ENVIRO-HIRLAM: An online integrated system

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INTRODUCTION - PRE

Offline coupled models: DERMA, CAC

Steps towards ENVIRO-HIRLAM:

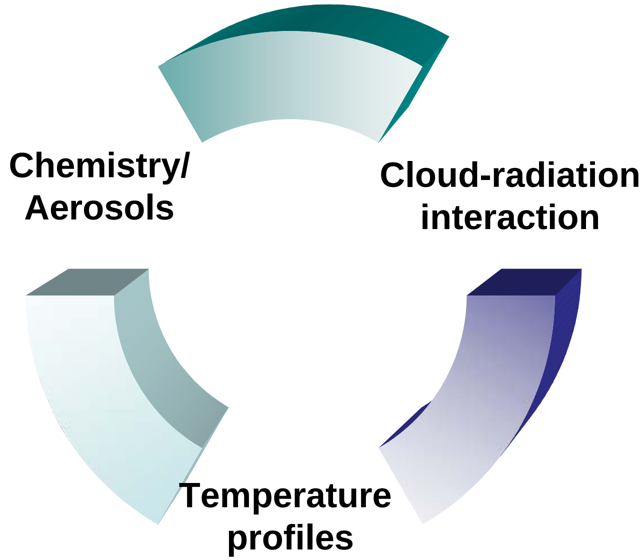
- Improved representation of pbl. and sl.
- ‘Urbanisation’ of the NWP model
- Improvement of advection schemes
- Implementation of chemical mechanisms
- Implementation of aerosol dynamics
- Realisation of feedback mechanisms (microphysics)
- Assimilation of monitoring data

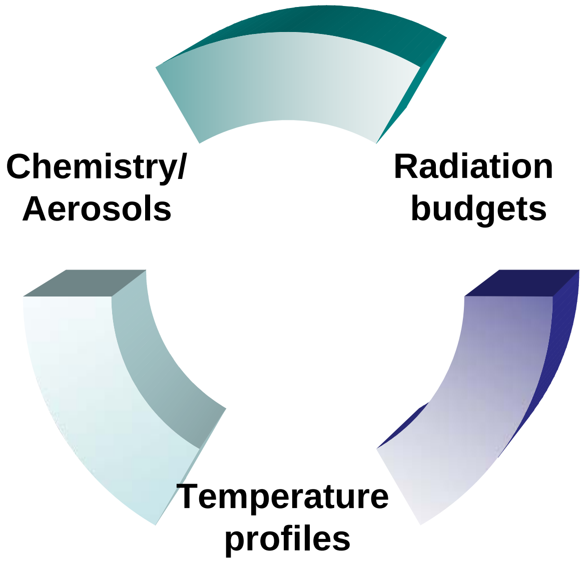
INTRODUCTION - MOTIVATION

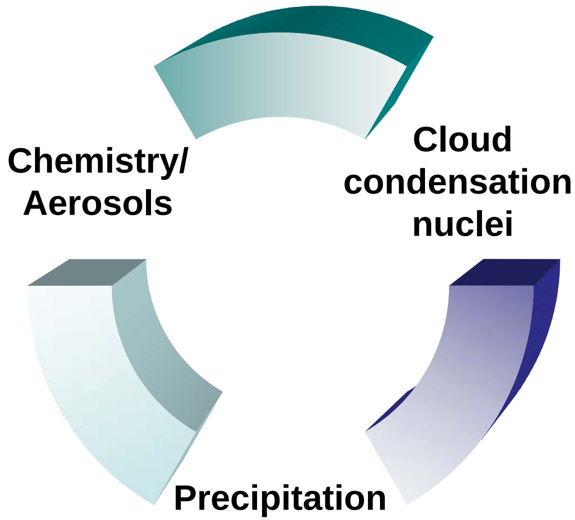
- Environmental: air pollution forecasts; pollen, ozone
- Short range weather forecasting
- Climate: direct effects, indirect effects, semi-direct effects, large scale dynamical feedbacks

INTRODUCTION - FEEDBACKS

- Photochemistry effect
- Daytime stability effect
- Indirect effect
- Semi-direct effect
- Smudge-pot effect
- Self-feedback effect







INTRODUCTION - DEFINITIONS

off-line models comprise:

Separate CTMs driven by meteorological input data from meteo-preprocessors, measurements or diagnostic models

Separate CTMs driven by analysed or forecasted meteo-data from NWP archives or data sets

Separate CTMs reading output files from operational NWP models or specific MetMs with limited temporal resolution (e.g. 1, 3, 6 hours)

on-line models comprise:

On-line access models when meteo-data is available at each time step

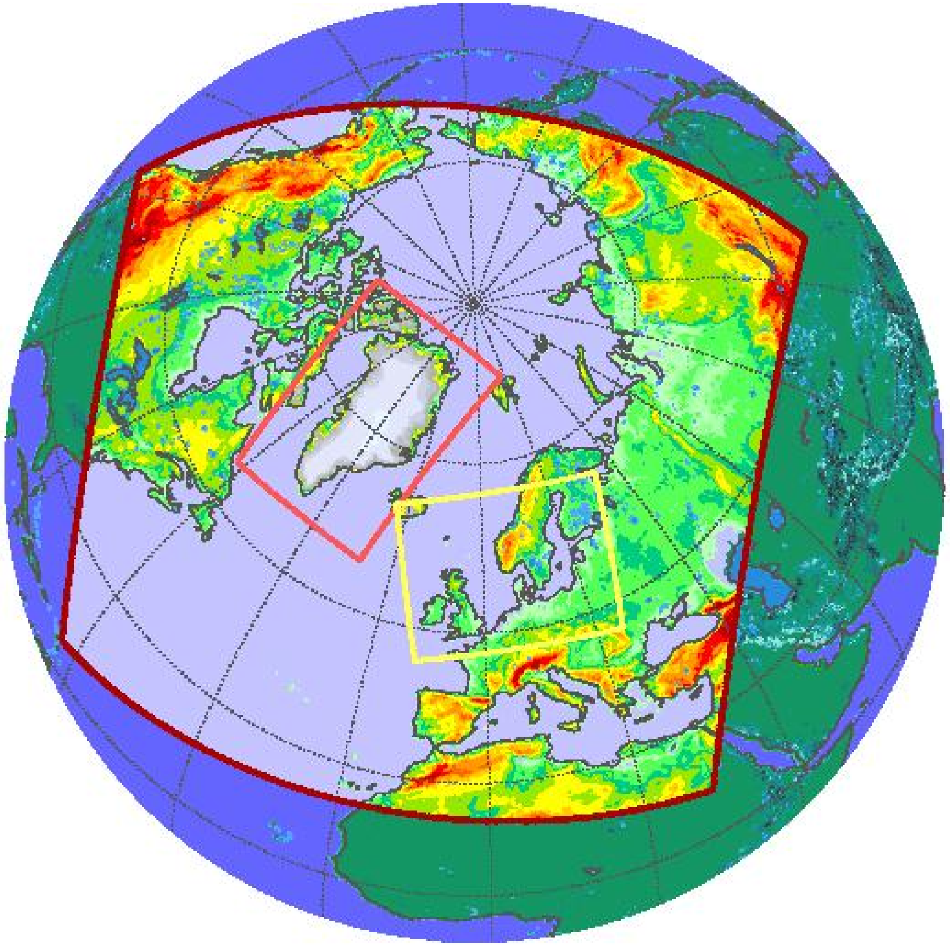
On-line integration of a CTM into a MetM; feedbacks are possible: **on-line coupled modeling**

