Variational Assimilation of combined satellite retrieved and in situ aerosol data in an advanced Chemistry Transport Model

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Outline

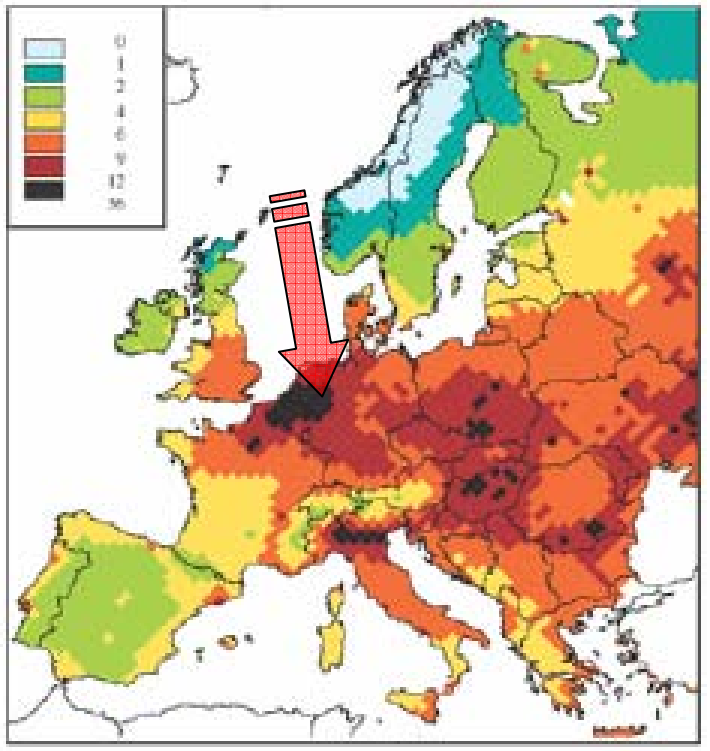
- Introduction
- Aerosol observations
- Data Assimilation (3Dvar)
- Case study
- Summary

Introduction

- The impact of PM_x (Particulate Matter) on human health is strong
- CAFE (Clean Air For Europe, 2005) final report states:
  - Estimated reduction of lifetime expectance due to $PM_{2.5}$ is large
  - Modelling of TPM is not yet satisfying
    - Too few measurements
    - Too large model uncertainties
- Reliable gridded analyses are necessary as well as exposure studies

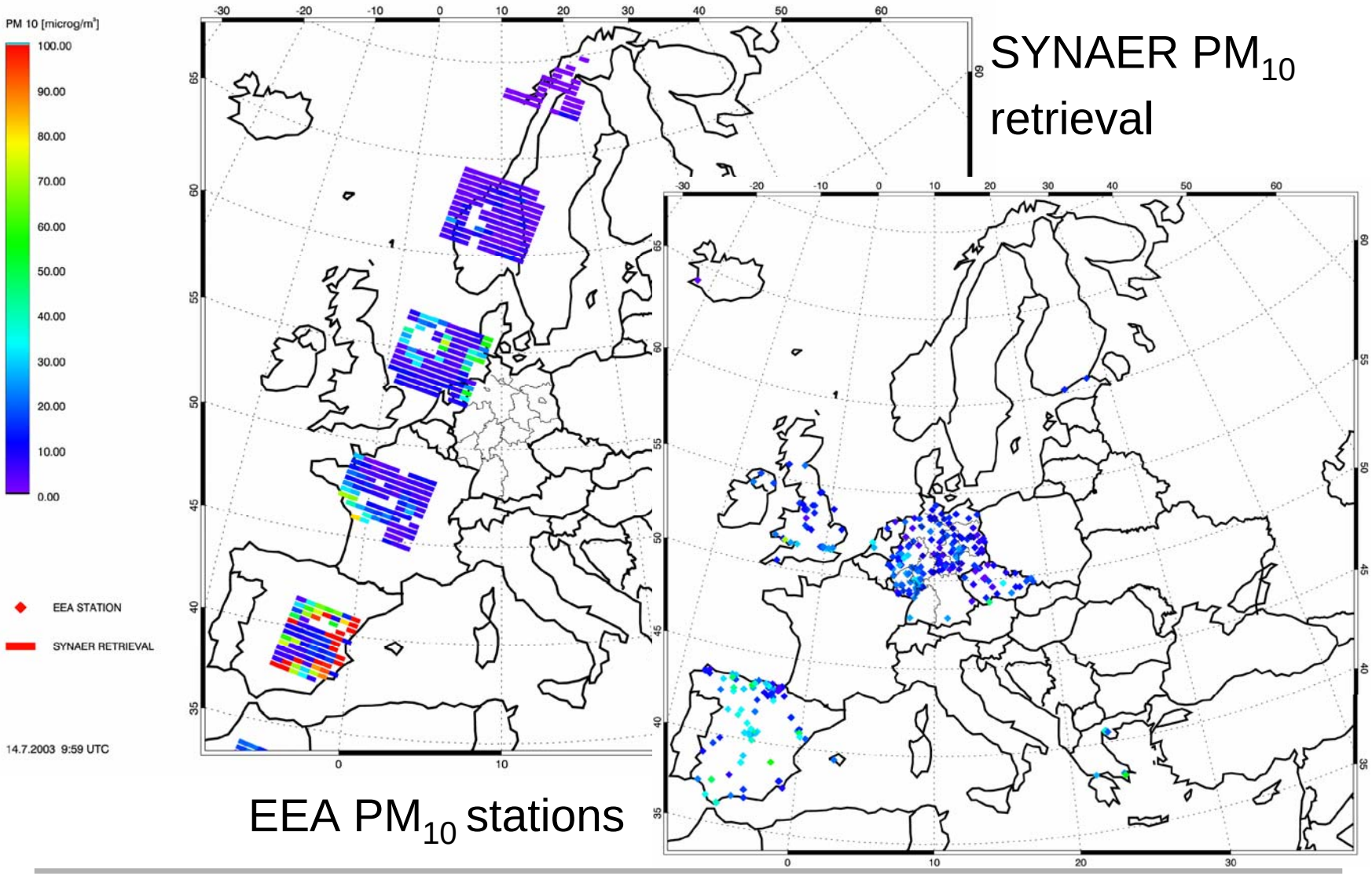
How to get to a more reliable estimation of aerosol load and exposure?

