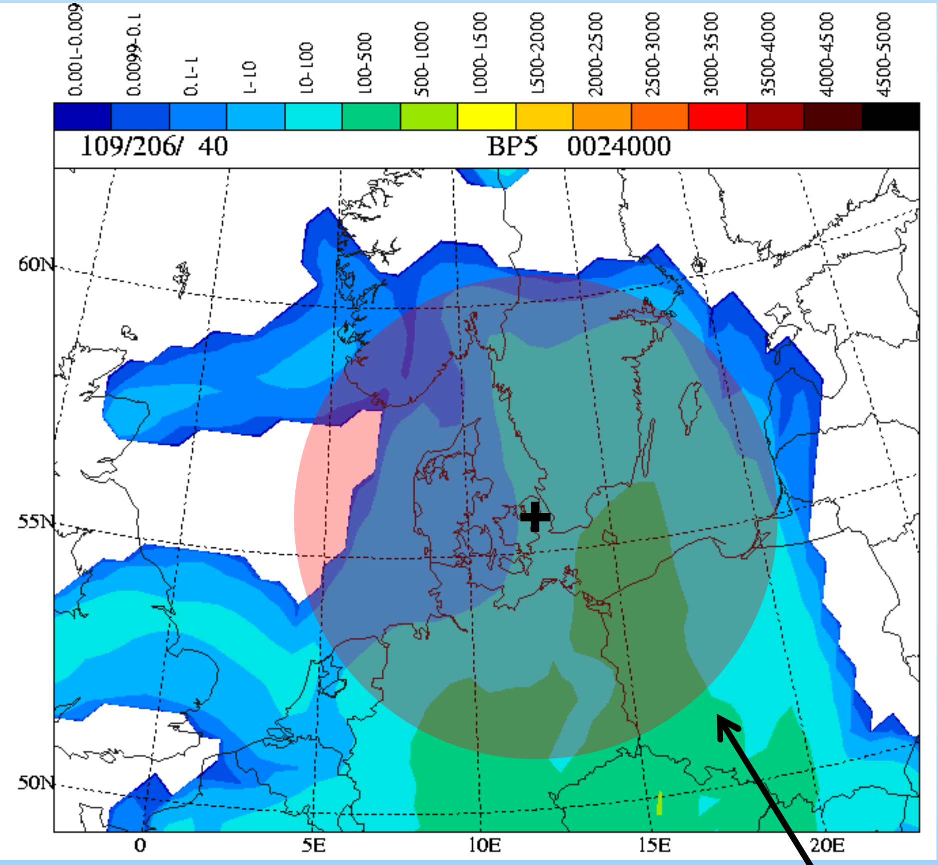
BIRCH POLLEN FORECAST / Enviro-HIRLAM



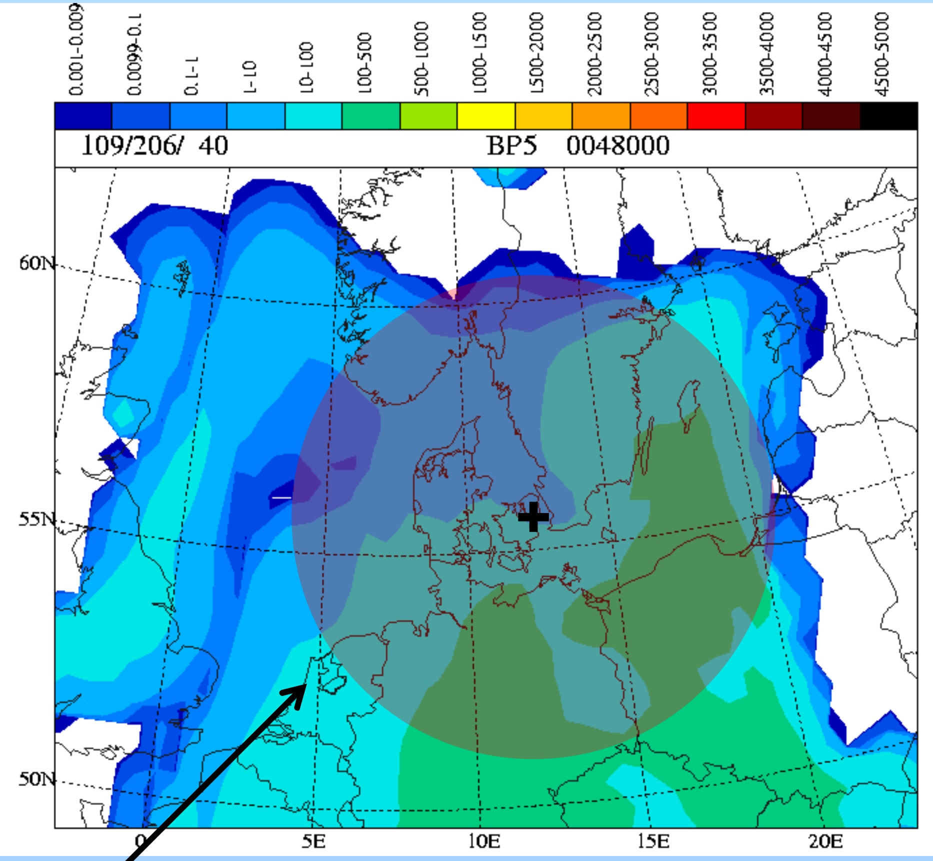
TEST OF A POLLEN FORECAST

Normalized concentrations

24 hours forecast

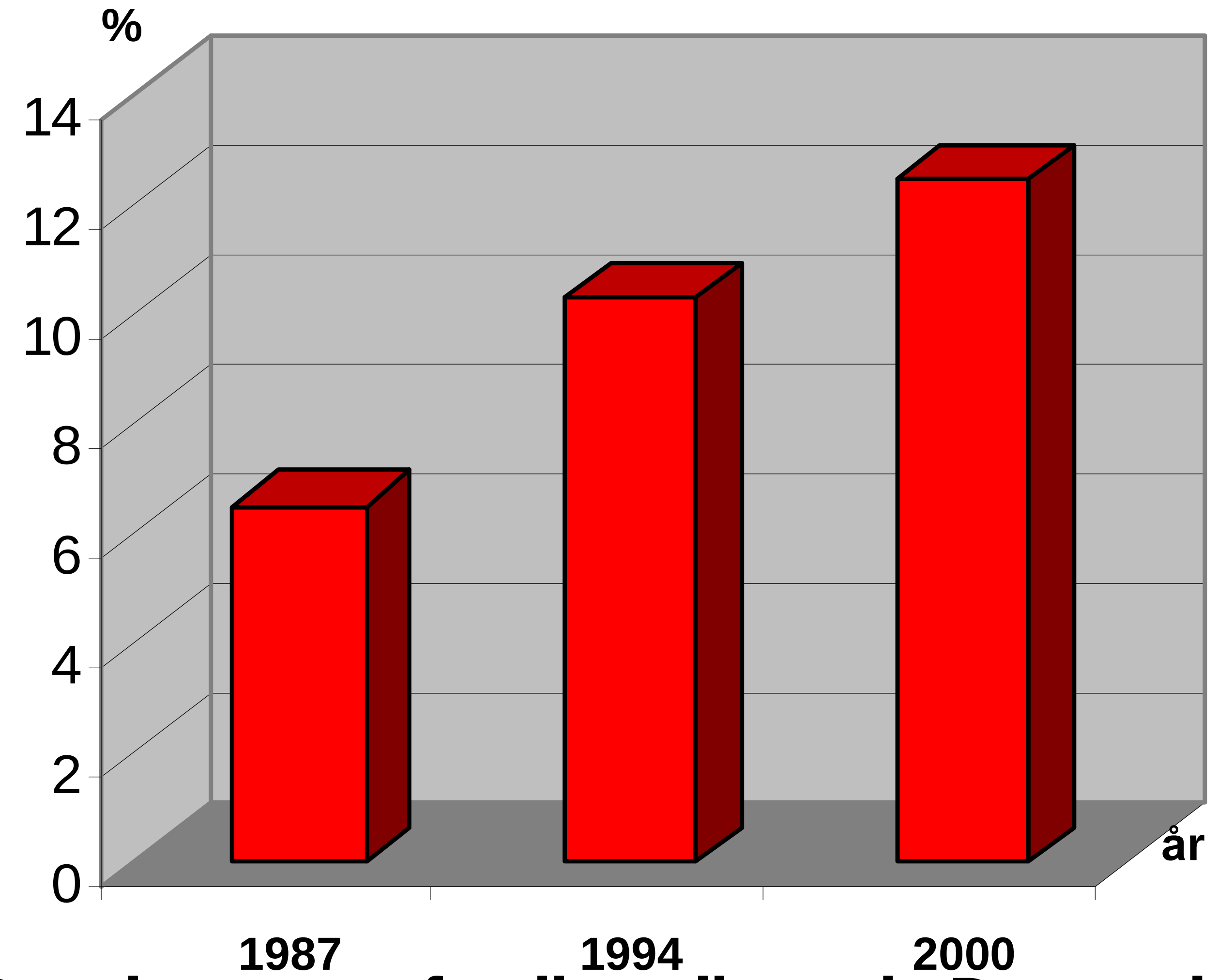


48 hours forecast



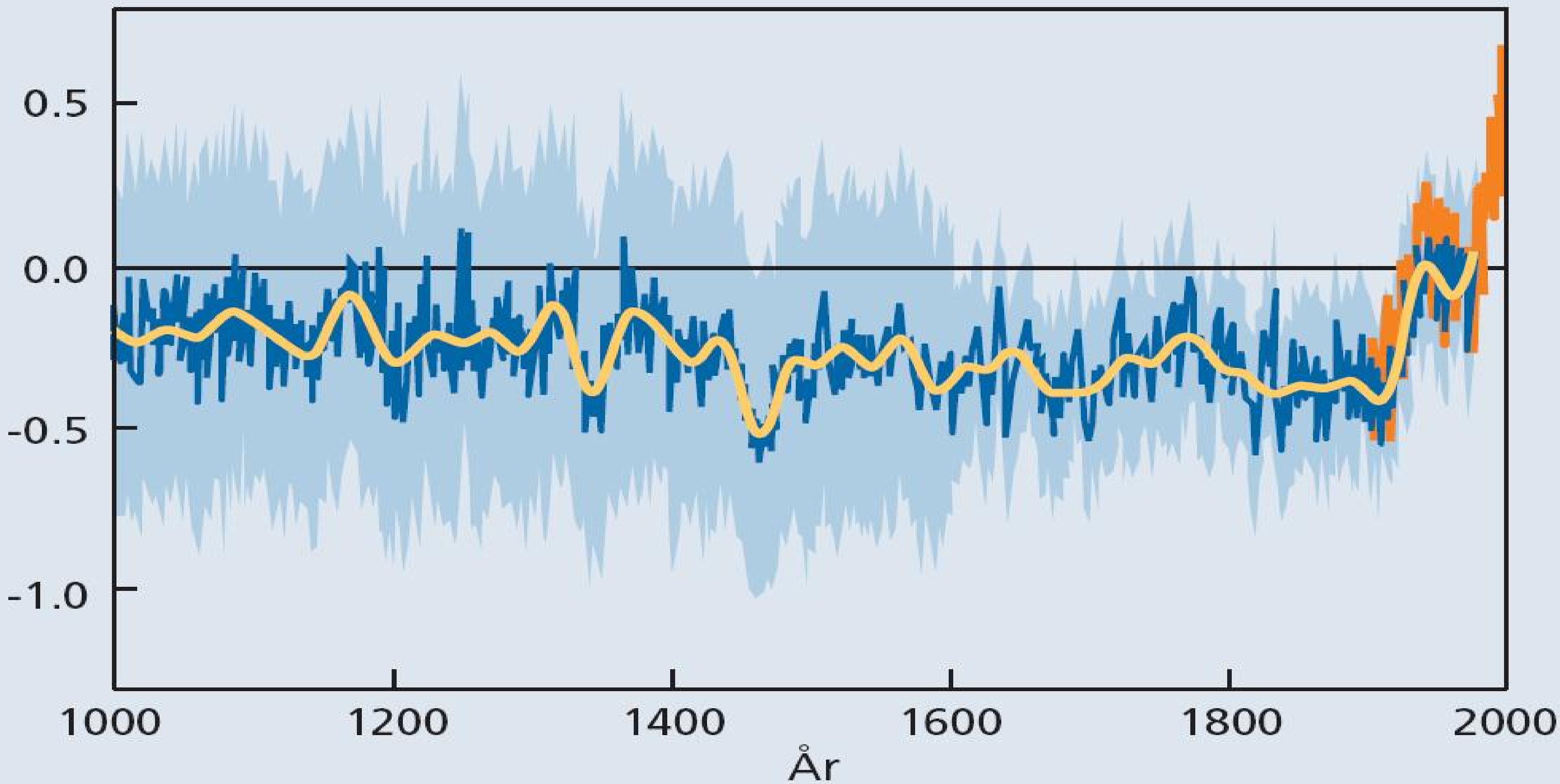