OUTLINE AND OBJECTIVE

Objective: To illustrate differences between on-line and off-line coupled models

1. Introduction – Perspective
2. Model description
3. Model evaluation
4. On-line/Off-line Comparison
5. Feedbacks
6. Conclusions
7. References and acknowledgements

DMI-ENVIRO-HIRLAM - OPERATIONAL



Model identification	T15	S05
grid points (mlon)	610	496
grid points (mlat)	568	372
number of vertical levels	40	40
horizontal resolution (deg)	0.15°	0.05°
time step (dynamics)	360s	120s
time step (physics)	360s	120s
host model	ECMWF	T15

U01: 1.4 km resolution covering part of Denmark

DMI-ENVIRO-HIRLAM - OPERATIONAL

- 3d-var/4d-var upper air data-assimilation
- Surface data assimilation
- Boundary layer height: Ri approach (*Toren and Mahrt, 1986*)
- Vertical diffusion: CBR-scheme (*Cuxart et al., 2000*)

  Coefficient defined by mixing length formulation in
  Stable/unstable conditions

DMI-ENVIRO-HIRLAM - DYNAMICS

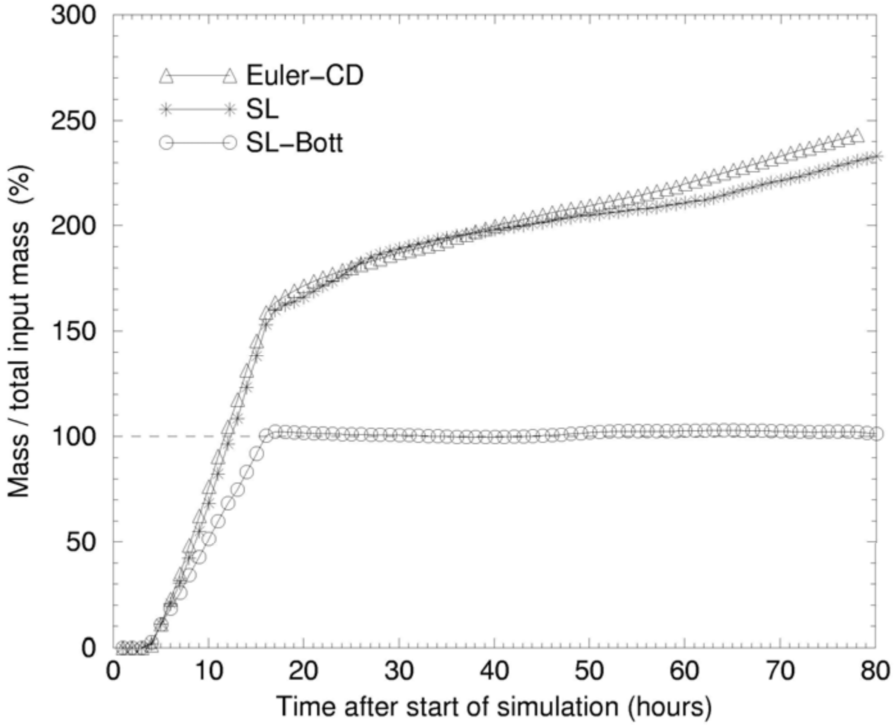
- Bott advection (*Bott, 1989*) + Easter update for tracers (*Easter, 1993*); 4th order polynomials in x and y; 2nd order polynomials in z; uses lower time step than meteorology.
- Semi-Lagrangian for meteorology
  - Risk of mass-wind inconsistency

- Non-staggered finite differences (vertical)
- Hybrid coordinate η:

  $P = A(\eta) + B(\eta)\, P_{surface}$

  A=0; σ – coordinates

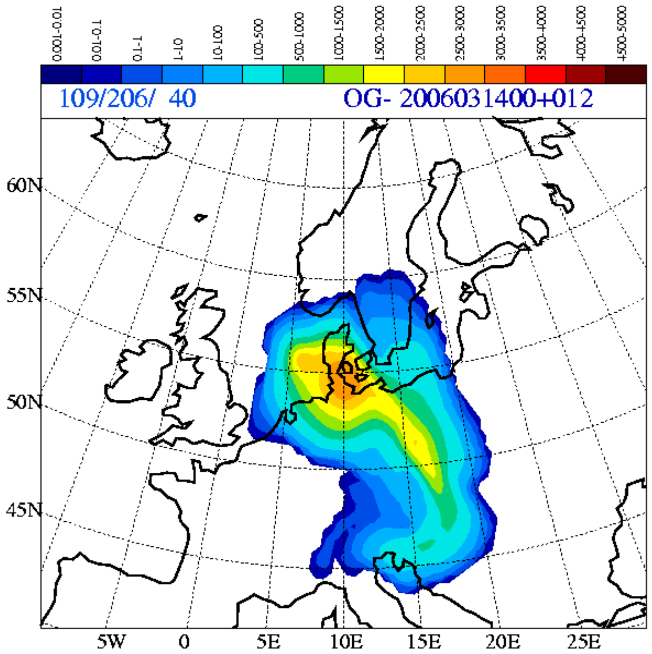
  B=0; P – coordinates
- Arakawa C grid
- Implicit 4th horizontal diffusion