→ Data Assimilation



Estimated $PM_{2.5}$ caused reduction of lifetime expectance in months (Emissions 2000)[CAFE]

Aerosol observations



SYNAER PM_{10} retrieval

EEA PM_{10} stations

Aerosol observations

- In situ:

  EEA Airbase: Database of groundstations of EU member countries & states:
  - 450 stations for PM_{10} (2003)
  - No $PM_{2.5}$. (4 stations in UK only)

- Satellite measurements:

  SYNAER (SYNergetic AErosol Retrieval, DLR-DFD, [Holzer-Popp, 2001])*
  - combines GOME&ATSR-2, SCIAMACHY&AATSR measurements aboard ERS-2/ENVISAT
  - ATSR-2/AATSR:
    dark field detection, BLAOT (Boundary Layer Aerosol Optical Thickness) and albedo are calculated
  - GOME/SCIAMACHY:
    referring to BLAOT, calculated spectra of 40 predefined aerosol mixtures are compared to measured spectrum
  - Provides $PM_{0.5}$, $PM_{2.5}$ and PM_{10} columns and its composition (6 intrinsic species)

**see posters/presentation of T. Holzer-Popp and M. Schroedter-Homscheidt for details*

Data Assimilation

Data assimilation provides the best knowledge of the state of the atmosphere, based on model information and available measurements

- Two major challenges for aerosol data assimilation:
  1. How to assess highly irregular surface structure and emission patterns?

     Problem of observation representativity
  2. How to introduce this information into an advanced data assimilation scheme?

     Problem of covariance design (complexity, positive definiteness)

Data Assimilation

Answers and approach:

Take three dimensional variational (3Dvar) assimilation, because:

- 3Dvar provides a BLUE (Best Linear Unbiased Estimate)
- Variational approach allows assimilation of columns and remote sensing data

Observation problem:

- Estimate anisotropic and inhomogenous radii of influence (representativity) using the ensemble or NMC method

Covariances:

- Introduce this information into Background Error Covariance Matrix by using the diffusion scheme by Weaver and Courtier[2001] (Preserves positive definiteness)

3Dvar

Costfunction J(x) ist set up to weight observation against model:

$$J(x) = \frac{1}{2}\left(\underbrace{(x - x_b)^T B^{-1}(x - x_b)}_{\text{Background:}} + \underbrace{(H(x) - y)^T R^{-1}(H(x) - y)}_{\text{Observations:}}\right)$$

Background:

x:	current state
x_b:	background
B:	background error covariance matrix

Observations:

x:	current state
y:	observations
R:	observation error covariance matrix
H:	forward observation operator

Minimisation of J w.r.t. x returns the most probable state of the atmosphere (BLUE analysis)

BECM – Background Error Covariance Matrix B (short survey)

Ensemble/NMC approach:

$$B_{ij} = \frac{1}{K}\sum_{n=1}^{K}\left(x_i^n - \bar{x}_i\right)\left(x_j^n - \bar{x}_j\right)$$

K=# Ensembles; i,j neighboring cells

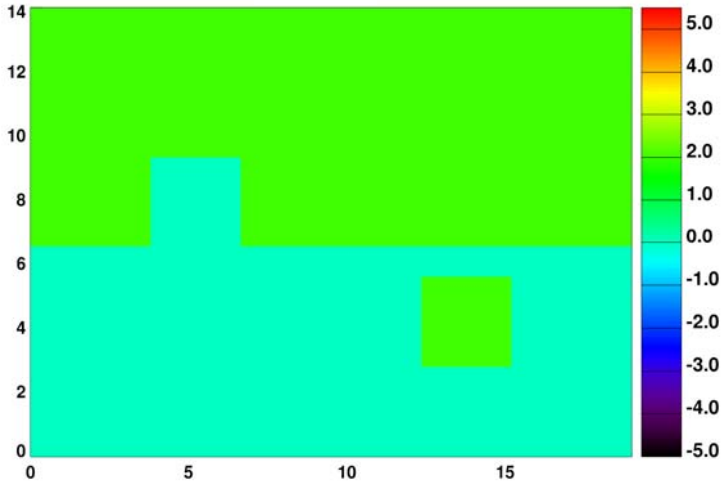
Correlation length L to neighboring gridcell:

$$B(r) = B(0)\exp\left(-\frac{r^2}{2L^2}\right), \quad r = 1, \quad B(1) = B_{ij}, \quad B(0) = \frac{1}{2}\left(B_{ii} + B_{jj}\right)$$

$$\Rightarrow L = \left(2\ln\left(\frac{B(0)}{B(1)}\right)\right)^{-\frac{1}{2}}$$

Diffusioncoefficients κ : $L = \sqrt{2\kappa T}$

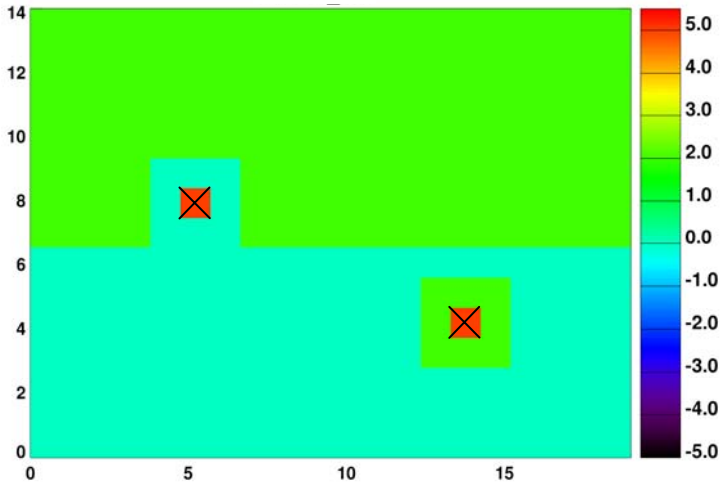
Anisotropic & inhomogeneous diffusion in 2 regimes

