Ανάπτυξη Μεθόδων Αφομοίωσης Παρατηρήσεων (“DATA ASSIMILATION”) σε Μοντέλα Ατμοσφαιρικής Διασποράς

Βασιλική Τσιουρή
Υποψήφια Διδάκτωρ στο Παν/μιο Δυτικής Μακεδονίας, Τμήμα Μηχανικών Διαχείρισης Ενεργειακών Πόρων

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Recently

"DATA ASSIMILATION"

in the atmospheric dispersion models

became one of the challenging problems

DATA ASSIMILATION

MODEL

-FORECAST

-HIGH SPACIAL AND TEMPORAL COVERAGE

-PHYSICAL LAWS

-IMPERFECT MODEL

OBSERVATIONS

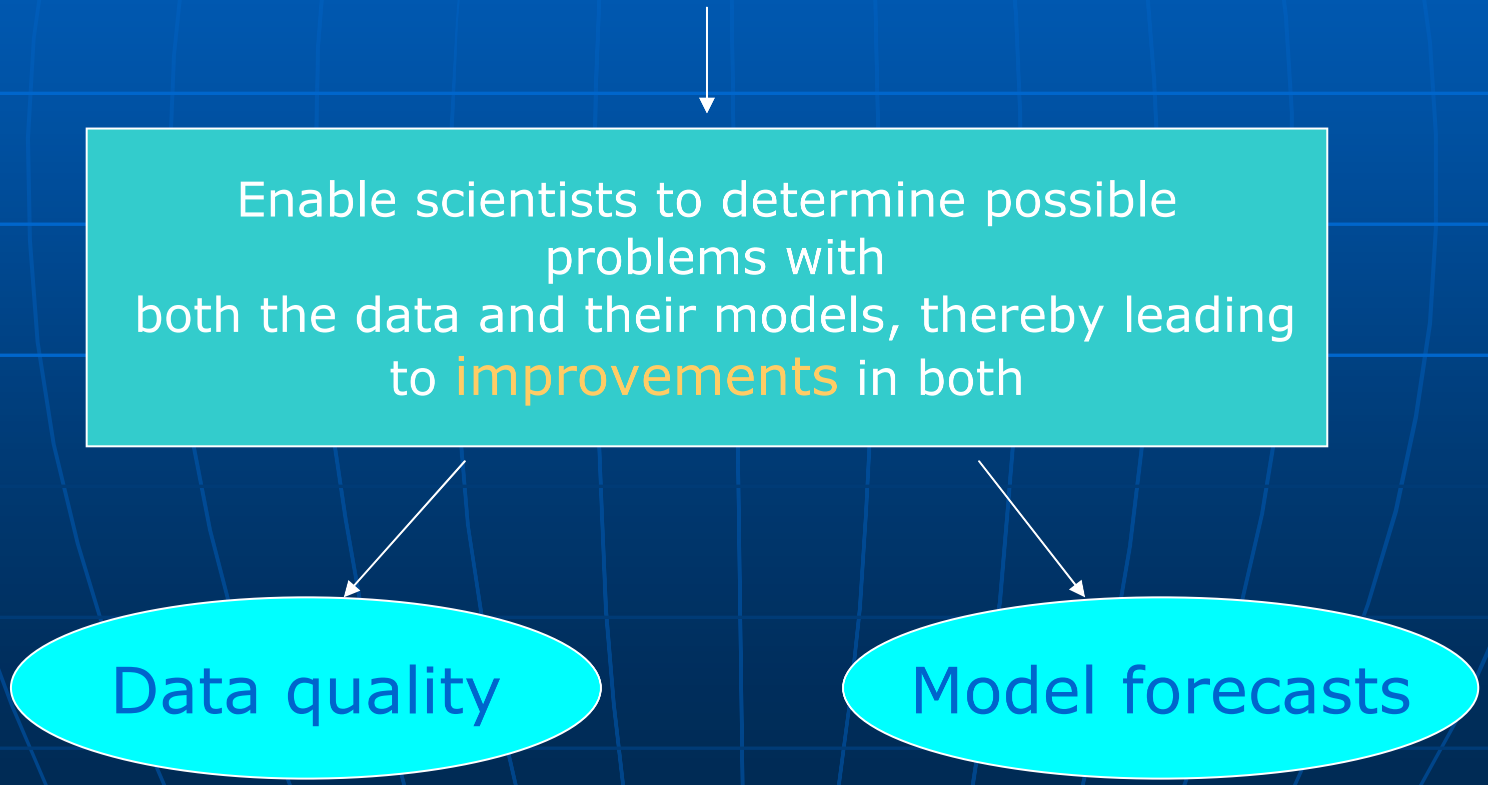
-REPRESENTATION OF REALITY

-INCOMPLETE COVERAGE

use the advantages of both a model and the measurements by combining their respective information in an optimal way

THE BENEFITS OF DATA ASSIMILATION

By combining (and comparing) model forecasts and observational data, D.A. can



"DATA ASSIMILATION"
AN INVERSE PROBLEM

DATA ASSIMILATION methodology
should be viewed more like an
'inverse problem'

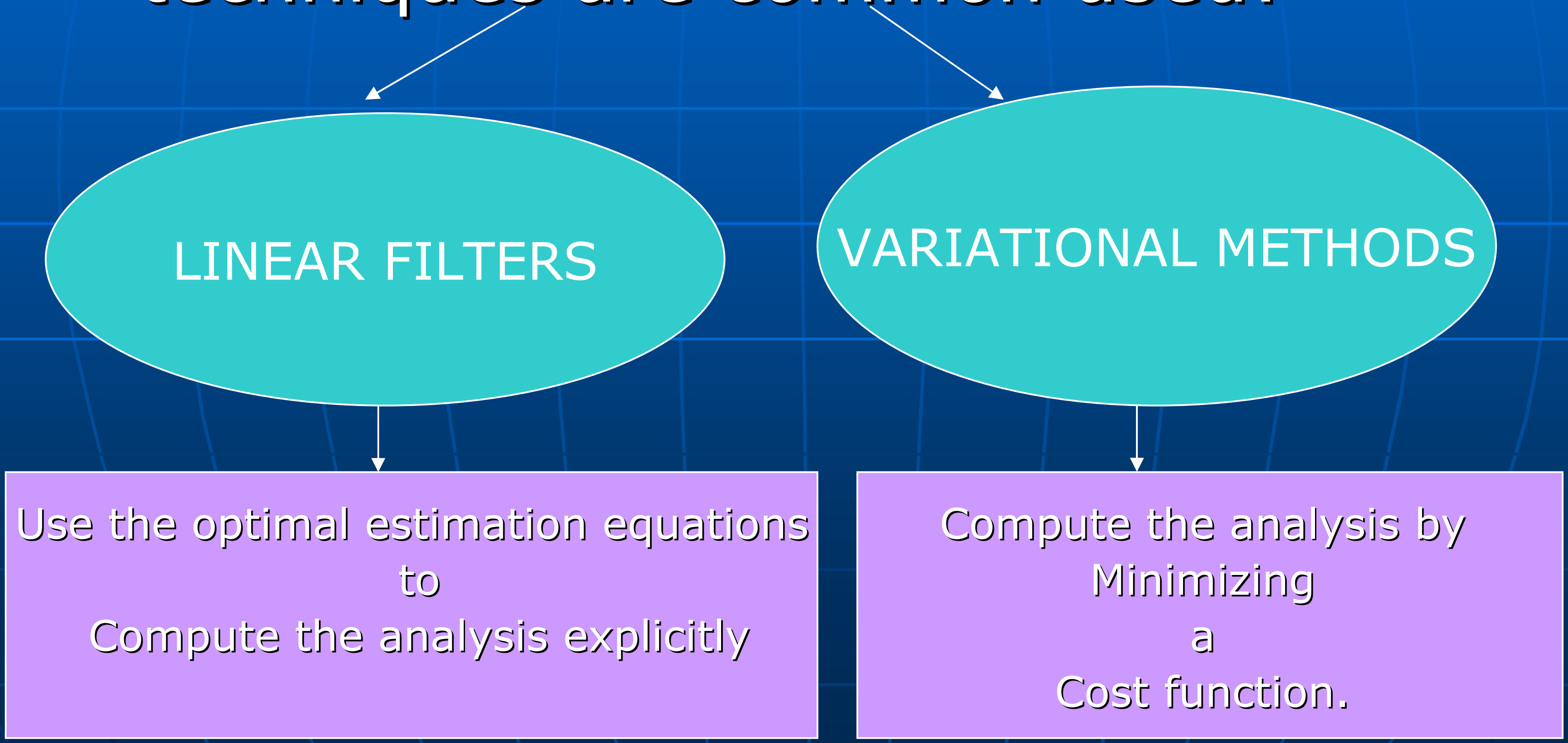
As long as we have the ability to predict the observations from the model state (the 'forward problem')