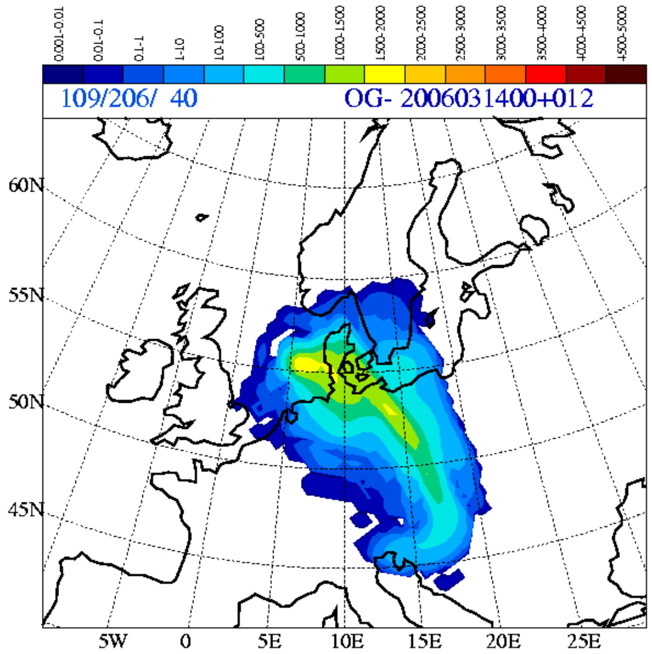
Mass conservation test for ETEX release

DMI-ENVIRO-HIRLAM - DYNAMICS

ETEX 1, 48 hours after start of release



Semi-Lagrangian



Bott

DMI-ENVIRO-HIRLAM - DEPOSITION

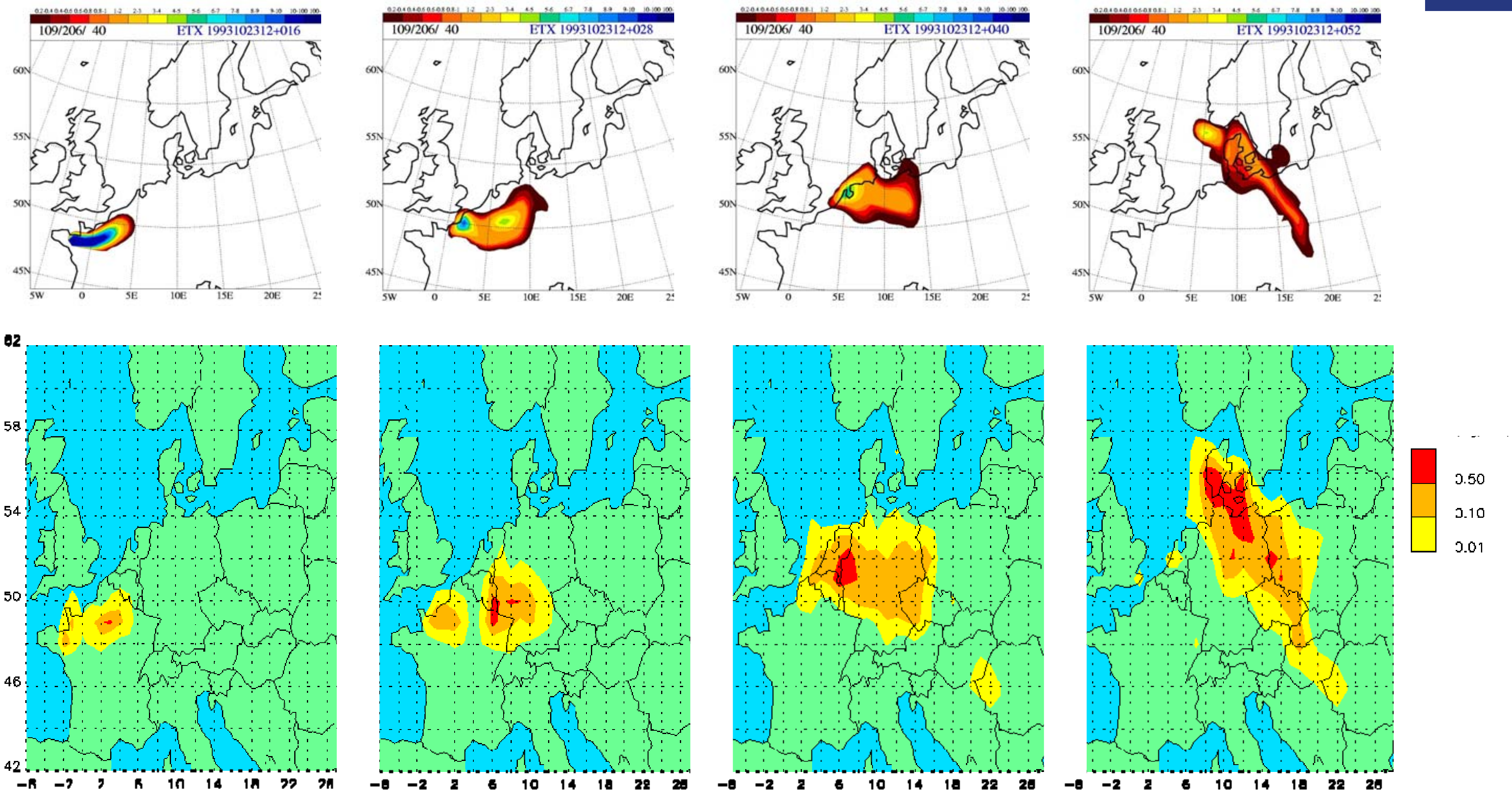
- Emissions -> Eulerian point sources
- Particle size dependent parameterizations for dry and wet deposition
- Resistance approach for dry deposition (*Wesley, 1989; Zanetti, 1990*)
- Terminal settling velocity in different regimes:
  - Stokes' law
  - non-stationary turbulence regime
  - correction for small particles
- Dependent on land use classification
- Below-cloud scavenging (washout); precipitation rates (*Baklanov & Sørensen, 2001*)
- Scavenging by snow (*Maryon et al., 1996*)
- Different scavenging of particles and gases

DMI-ENVIRO-HIRLAM - NEXT

- Rainout into 3D clouds (based on on-line coupling):
  - convective precipitation
  - stratiform precipitation

- Implementation of chemical mechanisms
- Implementation of aerosol dynamics

EVALUATION – ETEX-1



Tracer concentration (ng/m³) at 12, 24, 36, 48 hours after start of release.

Top panel: simulation, bottom panel: measurements.