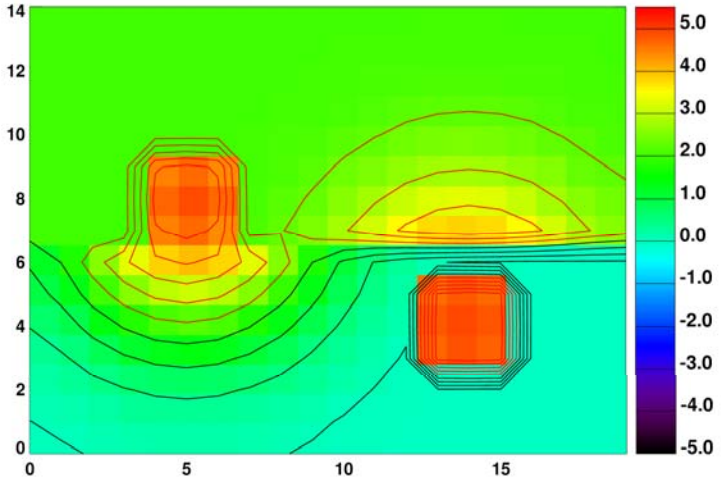


Regime A

Regime B

Observation





Case Study: ASSET-Episode

ASSET (ASSimilation of Envisat daTa) is an EU – framework 5 project, 01.07.2003 – 30.11.2003

9 Ensembles members to gain covariances by perturbing

- gaseous precursor (SO_2, H_2SO_4, NH_3, NO_x) emissions
- direct aerosol emissions (EC,OC, not identified anthropogenic particles)

by the factors [0.7; 1; 0.7^{-1}] each

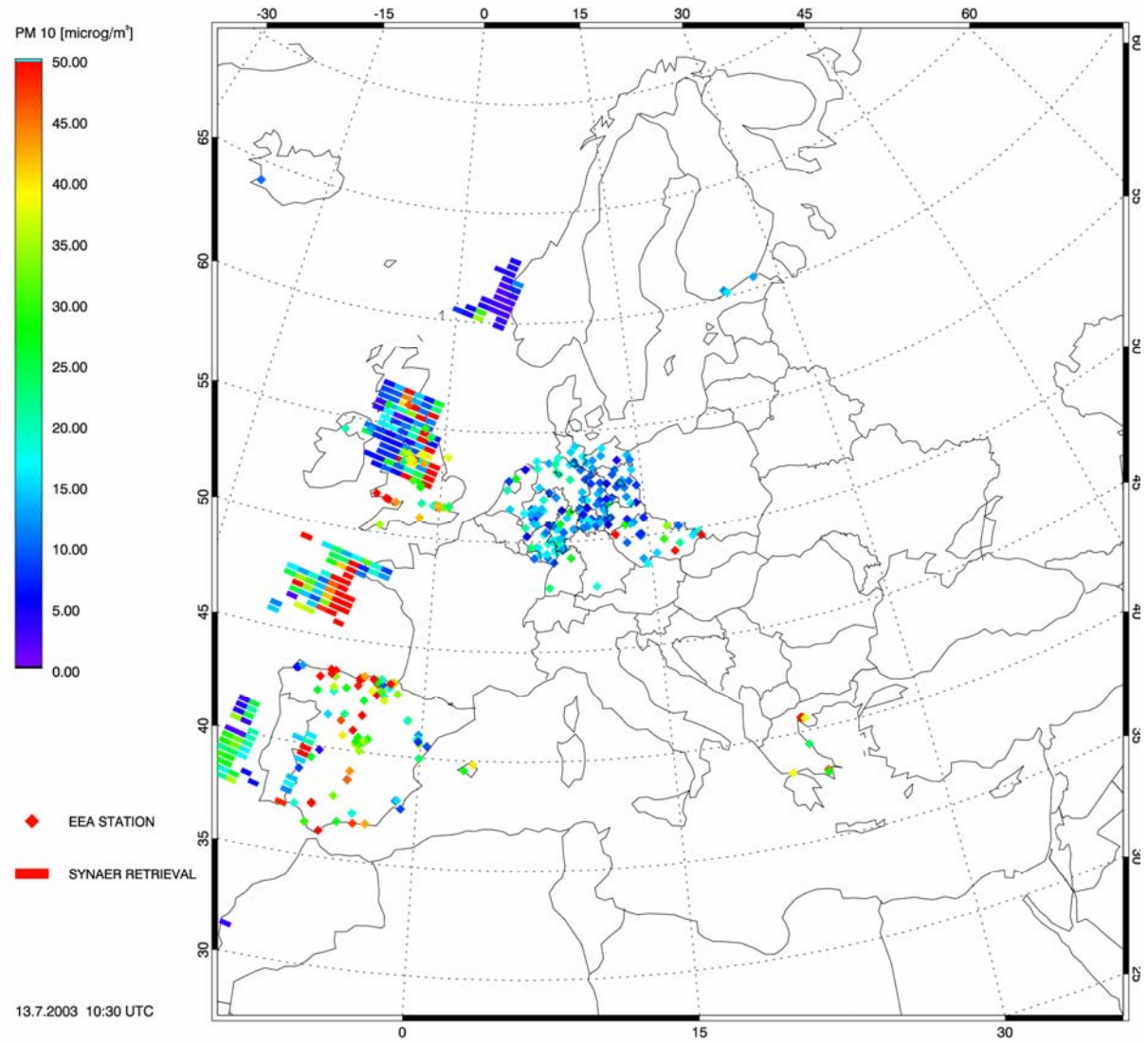
Spin Up: 01. – 05.07.2003

Configuration:

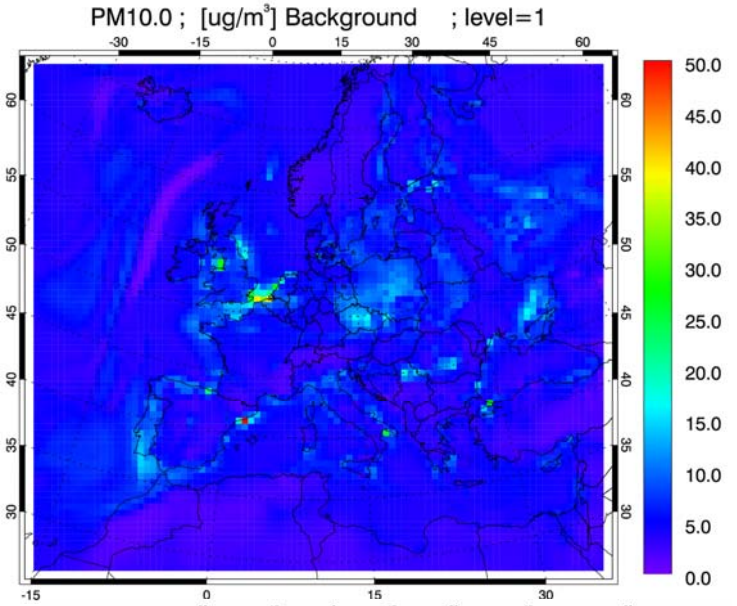
Assimilation at 10 UTC: 06. – 14.07.2003

- in situ data only (EEA Airbase)
- satellite columns only (SYNAER retrievals)
- both