1000 km radius

Pollen Allergy Is Increasing
Why?



Development of pollen allergy in Denmark

The increase of the temperature in the atmosphere



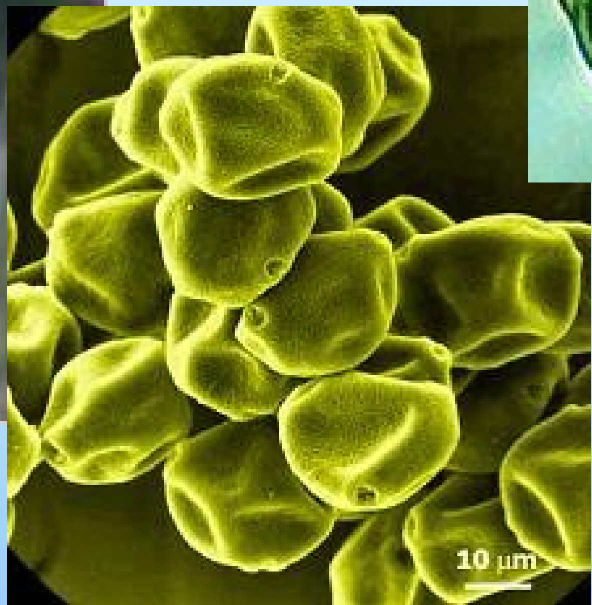
Trends in start, duration (length), and intensity (annual totals) of pollen seasons in Europe 1974-2002 (Jeager 2001)

pollentype	n=	start	peak	end	len	nofdays	peakval	anntotl
		timing			duration		intensity	
Alnus	2305	-2	-2	-2	0	0	0	0
Corylus	2285	-2	-2	-2	2	0	0	0
Cupressaceae	1768	-2	-2	0	2	2	2	2
Populus	1650	-2	-2	-2	2	2	0	0
Salix	1706	-2	-2	-2	2	1	0	0
Betula **(Birch)**	2552	-2	-2	-2	0	-2	0	0
Fraxinus	2033	-2	-2	0	2	2	0	0
Platanus	1924	-2	-2	-2	0	2	2	2
Oleaceae	999	0	0	0	0	-2	0	0
Pinus	1877	-2	-2	0	2	2	0	0
Poaceae	2532	-2	-2	0	2	2	2	2
Castanea	1350	-2	-2	-2	0	0	2	2
Chenopdiaceae	1958	-2	0	2	2	2	2	2
Urticaceae	2184	-2	-2	2	2	2	2	2
Ambrosia	760	-1	0	2	2	2	1	2
Artemisia	2127	-2	0	2	2	2	0	0
Mercurialis	596	-2	-1	0	2	0	0	0

