Meteorological data assimilation effects on atmospheric dispersion models results

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Meteorological data Assimilation

- The procedure of integrating the prognostic with the observational meteorological data is known as Data Assimilation (DA).
- 3-Dimensional DA (3DDA): simultaneous use of Numerical Weather Prediction (NWP) data with meteorological measurements within a diagnostic meteorological model
- 3DDA procedures have been developed in a meteorological pre-processor (MPP) code used in an emergency-response system
- The objective of the above activity is to exploit in an optimized way the meteorological measurements obtained at a later time than when the prognostic data have been calculated.

Objective of the presented work

- To evaluate the use of the 3DDA procedures on the meteorological data *indirectly* through their effects on the results of an Atmospheric Dispersion Model
- Direct evaluation has already been presented in *Atmospheric Environment*, Vol. **38**, 457 – 467

Methodology

- Application of the modelling system:
  - Meteorological pre-processor (with and without DA)
  - Atmospheric dispersion model (DIPCOT – Lagrangian particles)
- Compare the results of atmospheric dispersion simulations with measured concentrations
- Evaluate the effect that meteorological Data Assimilation (DA) techniques have in the simulation of atmospheric dispersion

Work Outline

- The Lagrangian particle dispersion model DIPCOT was applied using the output of the MPP code.
- Two applications were performed using data from the European Tracer Experiment (ETEX) with and without the use of DA procedures in the MPP code.
- The first application used the MPP output obtained by only the prognostic meteorological fields from the ECMWF. The second application used the MPP output obtained by applying DA of the meteorological measurements in the prognostic fields.
- The ADM predictions in both cases were compared between themselves and to the experimental tracer concentration data.
- The model performance is evaluated in both cases and the differences are analysed and discussed.
- The predicted concentrations were statistically and qualitatively compared with the observed ones

ETEX

- European Tracer Experiment
- The data base includes prognostic and observational meteorological data as well as pollutant concentration measurements
- Long range tracer release
- Extensively used for Real-Time Long-Range dispersion model Evaluation
- Organised by : the Commission of the European Communities (CEC), the International Atomic Energy Agency (IAEA) and the Word Meteorological Organisation (WMO)

Details of the release

- Location of the release: 35 Km west of Rennes, at Monterfil, in Brittany, France, 90m above sea level
- Coordinates: 2° 00′ 30″ W, 48° 03′ 30″ N
- Duration: 12 hours
- Release start time: 23 October 1995, 16:00 UTC

Details of the release (2)

- Material: PHCH (perfluorocarbons)
- Material properties: inert, non-depositing, non-toxic
- Stack height: 8 m
- Source Strength: 7.95 gr/s
- Exit temperature: 84 °C
- Exit Velocity: 45 m/s

Description of the modelling system (1)

- Meteorological pre-processor (MPP)
  - Purpose: calculation of gridded meteorological data (horizontal grid: Cartesian, non-equidistant; vertical grid: terrain-following, non equidistant)
  - Input: observations from random stations + data from Numerical Weather Prediction models
  - Output: all meteorological data required by Atmospheric Dispersion Models
  - Method of calculations: $1/r^2$ interpolations horizontally; semi-empirical relations; linear, power-law, logarithmic, exponential interpolations vertically, according to variable; divergence minimisation for wind velocity horizontally
  - Operational use: in RODOS (Real-time On-line DecisiOn Support system for nuclear emergencies in Europe)

Description of the modelling system (2)

- Meteorological Data Assimilation (DA) steps:
  - 1st guess meteorological fields (by $1/r^2$ interpolation from the NWP model grid values)
  - Assimilation of the scalar variable measurements (surface temperature, cloud cover, net radiation, precipitation)
    - Iterations to Optimal Solution (IOS), with exponential weight function, defined radius of influence and ratio of background to observations square errors
  - Assimilation of wind velocity measurements
    - Multivariate Optimal Interpolation (OI), to account for correlations between the velocity components
  - Final calculation of remaining variables (stability, M-O length, friction velocity, etc.)