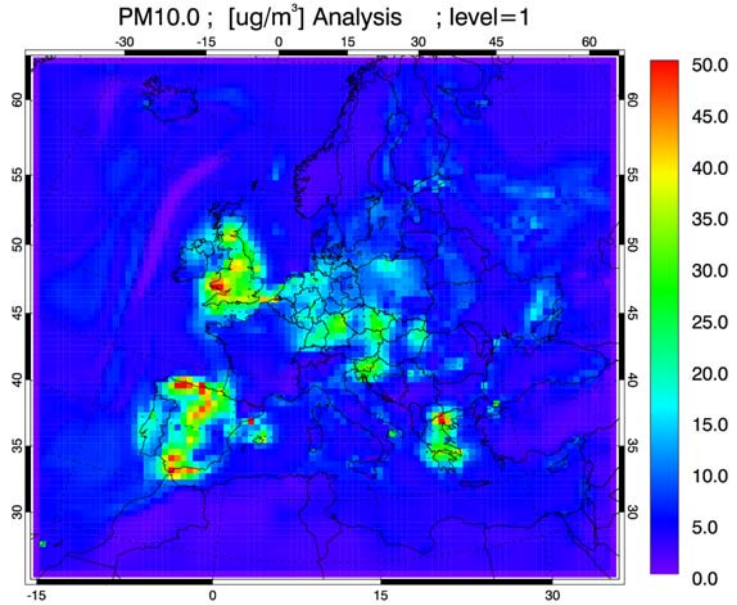
Test case: 13.07.2003

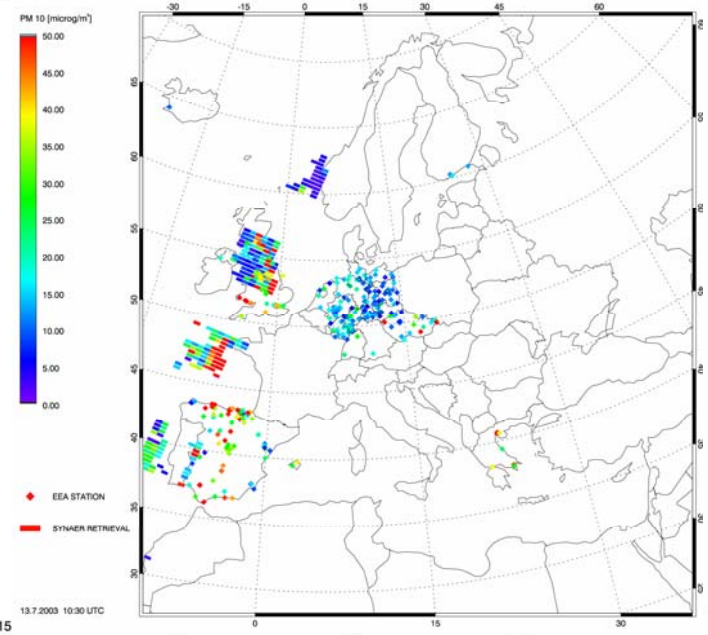


background

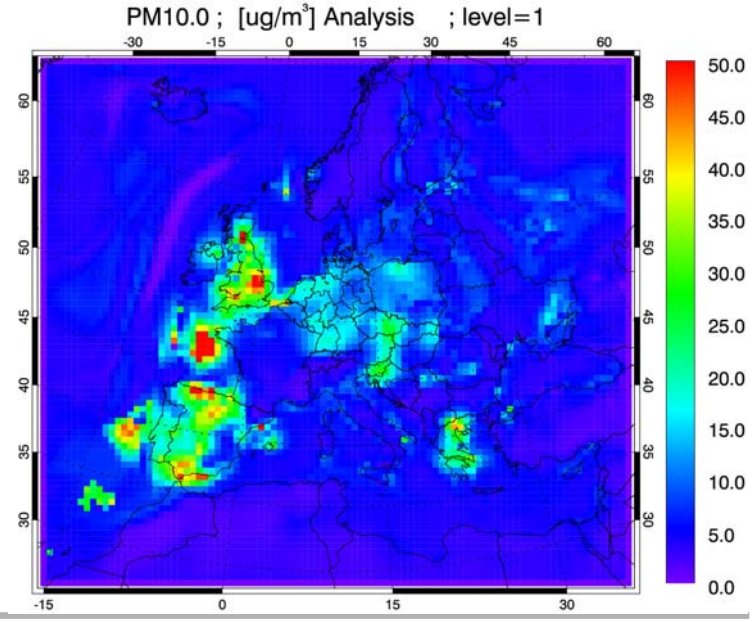


in situ only

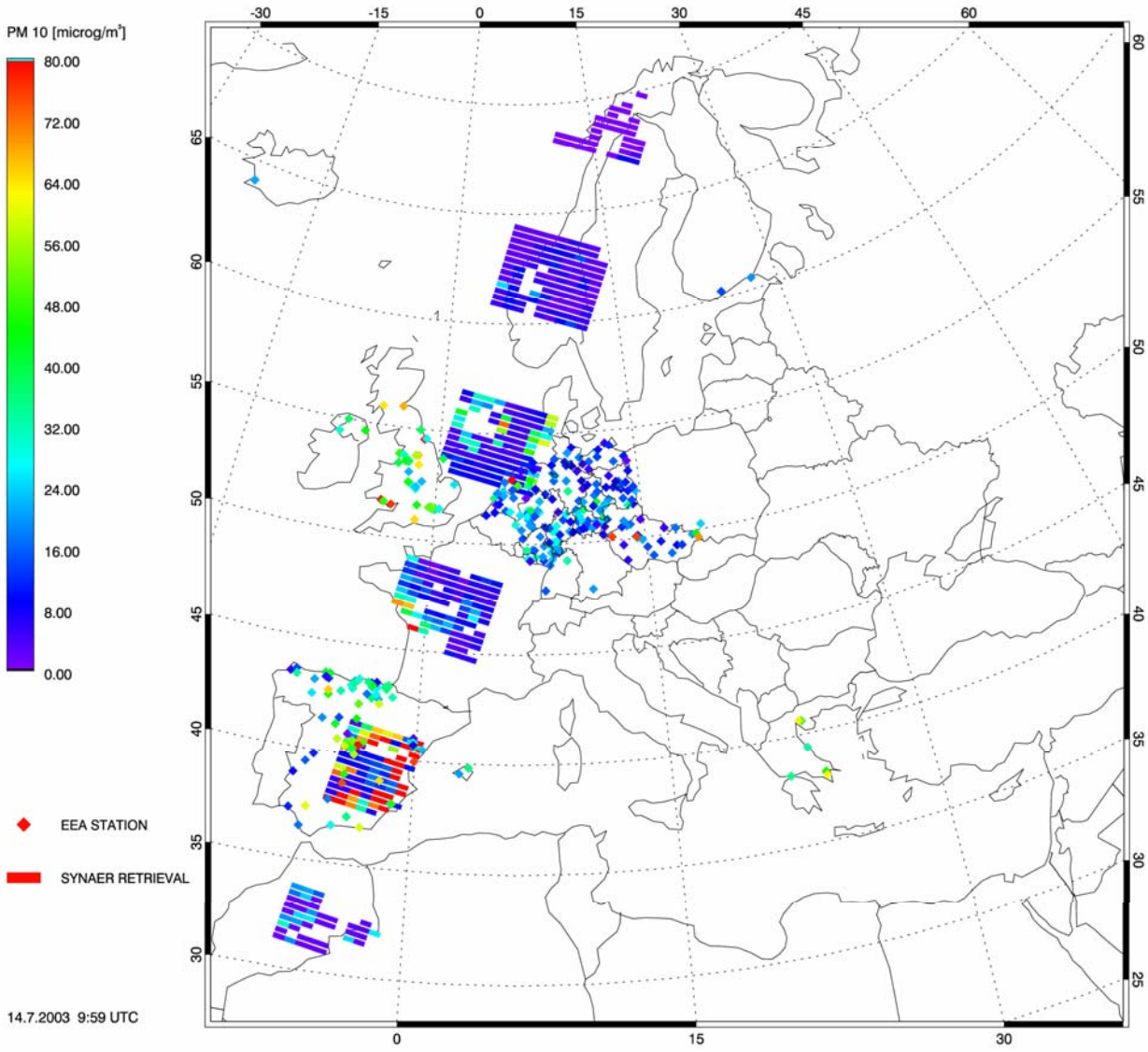




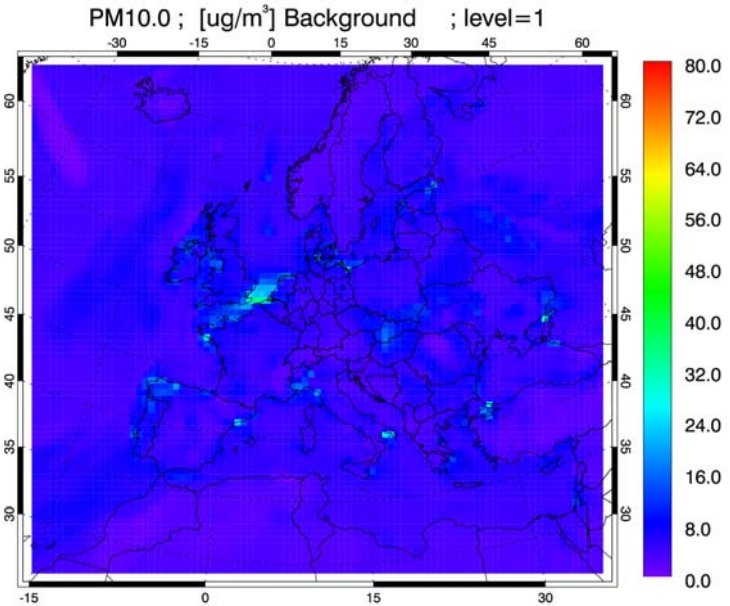
in situ & SYNAER

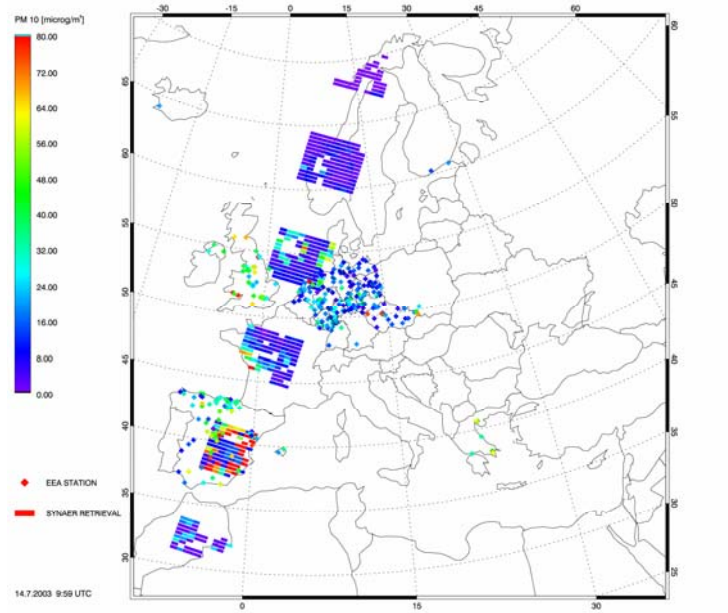


Test case: 14.07.2003

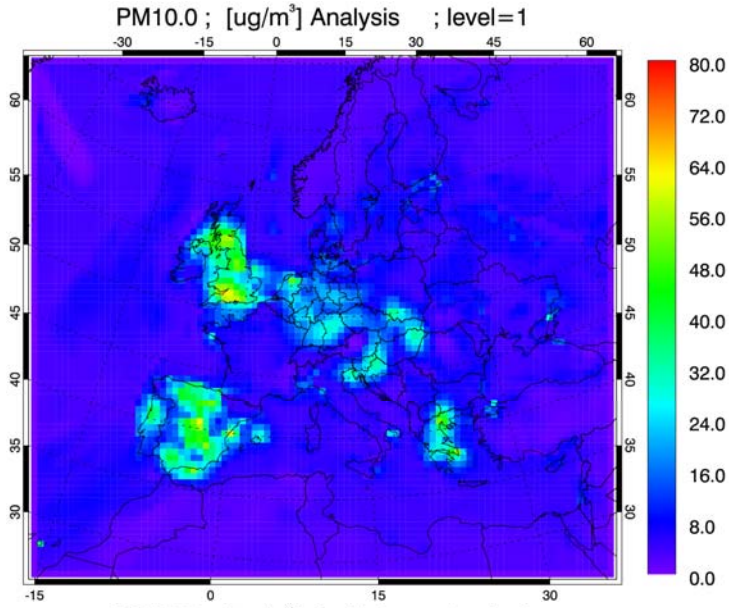