-2 earlier 2 later -2 less 2 more

Zoom of Birch pollen

Main pollen allergen in Denmark



Bet v 1 allergen

Article from the Danish newspaper Politiken, d. 26 February 2005

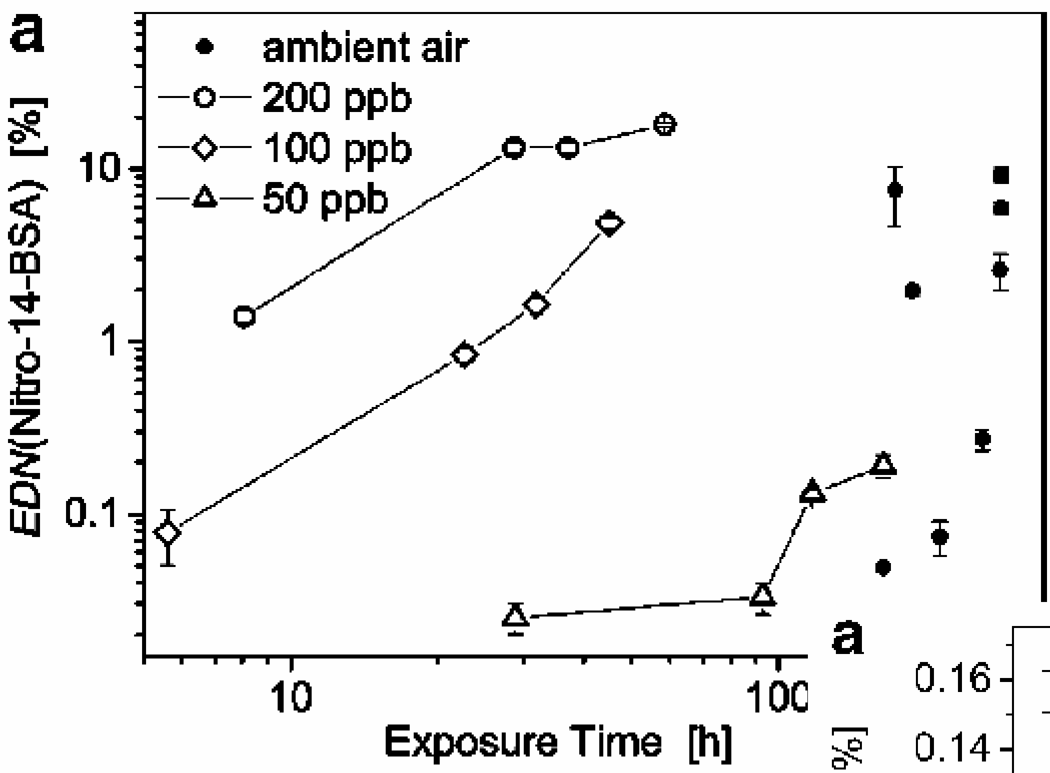
Biltrafik giver allergi

Udstødningsgas fra biler mistænkes for at gøre pollen mere allergifremmende, og øget biltrafik i byerne kan være forklaring på, hvorfor antallet af astma- og allergitilfælde vokser.

Forskerne har længe kendt den statistiske sammenhæng mellem øget luftforurening og et stigende antal sygdomstilfælde, men der har manglet en videnskabelig forklaring. Nu har et tysk forskerhold fra Münchens Tekniske Universitet fundet en mulig forklaring. De mener, at blandingen af kvælstofdioxid og ozon, der forekommer i luftforurening fra biler, kan omdanne proteiner i f.eks. pollen, oplyser Danmarks Meteorologiske Institut (DMI).