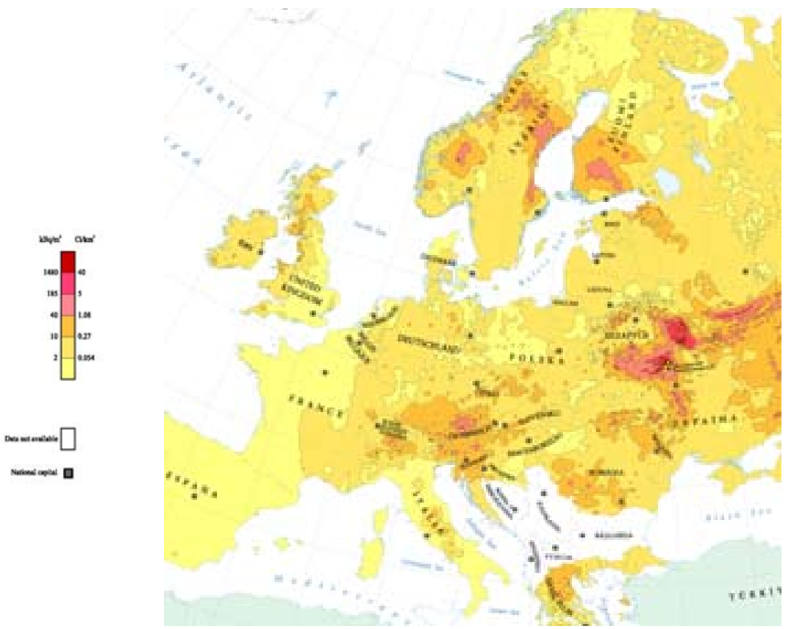
EVALUATION – ETEX-1

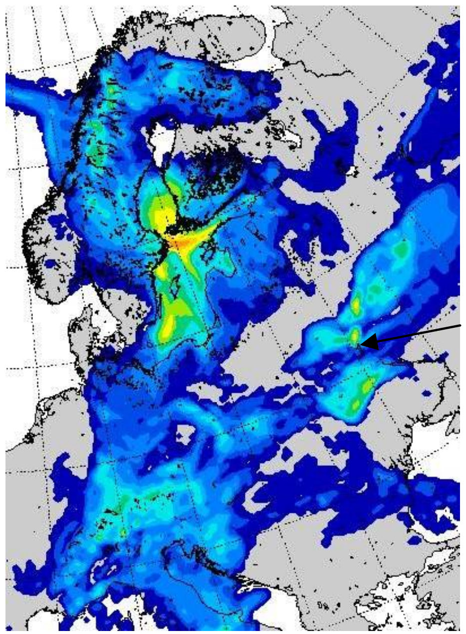
Station ->	B05	CR03	D05	D44	DK02	DK05	H02	D42	NL01	NL05	PL03
Bias (ngm^{-3})	0.76	-0.08	0.02	0.45	-0.01	-0.11	-0.02	-0.14	0.48	0.65	-0.06
NMSE	12.9	7.95	2.0	4.54	0.93	4.77	1.05	2.25	4.46	14.8	1.95
Correlation	0.80	0.92	0.29	0.64	0.68	0.08	0.86	0.46	-0.05	0.29	0.43
FMT (%)	12.9	26.1	29.6	32.1	51.4	15.4	49.3	32.7	15.9	19.1	38.4

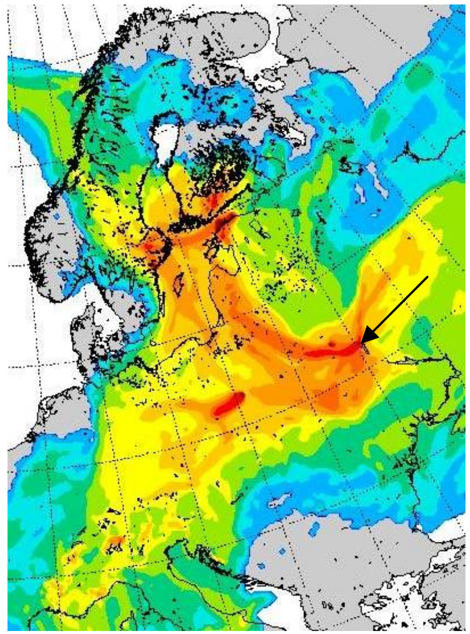
Averages: bias 0.18 ngm^{-3}; correlation 0.49; NMSE 5.25; FMT 29.4%
Global: bias 0.39 ngm^{-3}; correlation 0.57; NMSE 104.59; FMT 18.4 %

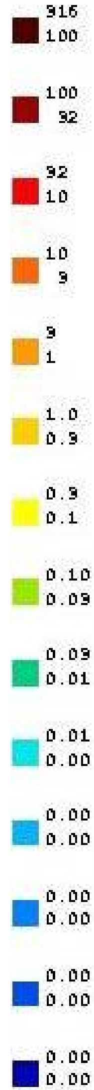
EVALUATION - CHERNOBYL

Chernobyl accident; point source emissions (*Devell et al., 1995, Persson et al., 1986*).
Date: 19860501 18:00 UTC





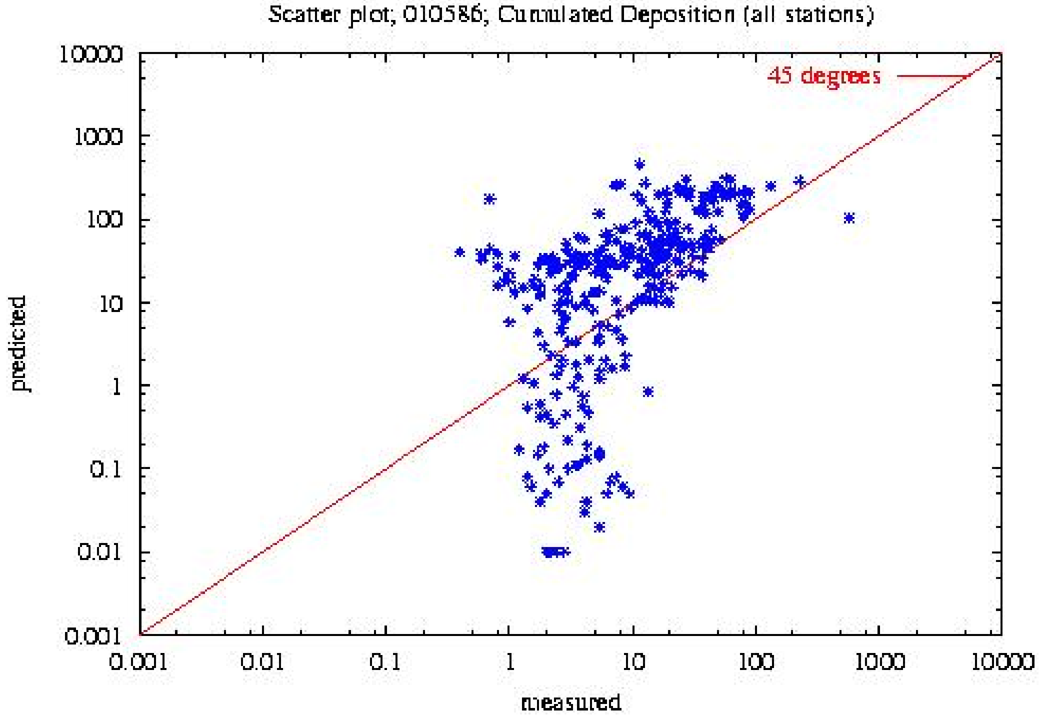




Left: Cesium deposition measurements (*De Cort et al., 1998*); Middle: Wet deposition; Right: Dry deposition. Units: KBq/m^2

EVALUATION - CHERNOBYL

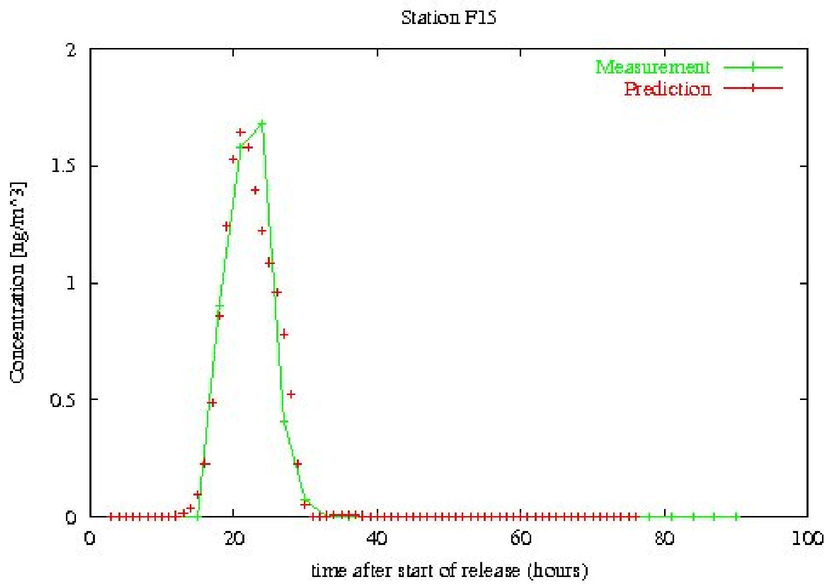
Global statistical scores	
Observed mean (Bq/m²)	17.97
Predicted mean (Bq/m²)	56.74
Correlation	0.59
Bias (Bq/m²)	38.77
NMSE	6.34
FMT (%)	26.29