background

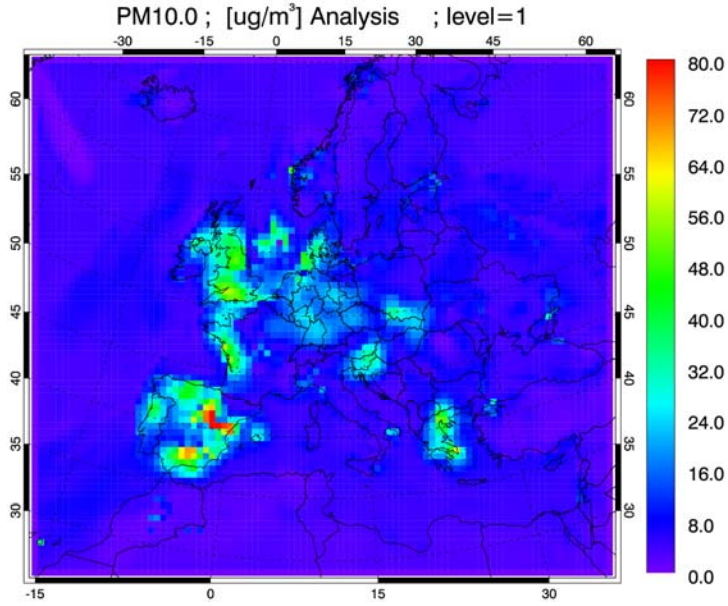




in situ only



in situ & SYNAER

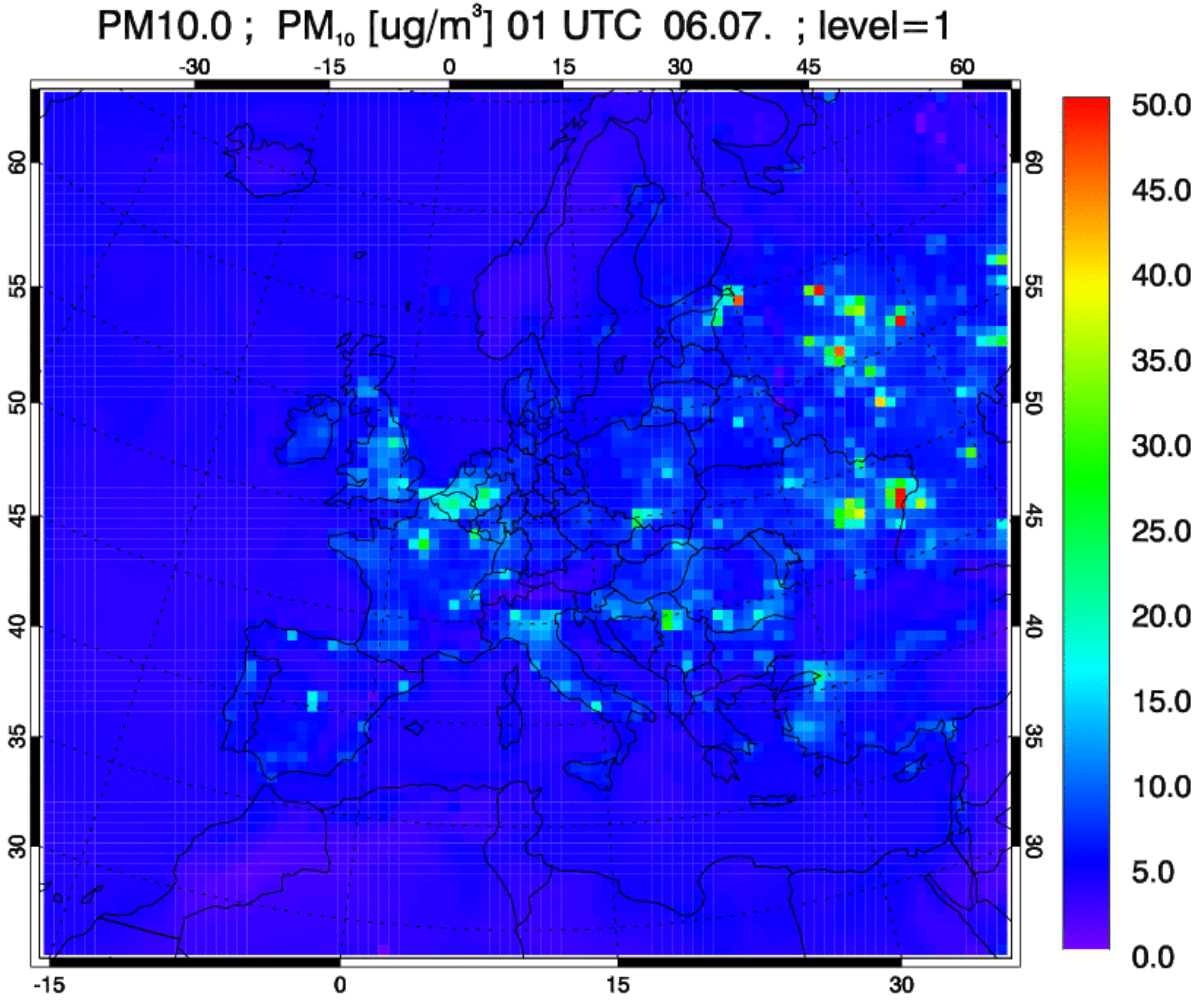


Validation

Date	# withheld stations	RMS [μg/m^3] (improvement)			Remarks
		no assim.	In situ only	In situ & sat	
06.07.2003	-	-	-	-	no sat data
07.07.2003	32	9.6	6.8 (29 %)	6.9 (28 %)	wildfires
08.07.2003	13	6.6	7.1 (-8%)	6.7 (-2%)	wildfires