Description of the modelling system (3)

- Atmospheric dispersion model DIPCOT
  - Lagrangian particles model
  - Particles are assumed to follow the wind flow $x_i^{n+1} = x_i^n + \left(\overline{u_i} + u_i'\right)\Delta t$
  - Turbulent velocity fluctuations are based on the assumption that turbulent diffusion can be modelled as a Markov process, using Langevin equation $du_i' = a_i dt + b_i dW_i(t)$
  - α_i, b_i are, in general, functions of time, space and velocity. The coefficient b_i is obtained through consistency with the Kolmogorov's similarity theory:

$$du_i'(t) = a_i dt + \sqrt{C_o \varepsilon(z)} dW_i$$

Description of the modelling system (4)

- Atmospheric dispersion model DIPCOT
  - α_i is determined by consistency between the Lagrangian and the Eulerian statistics, according to the "well-mixed criterion" (Thomson, 1987). Assuming Gaussian homogeneous turbulence for the horizontal plane and inhomogeneous skewed turbulence for the vertical direction

$$\alpha_{x,y} = -C_o\, \varepsilon\, u'_{x,y} / 2\sigma^2_{u,v}$$

$$\alpha_z = \left[\frac{\partial}{\partial u_z'}\left(\frac{1}{2}\sqrt{C_o \varepsilon(z)} P\right) + \phi\right] / P$$

$$\partial\phi / \partial u_z' = -u_z' \partial P / \partial z$$

Description of the modelling system (5)

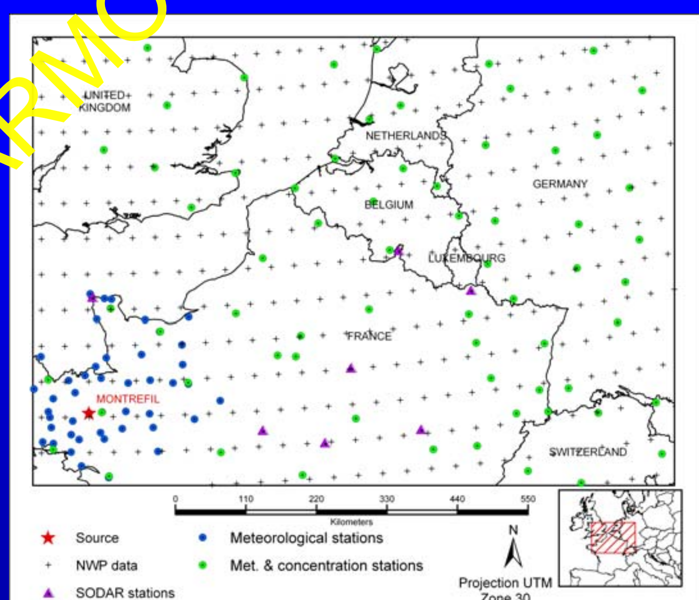
- Atmospheric dispersion model DIPCOT
  - –Concentration calculations: Gaussian-shaped density kernel (Yamada and Bunker 1988)

$$C = \frac{1}{(2\pi)^{3/2}} \sum_{p=1}^{N} \frac{m_p}{\sigma_x \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\frac{(x-x_o)^2}{\sigma_x^2}\right) \exp\left(-\frac{1}{2}\frac{(y-y_o)^2}{\sigma_y^2}\right)$$

$$\left\{\exp\left(-\frac{1}{2}\frac{(z-z_o)^2}{\sigma_z^2}\right) + \exp\left(-\frac{1}{2}\frac{(z+z_o-2z_g)^2}{\sigma_z^2}\right)\right\}$$

Where: (x_o, y_o, z_o) are the coordinates of the point where the concentration is estimated, Mp is the mass of the particle and Z_g is the ground height at particle location

Computational domain with the:
- *tracer release location*
- *Numerical Weather Prediction model grid*
- *Meteorological stations*
- *Tracer concentration stations*



Meteorological Calculations Details

- Computational domain dimensions: 1000 x 700 Km^2
- Discretizations:
  - Horizontal: 200 × 140 cells with dimensions 5 × 5 km^2
  - Vertical: 17 cells with dimensions 5 to 500 m up to 3.7 km
- 350 NWP grid points with prognostic data from ECMWF (ground level and vertical)
- 7 SODAR stations with measurements in the vertical
- 113 synoptic ground level stations

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Meteorological Calculations Details

- Measurement data used by the meteorological pre-processor
  - every 6 hours
  - wind velocity, temperature, pressure and cloud cover from the ground stations
  - Hourly profiles of wind at the 7 sodar stations
- Time period simulated: duration of the release, from 16:00 of 23/10 to 24:00 of 24/10 UTC
- Output data calculated every six hours: wind, temperature, stability, mixing layer height, pressure, Monin – Obukhov length etc.