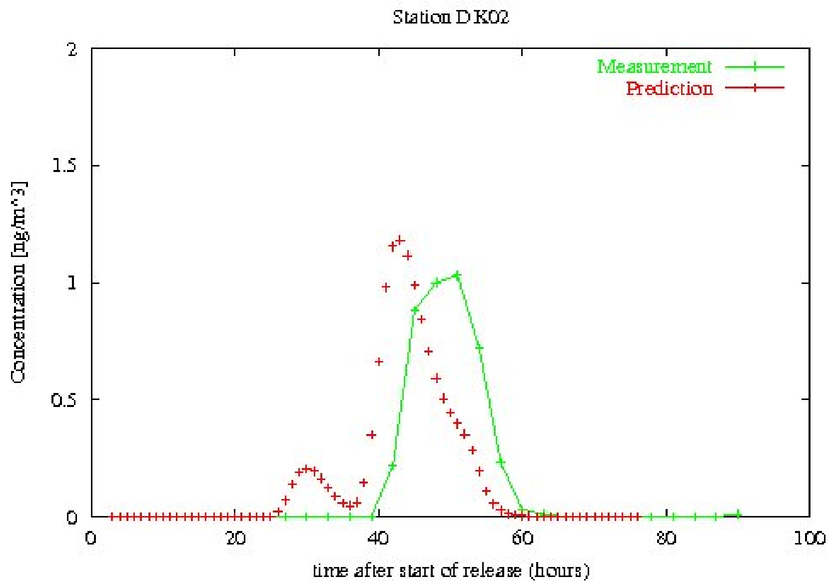


EVALUATION - CONCLUSION

- Transport and dispersion performs satisfactory when compared to ETEX-1
- Dry and wet deposition perform satisfactory when compared to Chernobyl accident data

ON-LINE/OFF-LINE COMPARISON





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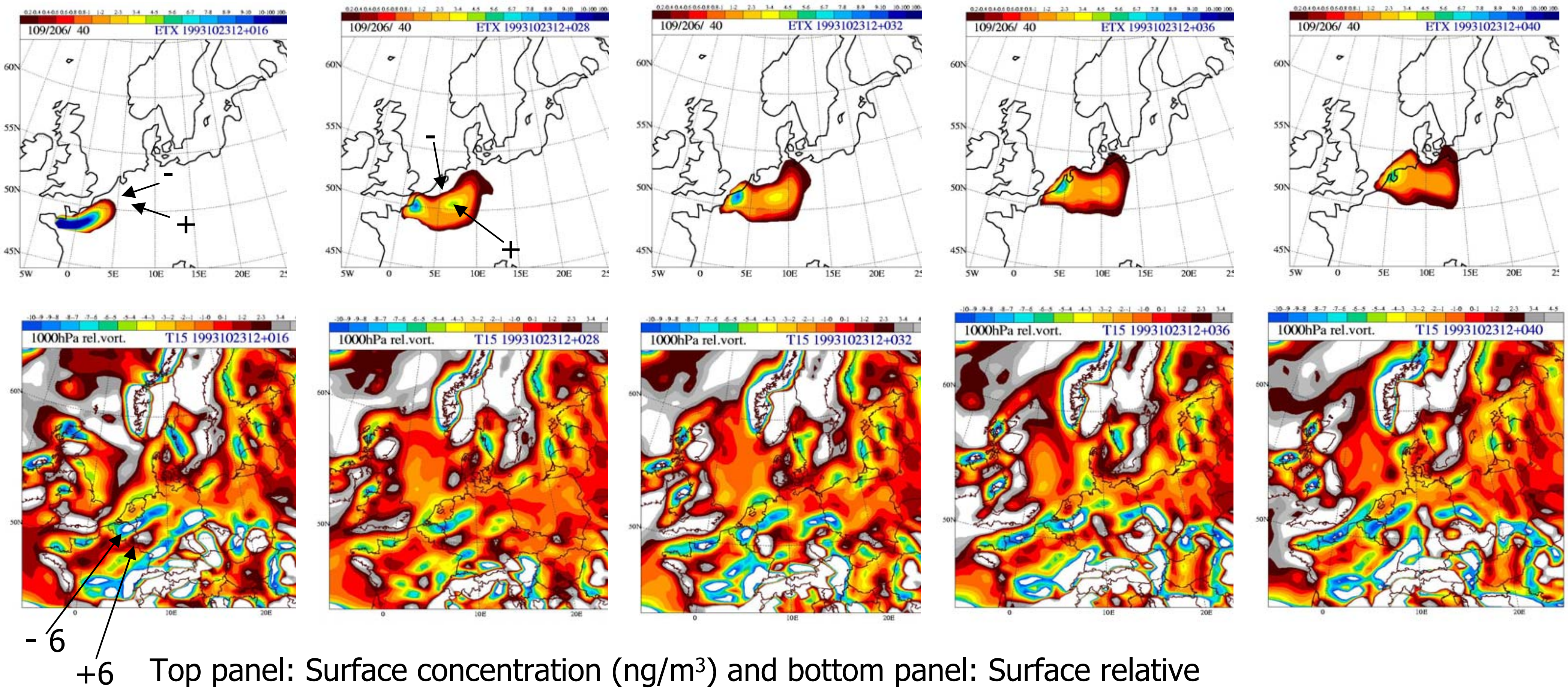
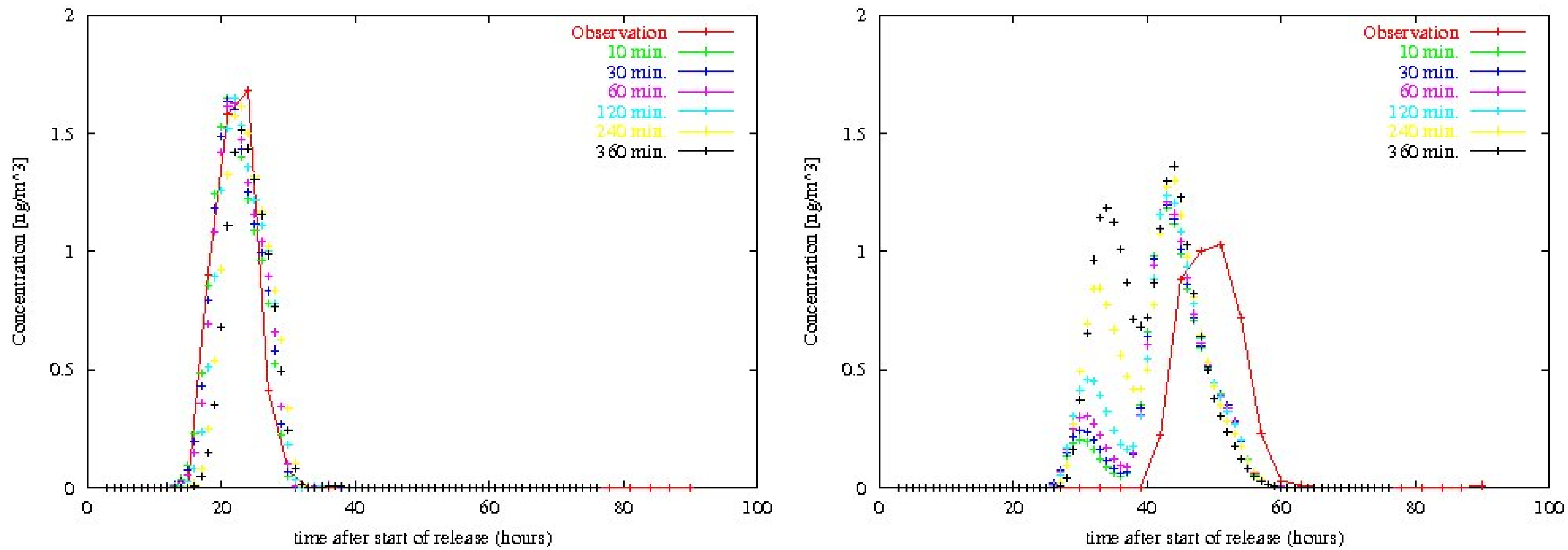
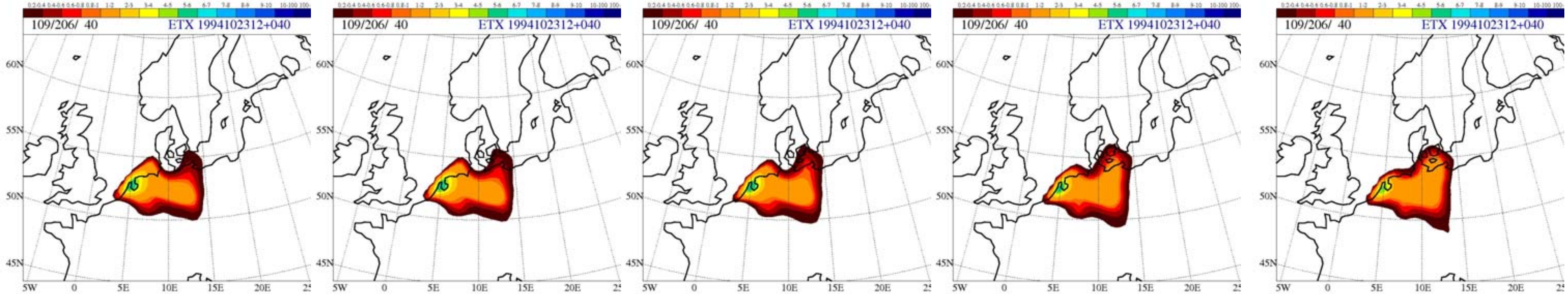