09.07.2003	-	-	-	-	no sat data
10.07.2003	27	9.3	6.5 (30%)	6.9(26%)	wildfires
11.07.2003	-	-	-	-	no sat data
12.07.2003	29	1.9	1.4 (30%)	1.3 (32%)	none
13.07.2003	20	6.3	2.5 (61%)	1.9 (70%)	none
14.07.2003	49	7.3	5.5 (24%)	5.3(28%)	wildfires

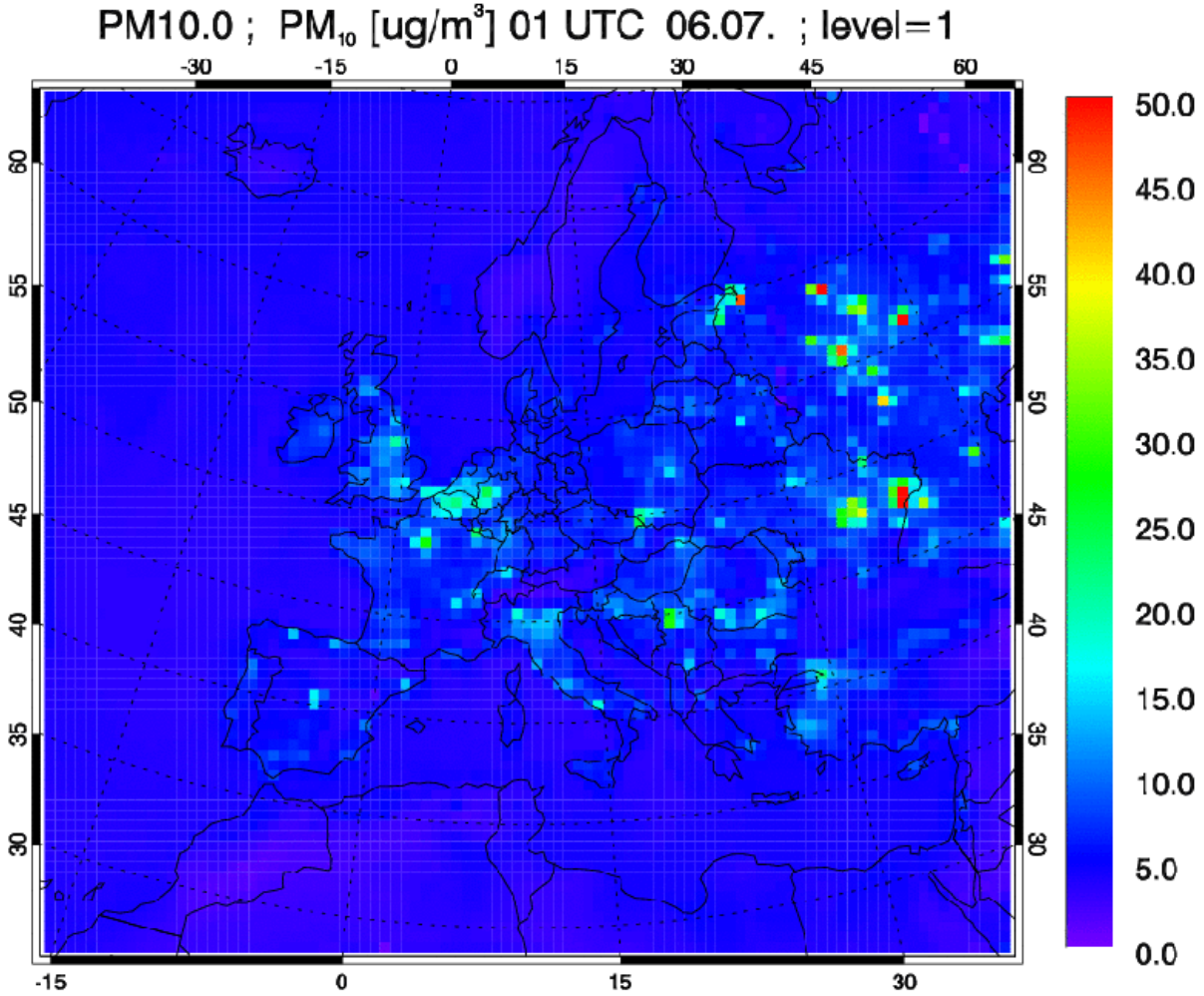
Surface stations in gridcells with SYNAER retrievals withheld for validation