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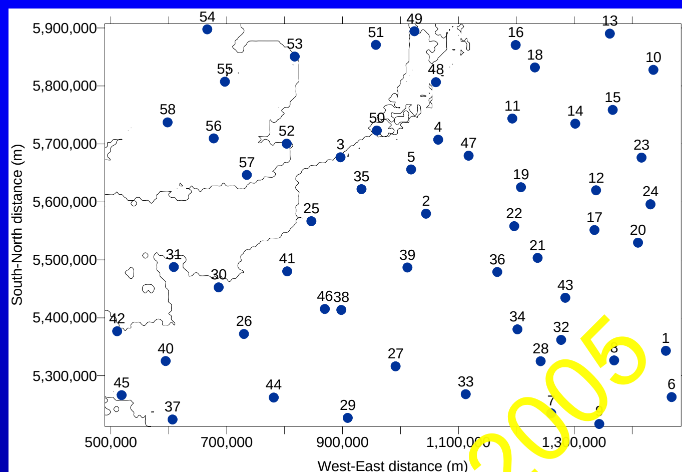
Atmospheric Dispersion Calculations Details

- Domain Dimensions: 1000 x 700 Km^2
- Number of concentration observation points: 58
- 3-hours average concentration
- 32 hours of dispersion simulations
- The predicted concentrations were compared with concentrations from the so-called "Global analysis" data

Atmospheric dispersion calculations

- Actual time-variation of the release
- The released pollutant quantity has been distributed to 12000 particles (1 particle emitted every 3.6 s)
- The lagrangian model calculated the particles displacement based on random velocities added to the mean wind velocity
- The concentrations have been calculated at the sampling locations at 3-hour intervals
- The dispersion calculations lasted the entire period of the simulations (from 16:00 of 23/10 to 24:00 of 24/10 UTC)

Computational domain with the observation points' locations



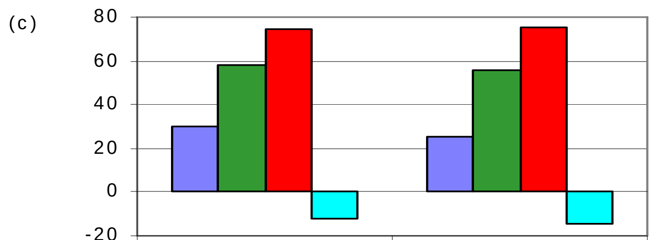
Evaluation Procedure

- Comparisons are made using pairs of observed and calculated ground level concentrations.
- Evaluation tools:
  - Scatter and Quantile-Quantile (Q-Q) plots
  - Statistical indices (using the Bootstrap re-sampling method):
    - Mean Fractional Bias (FB),
    - Geometric Mean bias (MG),
    - Normalised Mean Square Error (NMSE)
    - Geometric Variance
    - Factor-of-Two (*FACT2*)
    - Factor-of-Five (FACT5)
    - Factor-of-Ten (FACT10)
    - FOEX

For FB and MG the 95% confidence limits were calculated

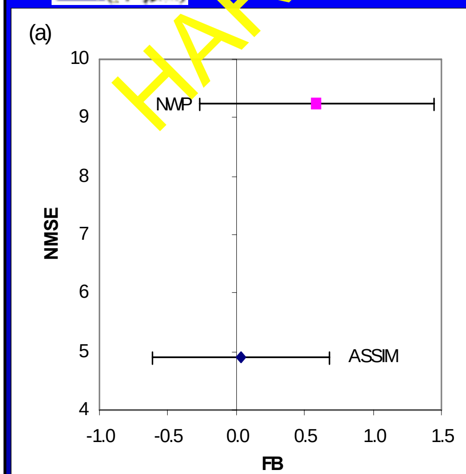
Dispersion model evaluation

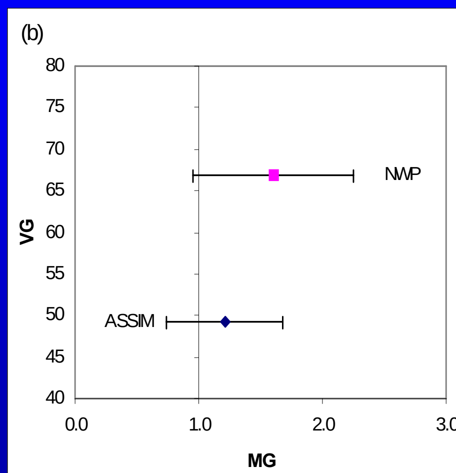
Indices from the statistical comparison of the predicted with the measured concentrations, using meteorological data with and without DA techniques



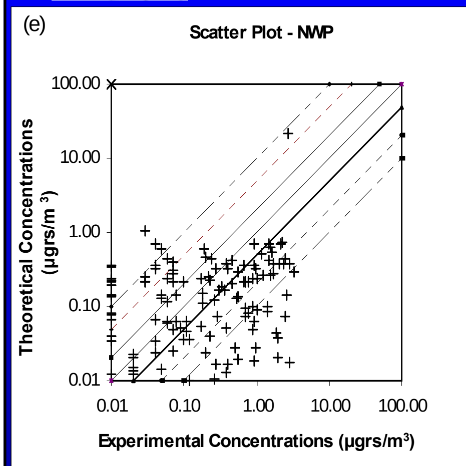
	ASSIM	NWP
FACT2	30.28	25.68
FACT5	57.75	55.41
FACT10	74.65	75[illegible]
FOEX	-11.97	-14.19