Top panel: Surface concentration (ng/m^3) and bottom panel: Surface relative vorticity (s^{-1}) at 12, 24, 28, 32, 36 hours after start of release.

ON-LINE/OFF-LINE COMPARISON





Top: concentration as function of time at F15 and DK02 for different coupling intervals: 30, 60, 120, 240, 360 minutes. Bottom: concentration after 36 hours with the same coupling intervals

ON-LINE/OFF-LINE COMPARISON - CONCLUSION

- The coupling interval is important in constraining the evolution of mesoscale disturbances

- If the mesoscale disturbances are not properly resolved, this may lead to errors in tracer distribution

FEEDBACKS/AEROSOL FORCING

For water clouds:

$r^3_{eff} = kr^3_v$

$r^3_{eff} = 3L/(4\pi\rho_l kN)$

(*Wyser et al. 1999*)

	k	N $[m^{-3}]$
Marine	0.81	10^8
Cont	0.69	$4x10^8$

Urban fractions [%; dark green – dark red]

L : Cloud condensate content

N: Number concentration of cloud droplets

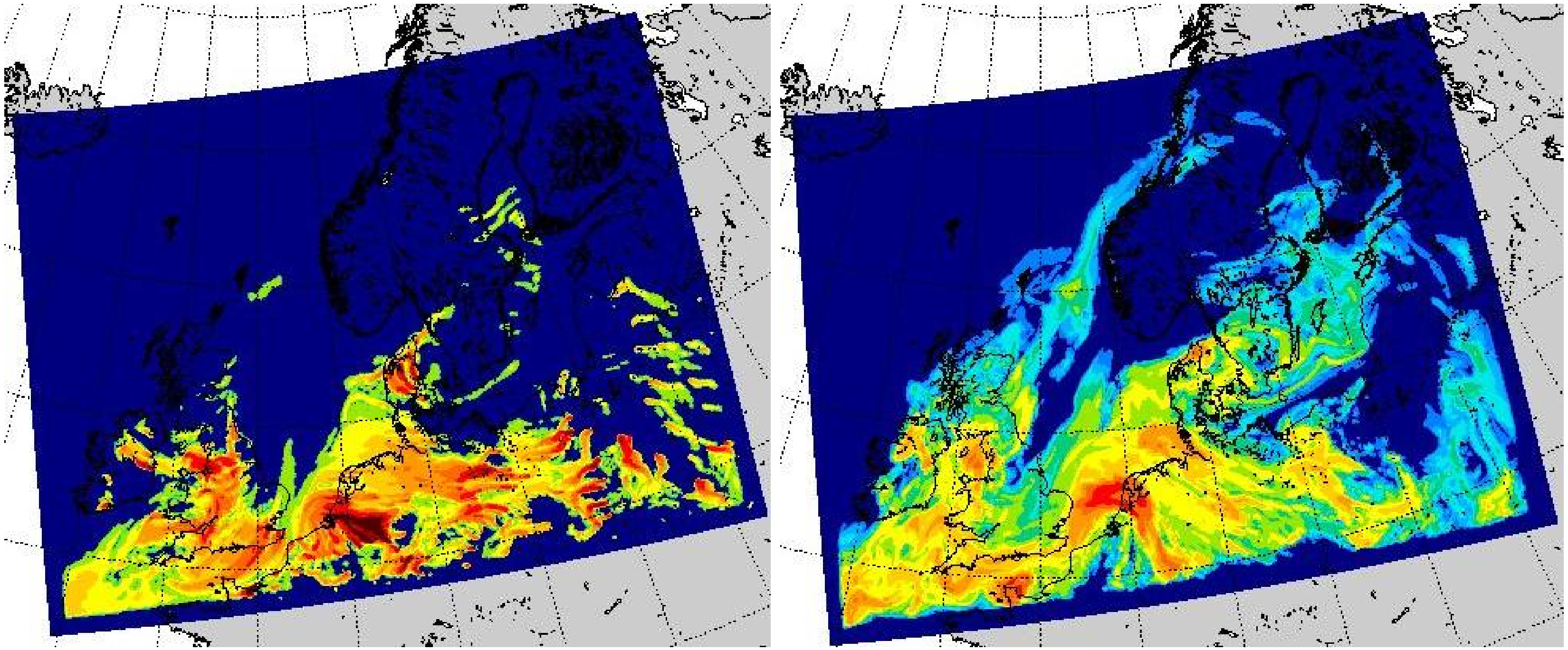
$\Delta N_{cont} = 10^{8.06}\ conc^{0.48}$