How long does assimilation prevail?



Model run 06. – 08. July; Assimilation at 10 UTC

How long does assimilation prevail?



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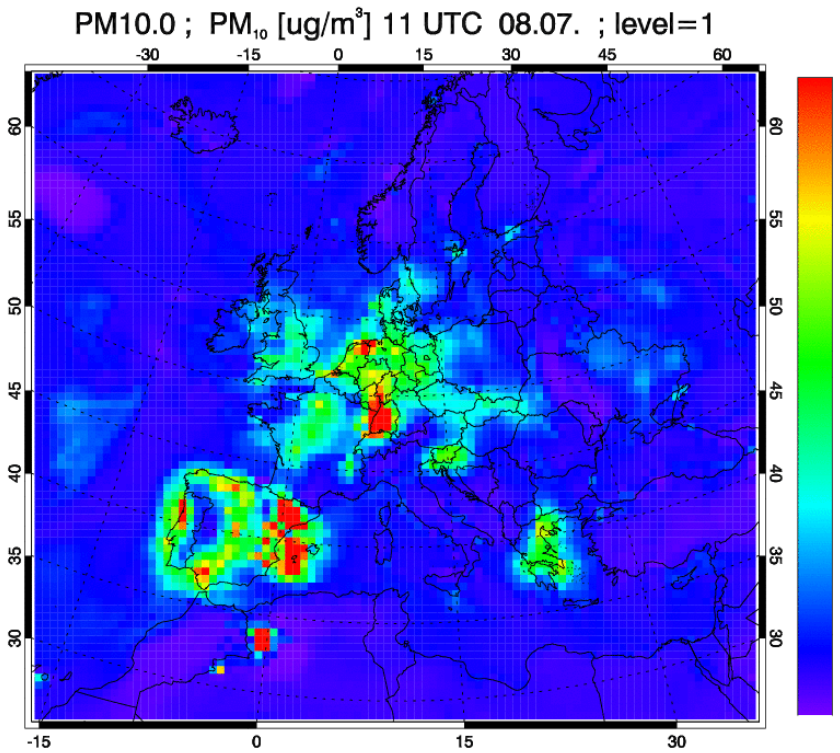
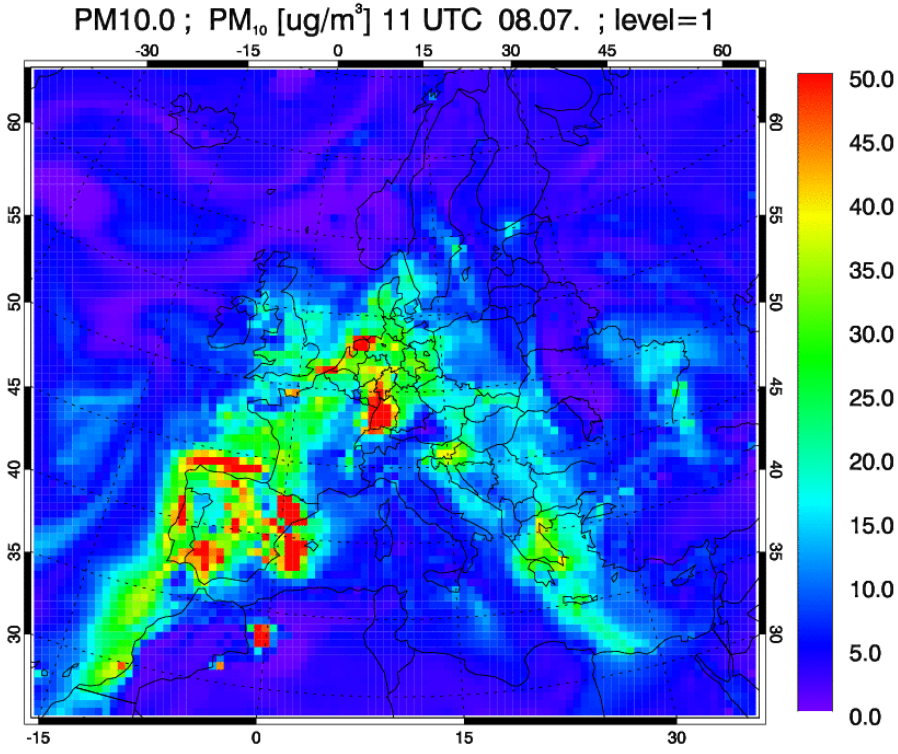


No previous assimilation



assimilation on previous days 10 UTC

Summary

- 3Dvar is able to include anisotropic and inhomogeneous BECM
- Much better coverage of Europe when including SYNAER retrievals
- For the first time *troposheric* satellite retrievals show added skill for surface data assimilation when validated against general air quality in situ measurements

Acknowledgements

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