then

DATA ASSIMILATION solves the
inverse problem
of determining the model state from the observations

DATA ASSIMILATION TECHNIQUES

Two families of data assimilation techniques are common used:



TYPES OF MODELS FOR THE SIMULATION OF ATMOSPERIC DISPERSION

EULERIAN MODELS

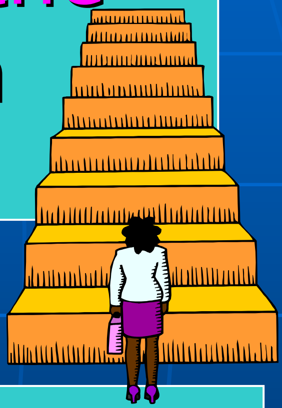
the model simulates the species concentrations
in an array of fixed computational cells, by solving the mass conservation equation.

LAGRANGIAN MODELS

The pollutant is emitted in parcels which move with the local wind speed.
The concentration is calculated by summing the contribution of all parcels.

STATEMENT of the PROBLEM

The problem of Atmospheric Dispersion forecast with the Assimilation of the Data of available concentration measurements is considered.



CURRENT WORK

Development of a Data Assimilation algorithm based on Variational approach and its implementation in a Lagrangian puff dispersion model.

THE MODEL

The Gaussian puff model used is a simplified version of the DIPCOT model

parcel of pollutant is characterized

by Gaussian distribution of concentration inside the parcel

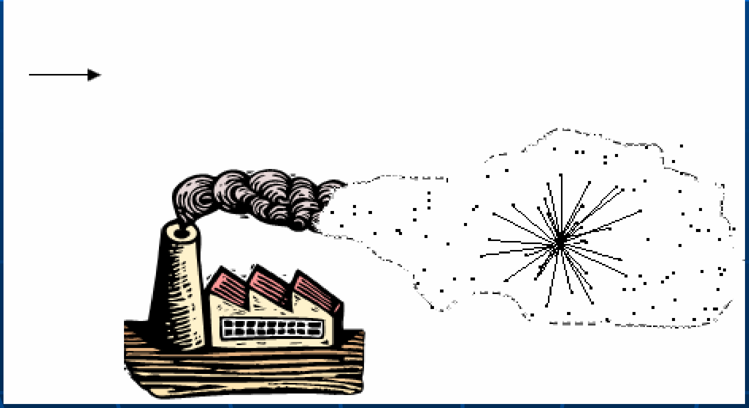
concentration in the given location is obtained

by summing of the impacts of all puffs

The concentration at every point (X,Y,Z) :

$$C^M(X,Y,Z) = \frac{1}{(2\pi)^{3/2}} \sum_{P=1}^{L} \frac{M_p}{\sigma_{xp}\sigma_{yp}\sigma_{zp}} \exp\left[-\frac{1}{2}\frac{(X_p - X)^2}{\sigma_{xp}^2}\right] \exp\left[-\frac{1}{2}\frac{(Y_p - Y)^2}{\sigma_{yp}^2}\right]$$

$$\left\{\exp\left[-\frac{1}{2}\frac{(Z_p - Z)^2}{\sigma_{zp}^2}\right] + \exp\left[-\frac{1}{2}\frac{(Z_p + Z - 2Z_g)^2}{\sigma_{zp}^2}\right]\right\}$$



VARIATIONAL METHOD

a set of unknown parameters is selected ("control variables")

↓

The unknown parameters are estimated such that minimize the functional

$$J = \sum_{n=1}^{N} \sum_{k=1}^{K} \left(\sigma_{nk}^{O}\right)^{-2} \left(C_{nk}^{O} - C_{nk}^{M}\right)^{2}$$

Where: N observation times and K measurement locations, and

- σ_{nk}^{O} root-mean-square error of the (*n*, *k*) observation
- C_{nk}^{O} measured concentration
- C_{nk}^{M} concentration predicted by the model

Selected Control Variables

the selected control variables are
the values of the source strength
during the release of each model puff.

In the event of accidental gas releases,
there is a high uncertainty regarding the release rate which is important
for forecasting the gas concentration

$$J = (\underline{\mathbf{C}}^{O} - \underline{\underline{\mathbf{G}}} \times \underline{\mathbf{q}})^{\mathrm{T}} \mathbf{O}^{-1} (\underline{\mathbf{C}}^{O} - \underline{\underline{\mathbf{G}}} \times \underline{\mathbf{q}}) + (\underline{\mathbf{q}} - \underline{\mathbf{q}}_{B})^{\mathrm{T}} \mathbf{B}^{-1} (\underline{\mathbf{q}} - \underline{\mathbf{q}}_{B})$$

Finally,

$$\left(I + \left(\underline{\underline{\mathbf{O}}}^{-1} \underline{\underline{\mathbf{G}}}\, \underline{\underline{\mathbf{B}}}\right)^{T} \underline{\underline{\mathbf{G}}}\right) \times \underline{\mathbf{q}} = \left(\underline{\underline{\mathbf{O}}}^{-1} \underline{\underline{\mathbf{G}}}\, \underline{\underline{\mathbf{B}}}\right)^{T} \underline{\mathbf{C}}^{O} + \underline{\mathbf{q}}_{B}$$

$$\left(\sigma^{2} + \mathbf{G}^{T}\mathbf{G}\right) \cdot \mathbf{q} = \mathbf{G}^{T}\mathbf{C}_{O} + \sigma^{2}\mathbf{q}_{B}$$

$$\left(\sigma^{2}_{\mathrm{modif}} + \mathbf{G}^{T}_{\mathrm{modif}}\mathbf{G}\right) \cdot \mathbf{q} = \mathbf{G}^{T}_{\mathrm{modif}}\mathbf{C}^{O} + \sigma^{2}_{\mathrm{modif}}\mathbf{q}_{B}$$

RESULTS

The "identical twin" experiments were used to evaluate the performance of the data assimilation methodology for the puff model.