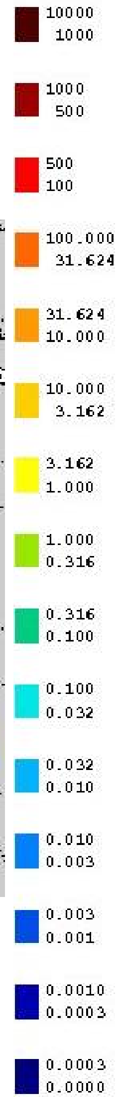
$\Delta N_{marine} = 10^{2.24}\ conc^{0.26}$

(*Boucher & Lohmann, 1995*)

Diameter: 1 μm

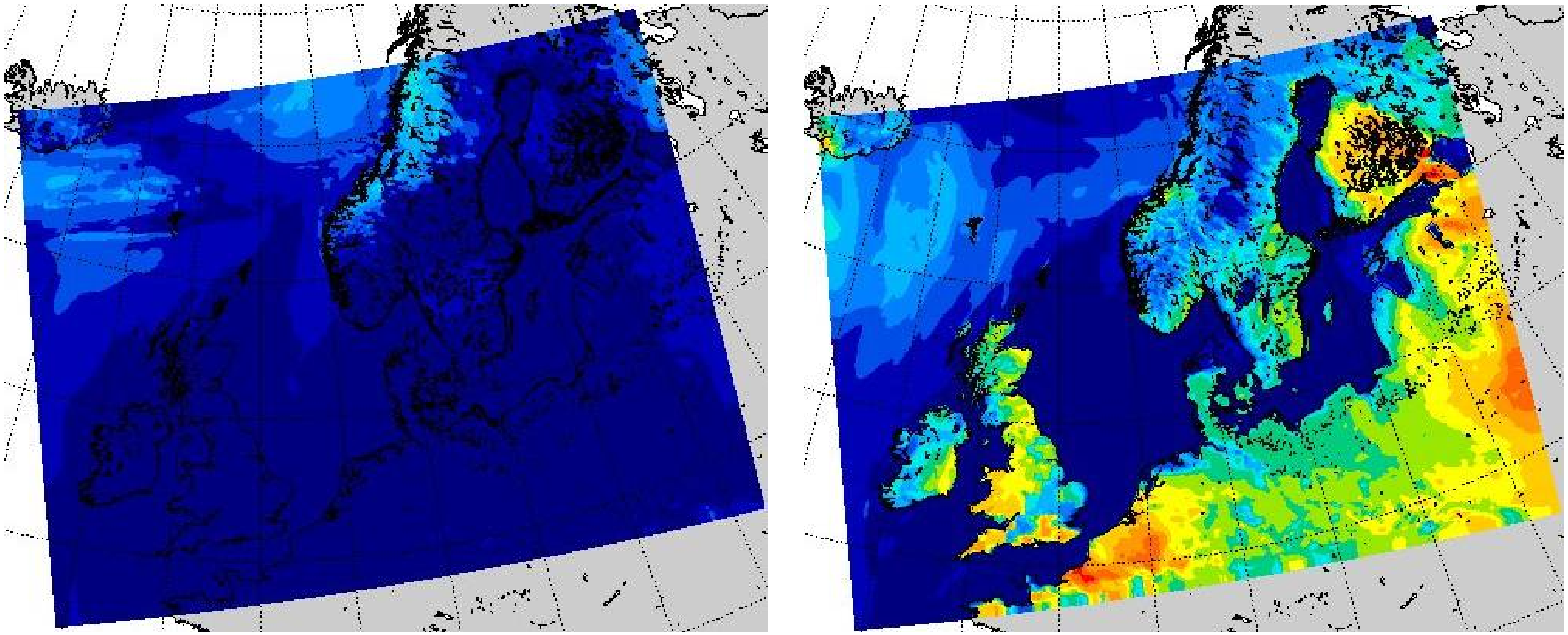
FEEDBACKS/AEROSOL FORCING

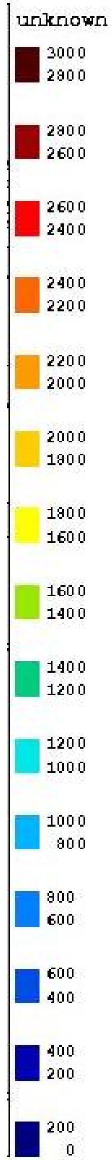




Reference concentration (µg/m^3) at surface (left) and at app. 400 m (right). Time: 06 UTC, date: 13-04-2007