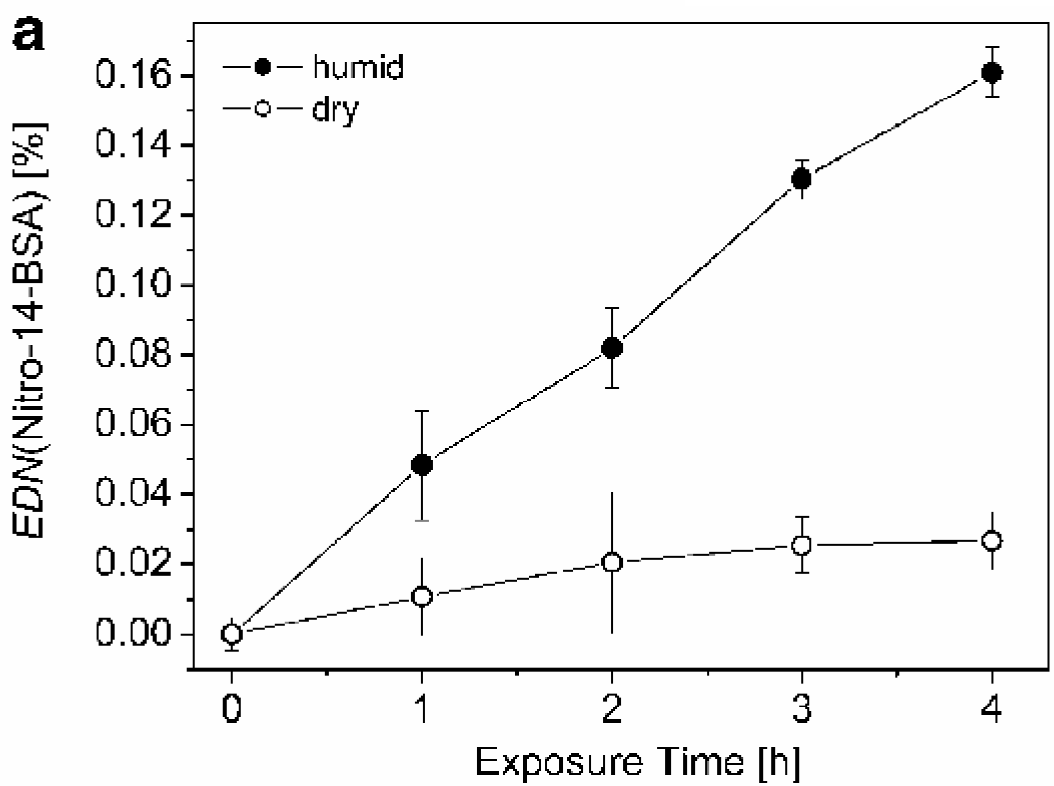
»De omdannede proteiner kan forårsage betændelser og allergi efter inhalering«, siger Allan Gross, ansvarlig for DMI's smog- og ozonberedskab. Pollenallergi er almindeligt i den danske befolkning. (Ritzau)

RH = 40 %
equal amounts of NO_2 and O_3



- RH = 40 %
- ○RH < 1 %

NO_2 = 500 ppbV
O_3 = 500 ppbV



- **10% of the allergens from pollen along a traffic will be nitrated.**
- **The nitrated proteins can increase the number of asthmatics and allergy suffers.**

(Franze et al, 2005)

Electron microscope picture of grass pollen before (a) and after (b) it has been exposed to aerosol particles