"Twin" experiment is a method for testing a DA algorithm, when real observations are not available.
"Twin" experiments include two parts:

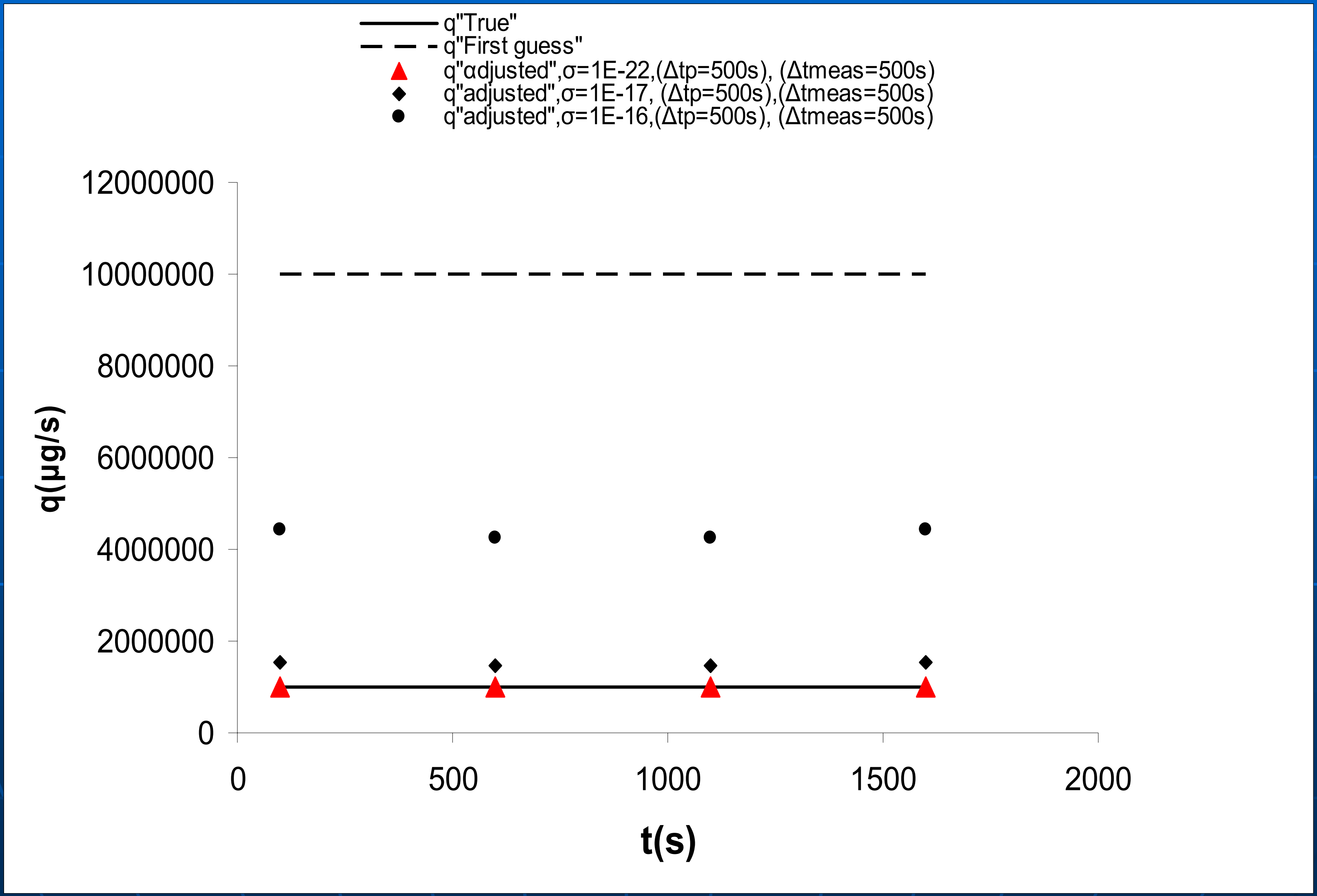
'truth' run and 'Simulation' run.

The dispersion model generates "concentration observations" using a "true" source term function.
Then the model is run again using an "assumed" source term and assimilating the observations with the aim to evaluate the true source function.

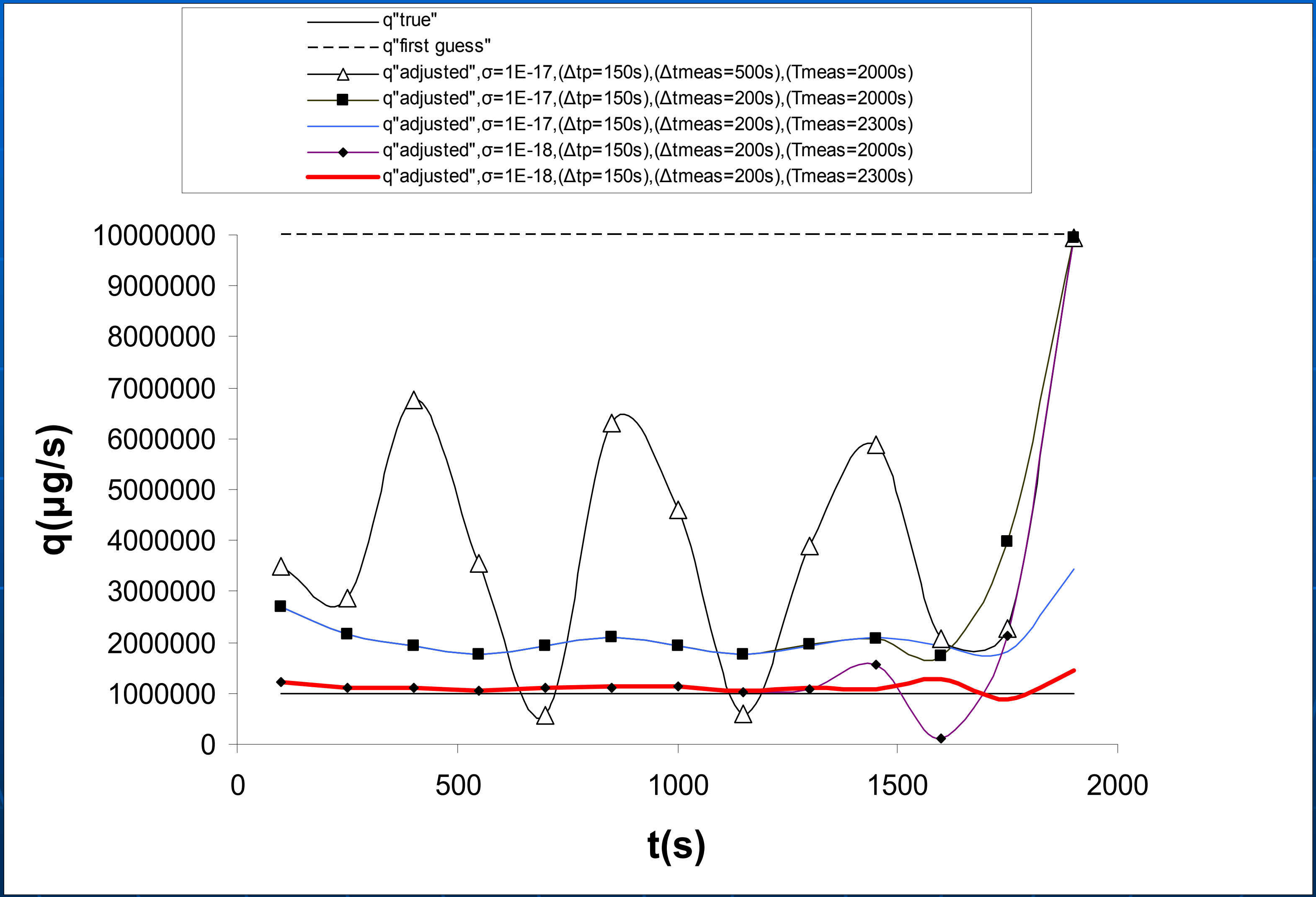
FIRST TESTS

- 1-dimensional dispersion
- constant in time source rate
- constant wind speed
- constant root mean square error of the observations
- one observation point