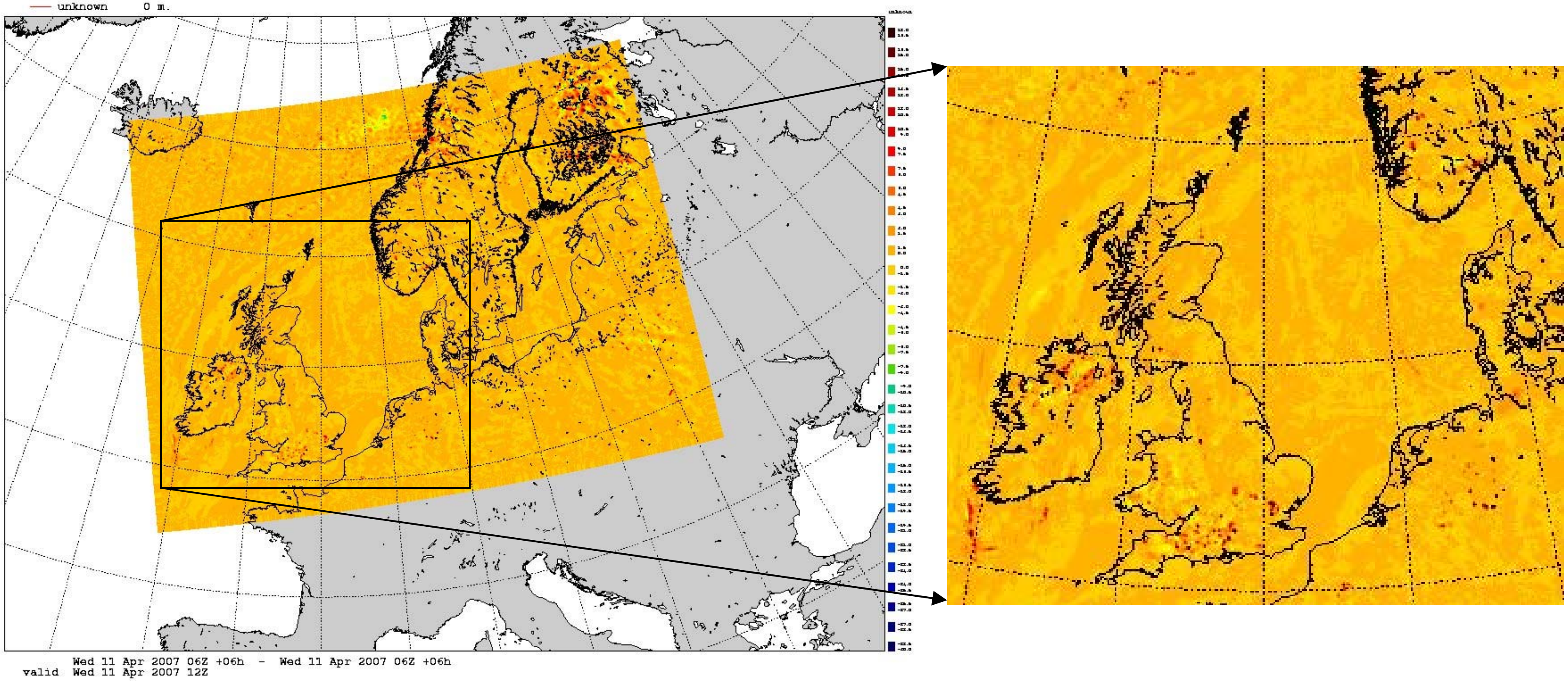
FEEDBACKS/AEROSOL FORCING





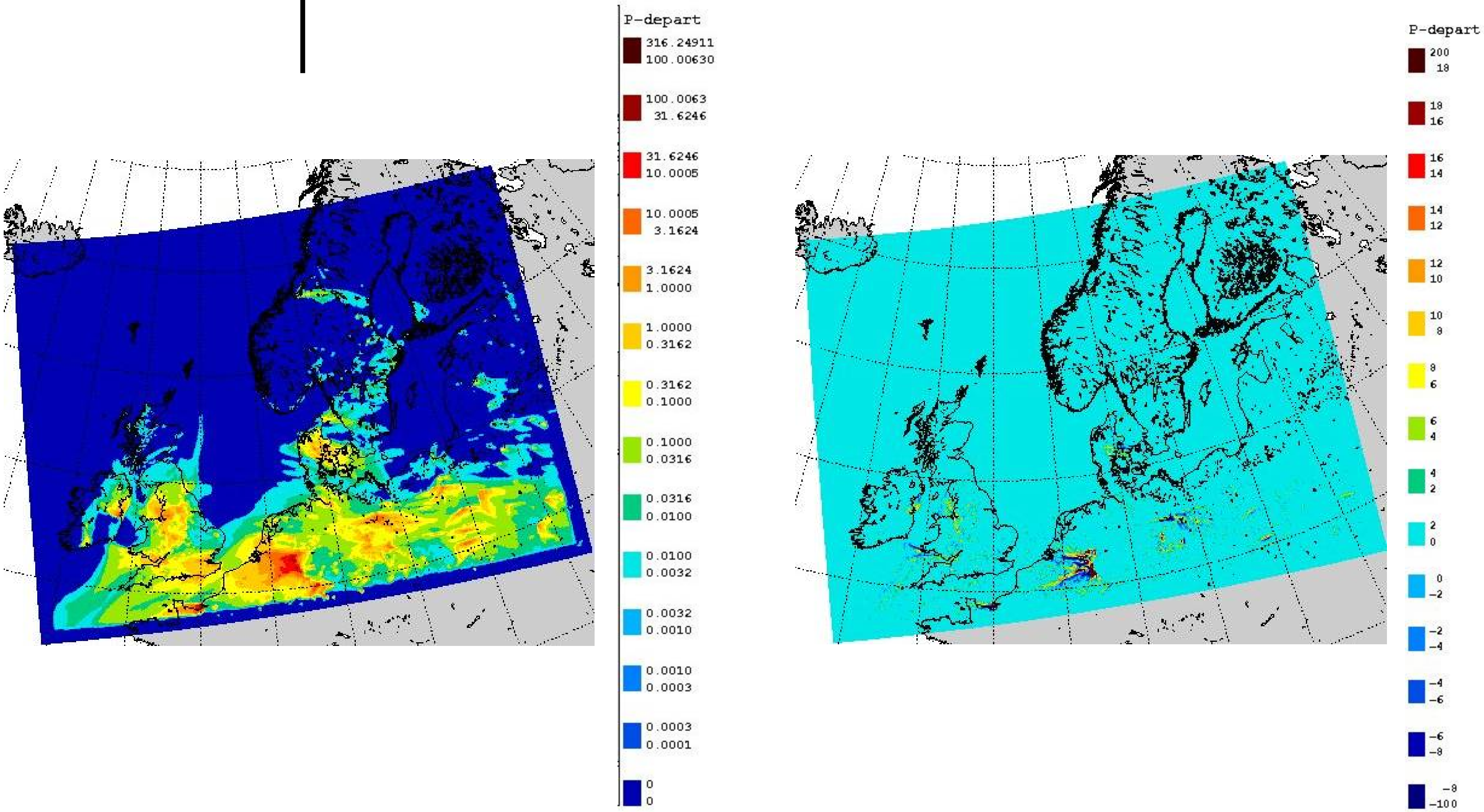
Boundary layer height (m) at 06 UTC on 13-04-2007 (left) and 12 UTC on 12-04-2007 (right)

FEEDBACKS/AEROSOL FORCING



PBLH (m) average from 06 UTC 11-04-2007 to 06 UTC 13-04-2007

FEEDBACKS/AEROSOL FORCING



Accumulated dry deposition (left) and difference in dry deposition (right) in µg/m² at 06 UTC 13-04-2007. Max difference app. +/- 100 µg/m²

FEEDBACKS - CONCLUSION

- Inclusion of the 1st indirect effect gives rise to feedbacks through which boundary layer height is modified

- The change in boundary layer height affects dispersion of pollutants and results in modifications of deposition patterns

- At a given time the increase in boundary layer height may of the same order (100 m) as the effect of urban representations on boundary layer height

FINAL COMMENTS

- Model performs satisfactory against ETEX-1 and Chernobyl accident data
- The coupling interval is important in constraining the evolution of mesoscale disturbances
- Inclusion of the 1st indirect effect may give rise to important feedbacks through which boundary layer height is modified and deposition is changed

Most important steps with respect to HIRLAM development:

- Improved representation of pbl. and sl.
- 'Urbanisation' of the NWP model
- Realisation of feedback mechanisms (microphysics)

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The HIRLAM development program at DMI
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Thank you for your attention

DMI

INTRODUCTION – ONLINE/OFFLINE

On-line coupling

- Only one grid; no interpolation in space
- No time interpolation
- Physical parameterizations are the same; no inconsistencies
- Possibility of feedbacks with meteorology
- All 3D meteorological variables are available at the right time (each time step); no restriction in variability of met. fields
- Does not need meteorological-pre/post-processors

Off-line

- Possibility of independent parameterizations
- Low computational cost if running many experiments with the same meteorological input
- Independence of meteorological model computations