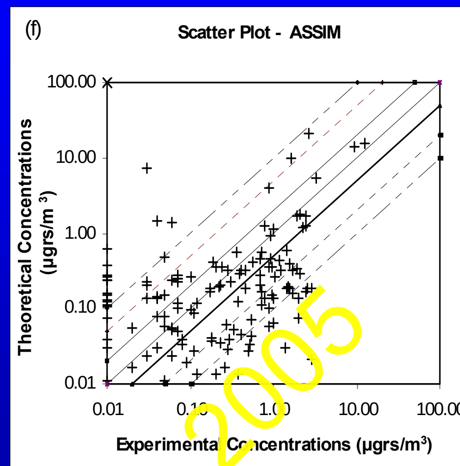
Dispersion model evaluation





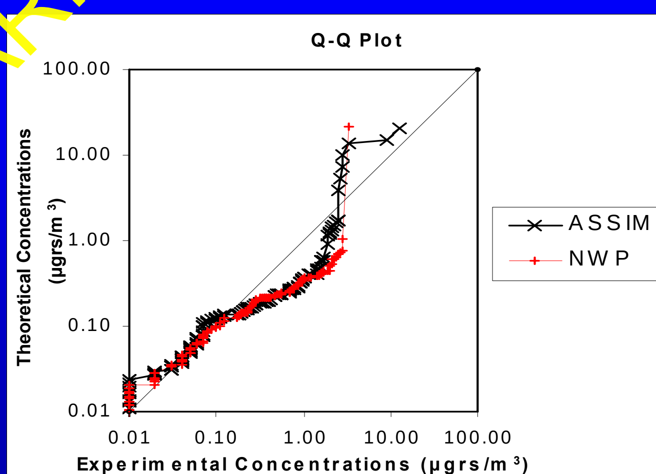
Dispersion model evaluation



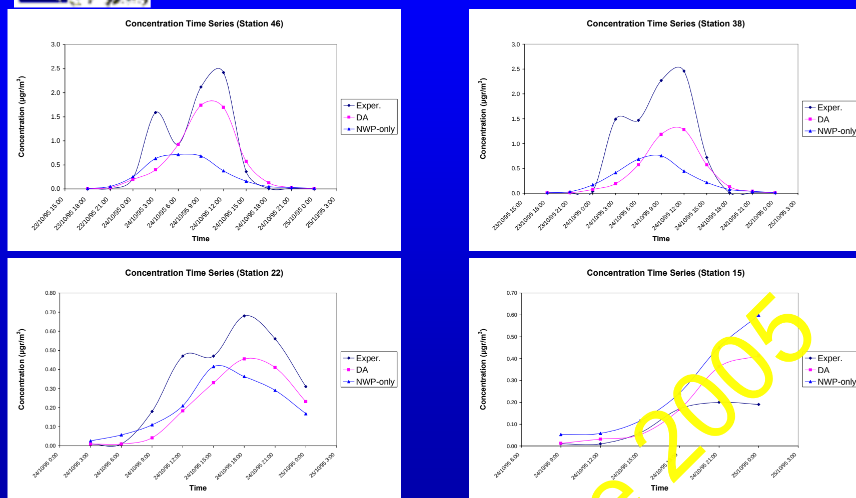


Dispersion model evaluation

Q-Q plots of predicted vs. observed concentrations using meteorological data with and without DA techniques



Effect of DA procedures



Conclusions (1)

- The statistical analysis showed that when DA procedures were employed in the MPP code the performance of the ADM model was improved.
- In both cases the model exhibits a tendency towards underprediction (the values of *FB* and *MG* are greater than 0 and 1). However, when DA techniques are used in the MPP code the underpredictions are reduced, especially at the higher concentrations.
- The effect of the DA procedures is more pronounced for the higher concentrations, close to the source.

Conclusions (2)

- The smaller concentration values are similar at the two applications and are generally underestimated. However, the values of *MG* and *VG*, which give the same weight to all the values contrary to the *FB* and *NMSE* values that are mainly affected by the higher concentrations, reveal a slightly better performance of the ADM model even for the smaller concentrations when the DA procedures are used in the MPP code
- Further tests must be carried out in order to examine the effect of DA procedures in dispersion simulation using data sets with more upper air meteorological measurements.