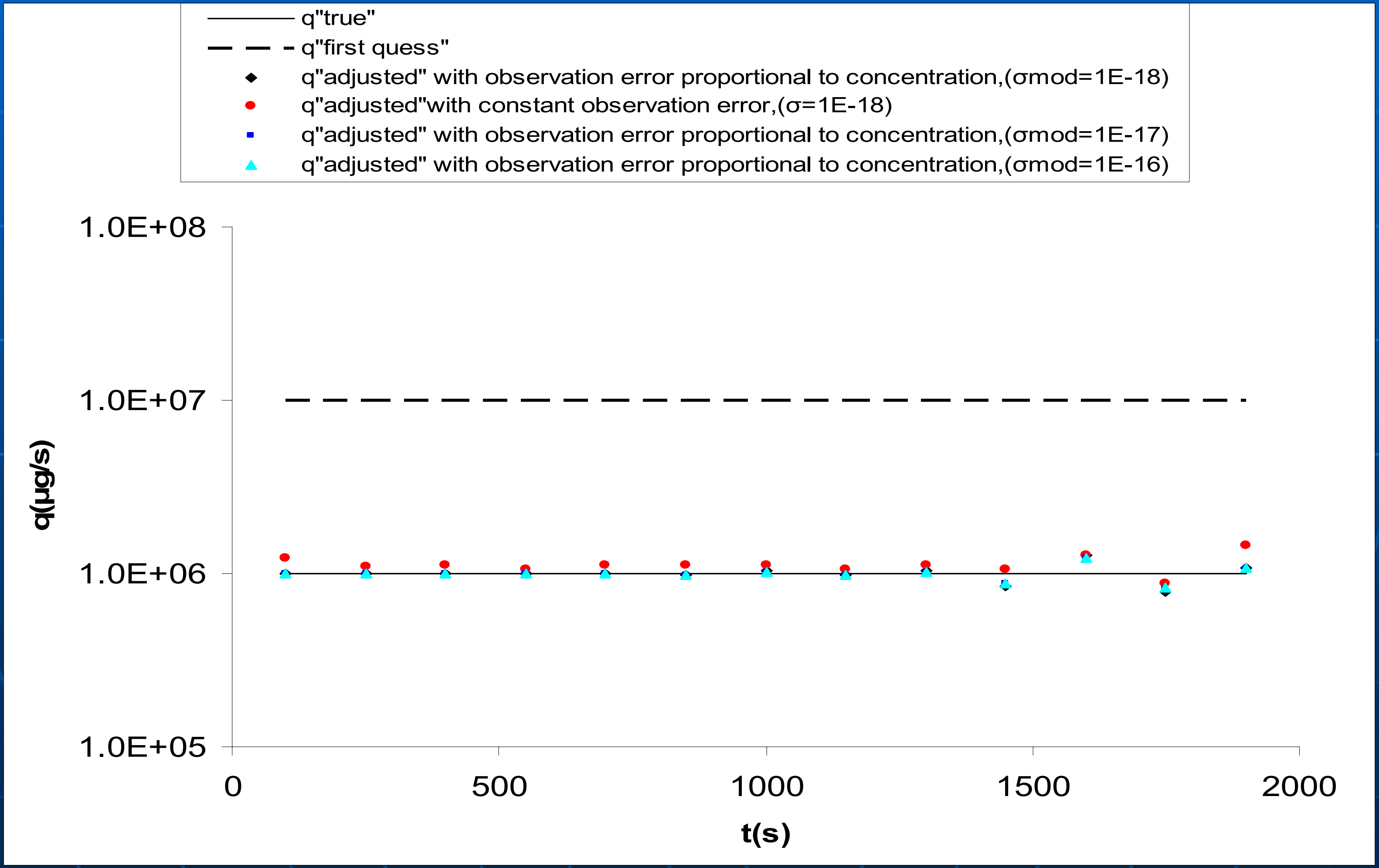
The initially assumed source term function, differs by a factor of 10 from the “true” one



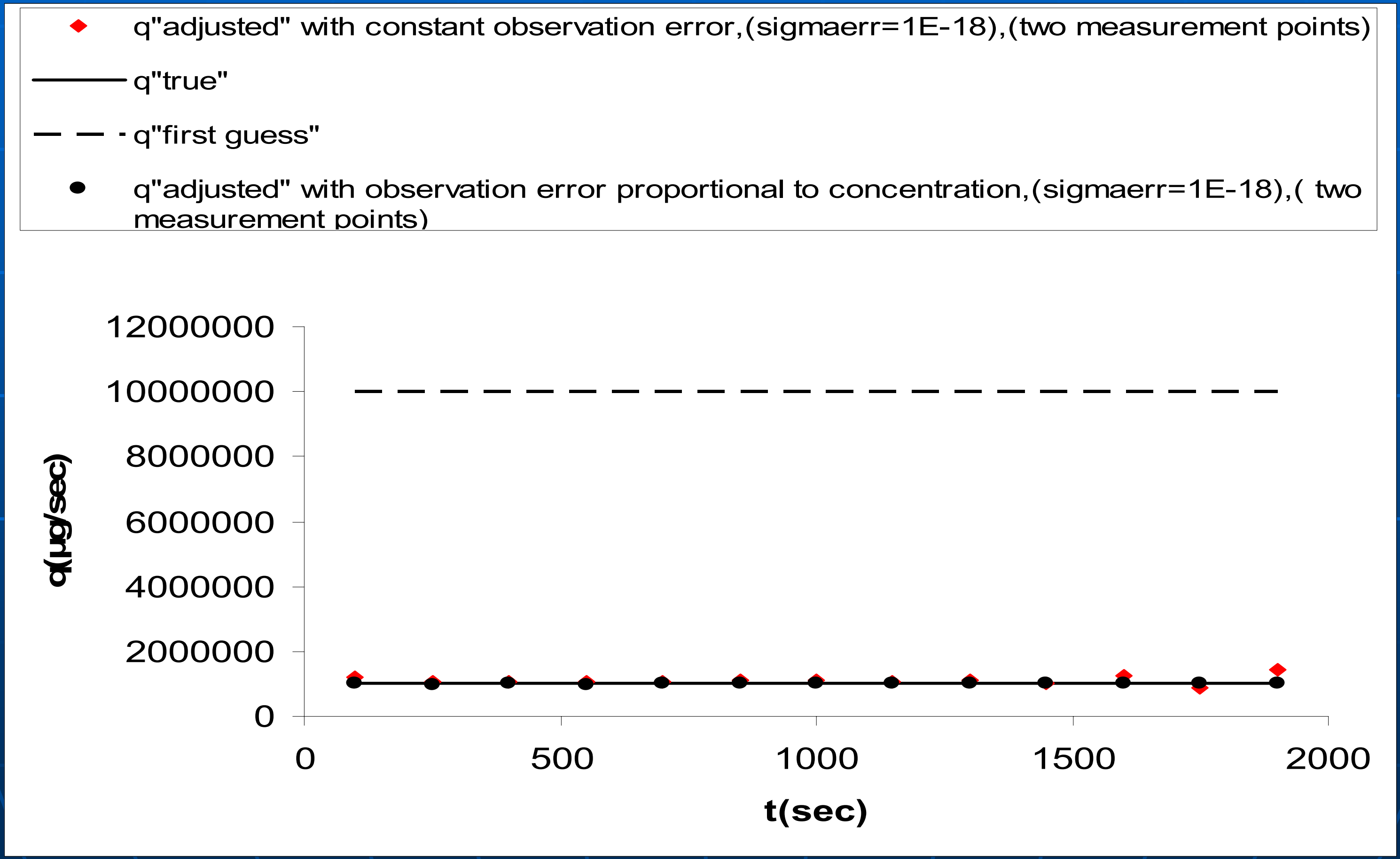
q"True"
q"First guess"
q"αdjusted",σ=1E-22,(Δtp=500s), (Δtmeas=500s)
q"adjusted",σ=1E-17, (Δtp=500s),(Δtmeas=500s)
q"adjusted",σ=1E-16,(Δtp=500s), (Δtmeas=500s)
12000000
10000000
8000000
6000000
4000000
2000000
0
q(μg/s)
0
500
1000
1500
2000
t(s)