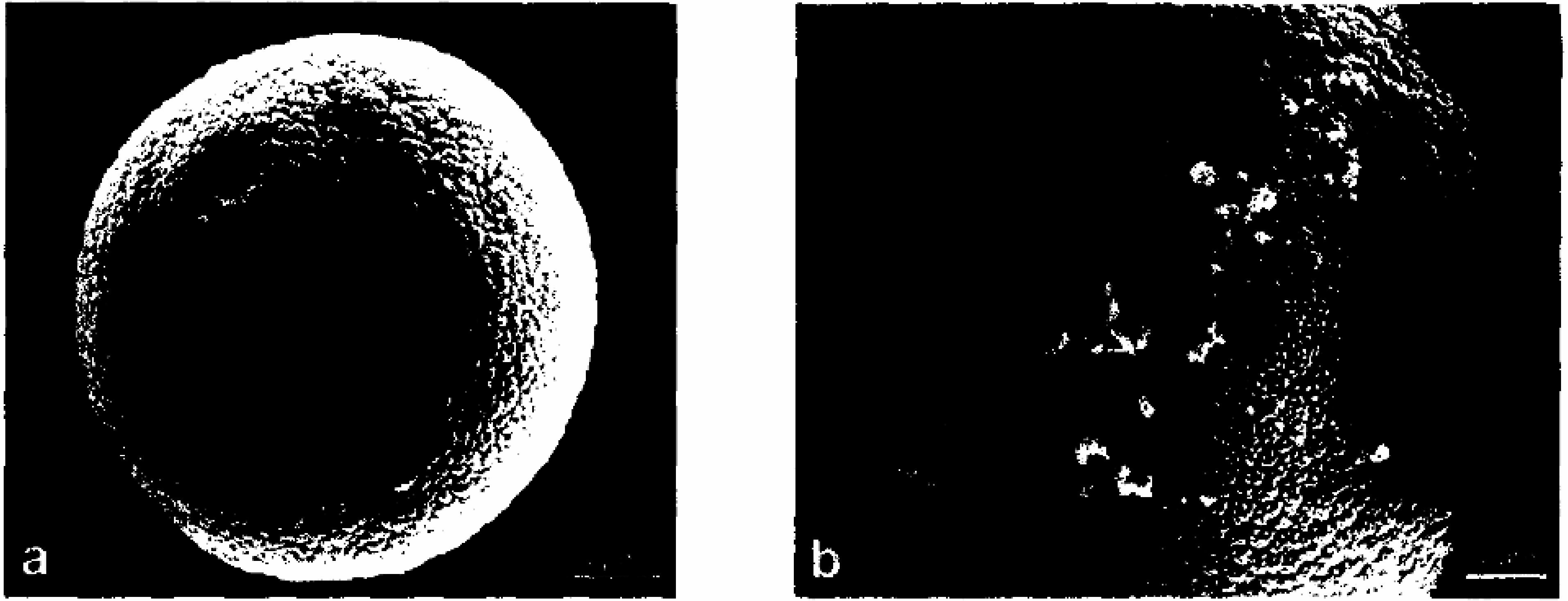


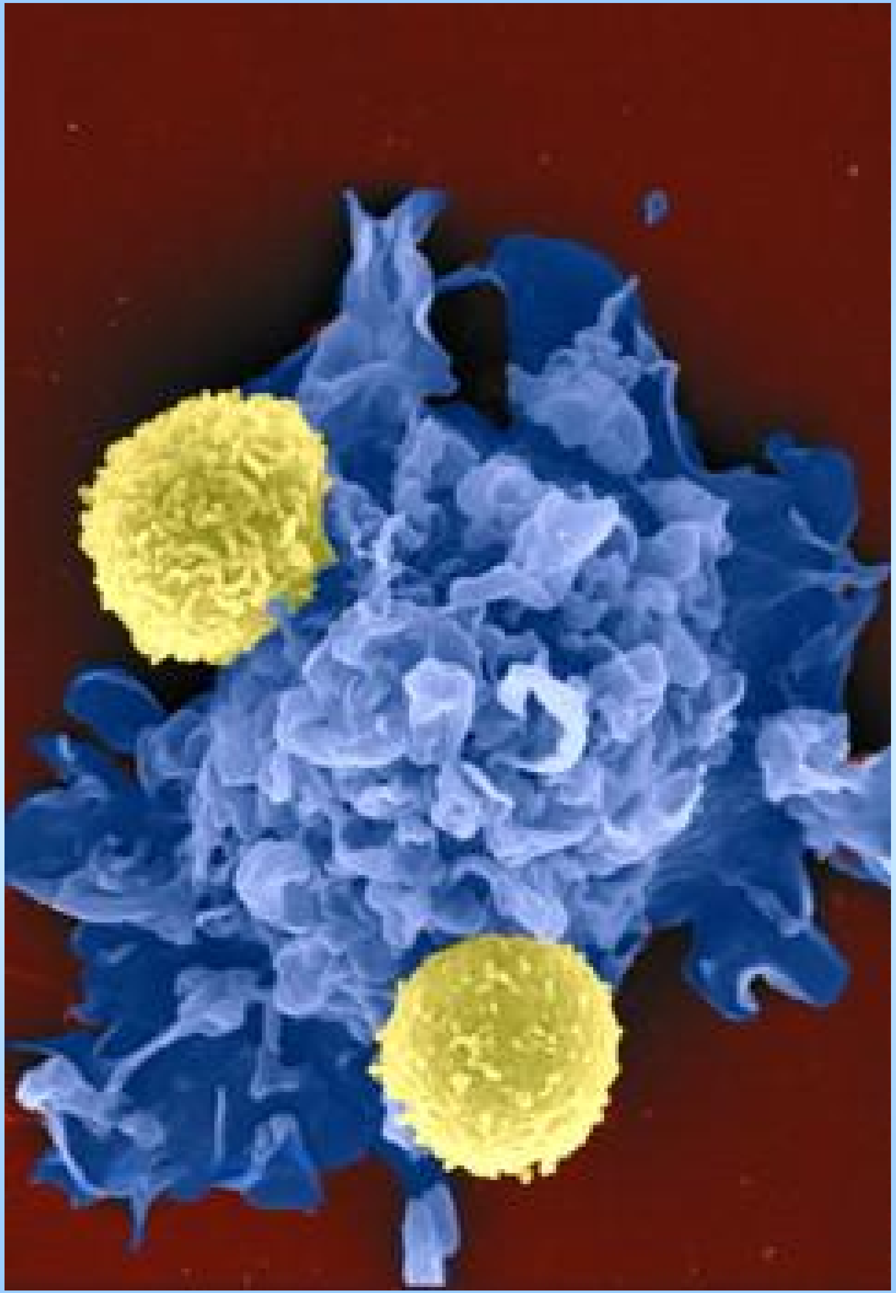
Fig. b: The surface of pollen is covered with aerosol particles.

The release of proteins increases with ca. 10 % when the pollen particle is exposed to road dust and the relative humidity is ca. 50 % in 4 hours.

Prick tests shows an increase reaction among allergy suffers, 30 to 45 %.

Risse et al., J. Aerosol Science, 2000

Direkte effekt



D cell (blue) exposed to lipids (yellow).

↓

Increase of a Th2 response.

↓

Provoke the allergy suffers and an outbreak.

Traidl-Hoffmann et al., JEM, 2005, have shown that this exposure increases in air pollution.

The mechanism is unknown but it is assumed that air pollution stress pollen. This results in an increase activation of lipids in pollen.

Summary

- Have illustrated the importance of urban meteorology in NWP and air quality modelling.
- Have illustrated in importance of on-line modelling. Needed of correct treatment of the advection.
- Shown the first preliminary test of a pollen forecast. In the moment there is a high focus on pollen allergy an Europe and USA.
- The is a connection between pollen allergy and air pollution. Have presented some possible explanations for this connection (urban effect on pollen).

Спасибо за внимаие!