q"true"
q"first guess"
q"adjusted",σ=1E-17,(Δtp=150s),(Δtmeas=500s),(Tmeas=2000s)
q"adjusted",σ=1E-17,(Δtp=150s),(Δtmeas=200s),(Tmeas=2000s)
q"adjusted",σ=1E-17,(Δtp=150s),(Δtmeas=200s),(Tmeas=2300s)
q"adjusted",σ=1E-18,(Δtp=150s),(Δtmeas=200s),(Tmeas=2000s)
q"adjusted",σ=1E-18,(Δtp=150s),(Δtmeas=200s),(Tmeas=2300s)
q(µg/s)
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
0
500
1000
1500
2000
t(s)

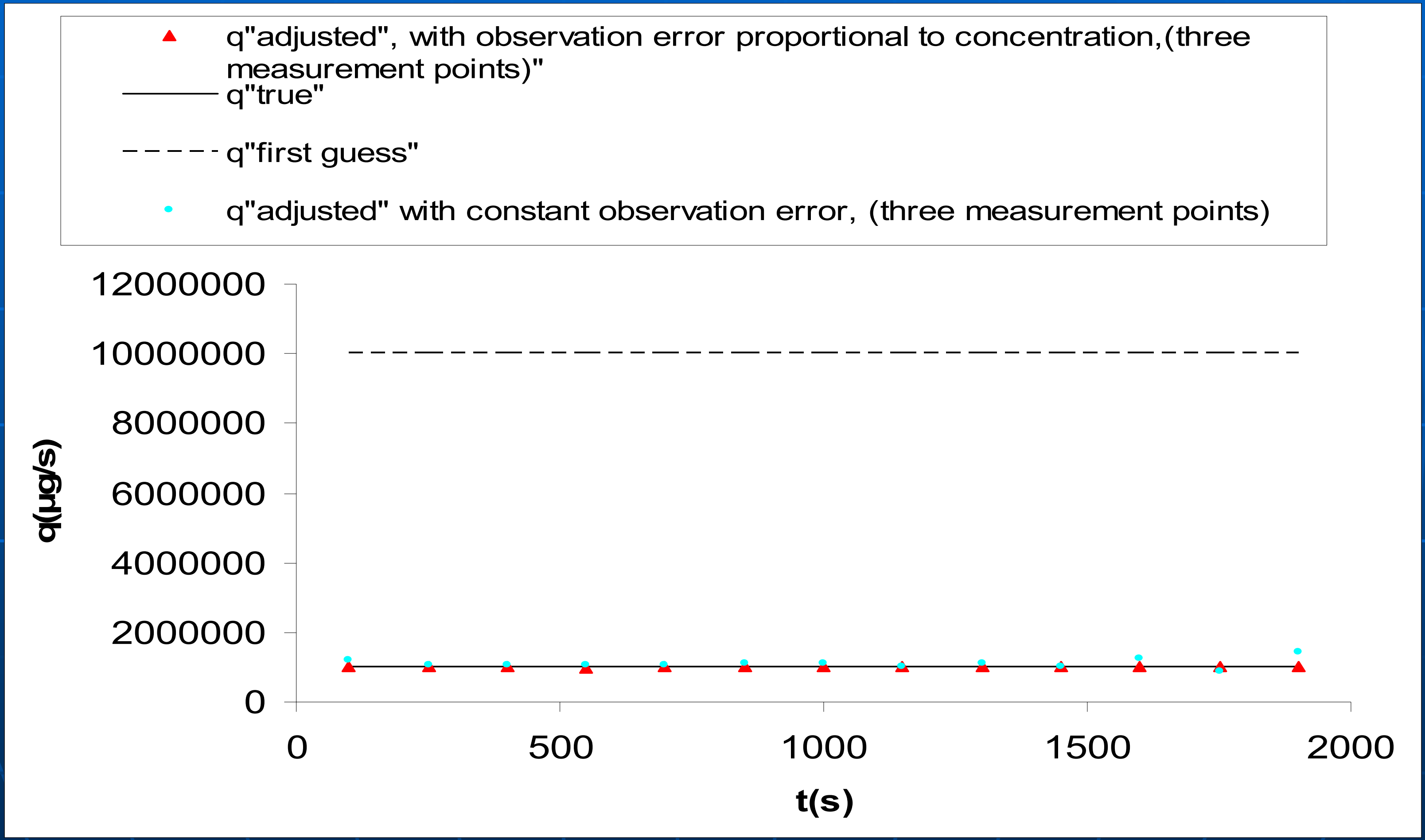
Root mean square error of the observations proportional to the values of concentration



2 MEASUREMENT POINTS

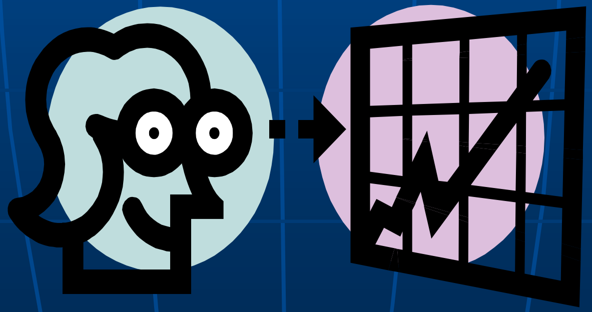


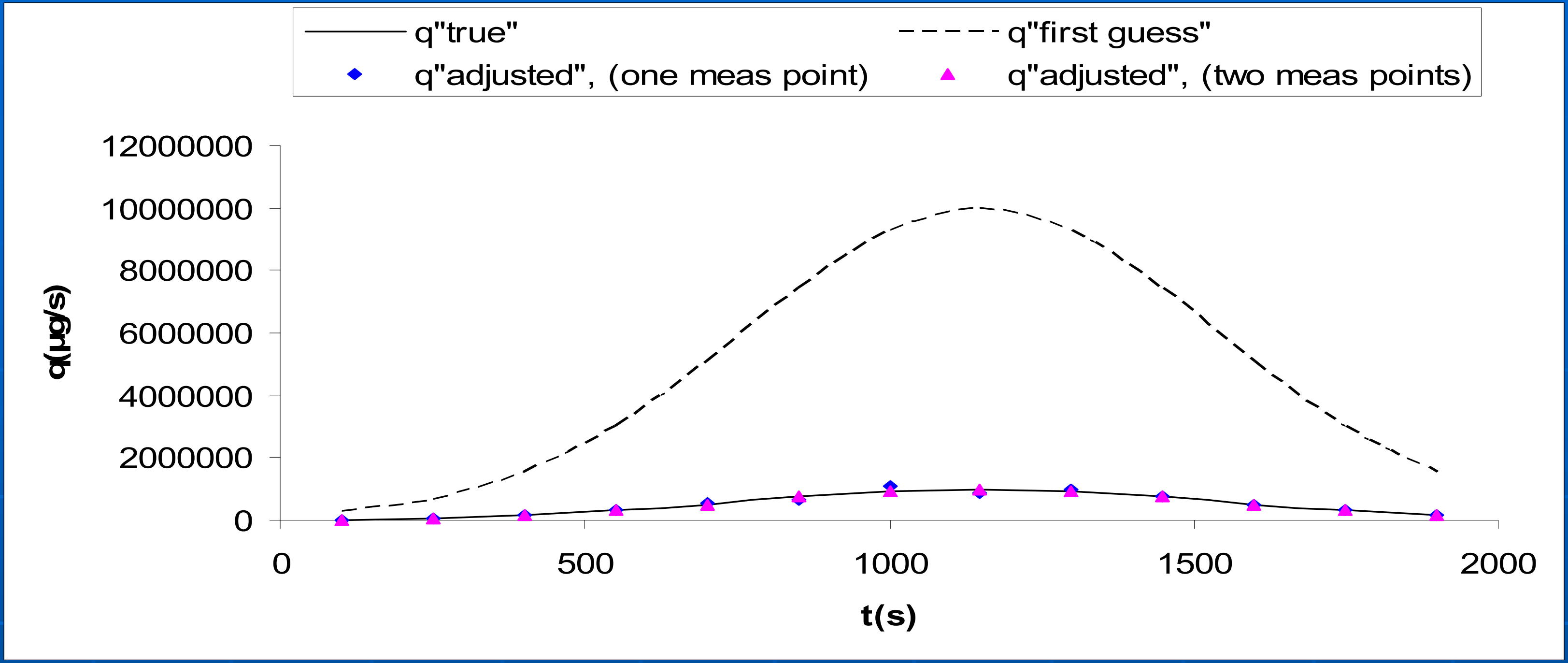
3 MEAUREMENT POINTS

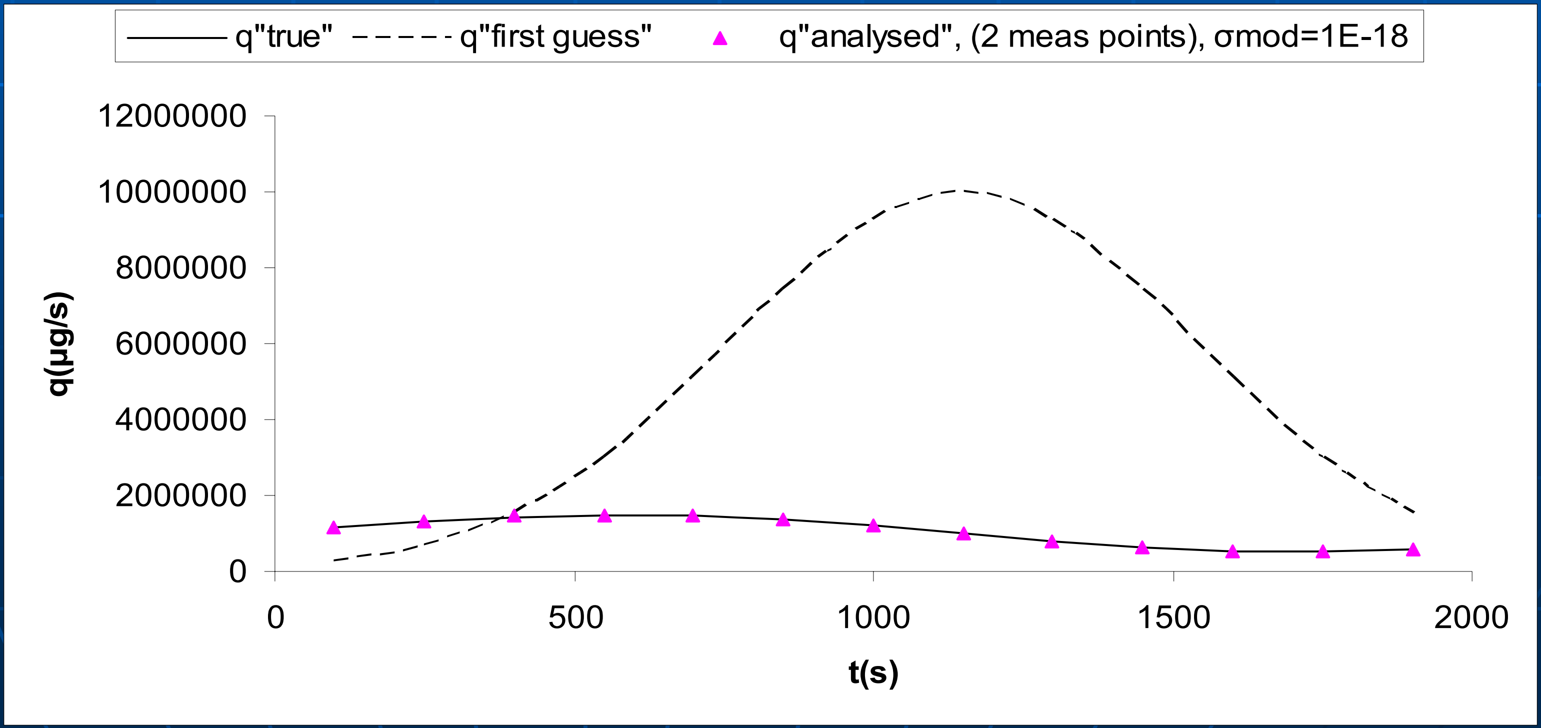


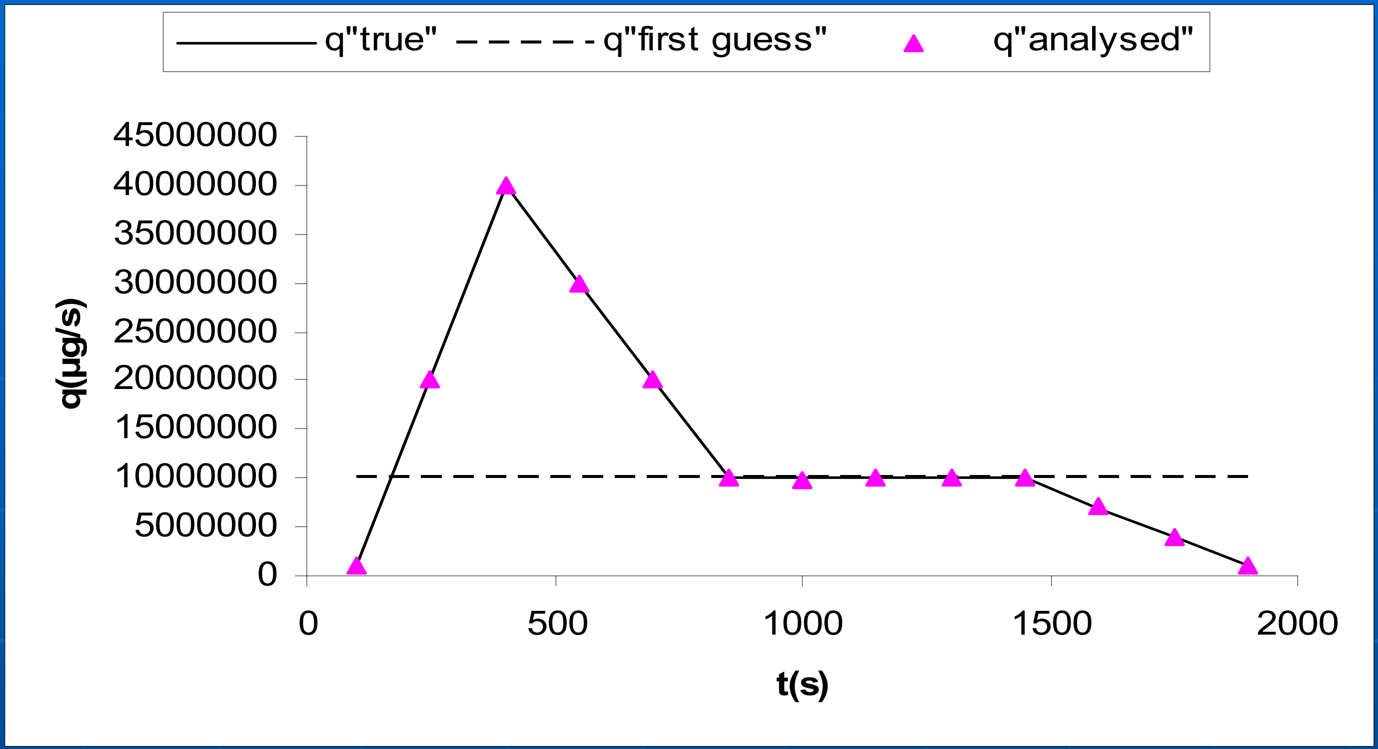
1-dimensional cases

- Several forms of Source term functions

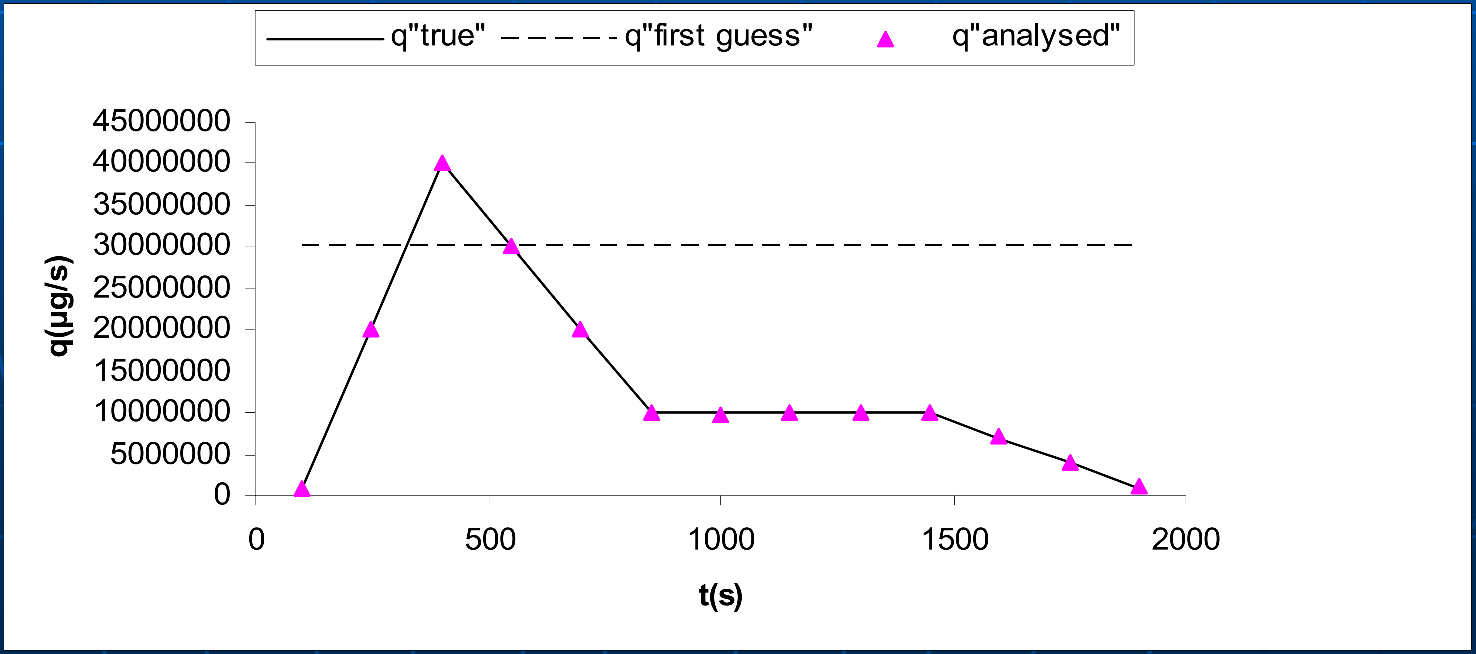



q"true"
q"first guess"
q"adjusted", (one meas point)
q"adjusted", (two meas points)
12000000
10000000
8000000
6000000
4000000
2000000
0
q(µg/s)
0
500
1000
1500
2000
t(s)


q"true"
q"first guess"
q"analysed", (2 meas points), σmod=1E-18
12000000
10000000
8000000
6000000
4000000
2000000
0
q(µg/s)
0
500
1000
1500
2000
t(s)



q"true"
q"first guess"
q"analysed"
45000000
40000000
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
q(µg/s)
0
500
1000
1500
2000
t(s)



q"true"
q"first guess"
q"analysed"
45000000
40000000
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
q(µg/s)
0
500
1000
1500
2000
t(s)

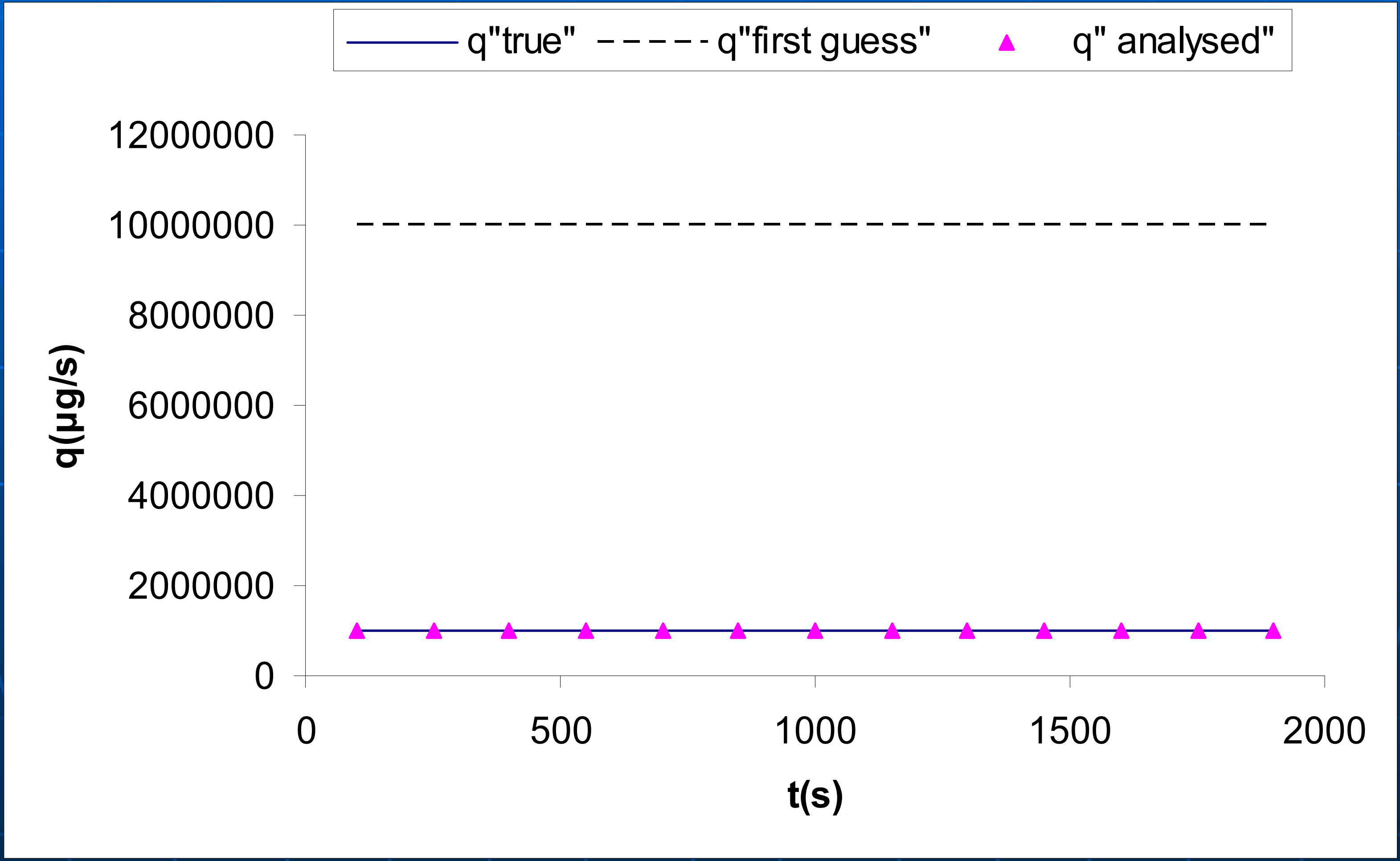
Variable Wind Speed

- instead of the constant wind speed of 10m/sec that we had in the previous tests

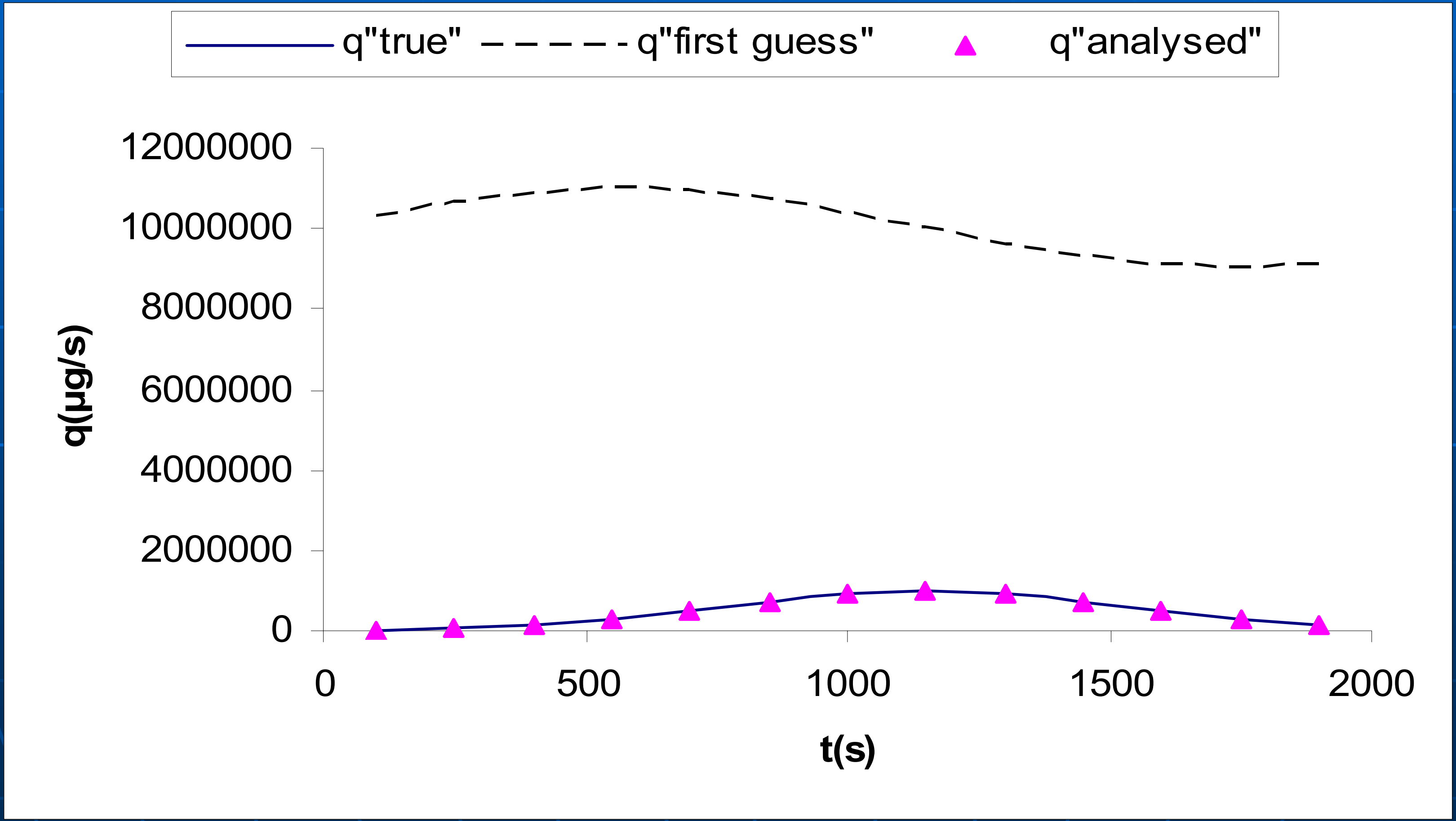
For different x -coordinate of the centre of each puff, different value of velocity exists - periodical perturbation

$$v = v_0 + A \sin k \times Xp$$

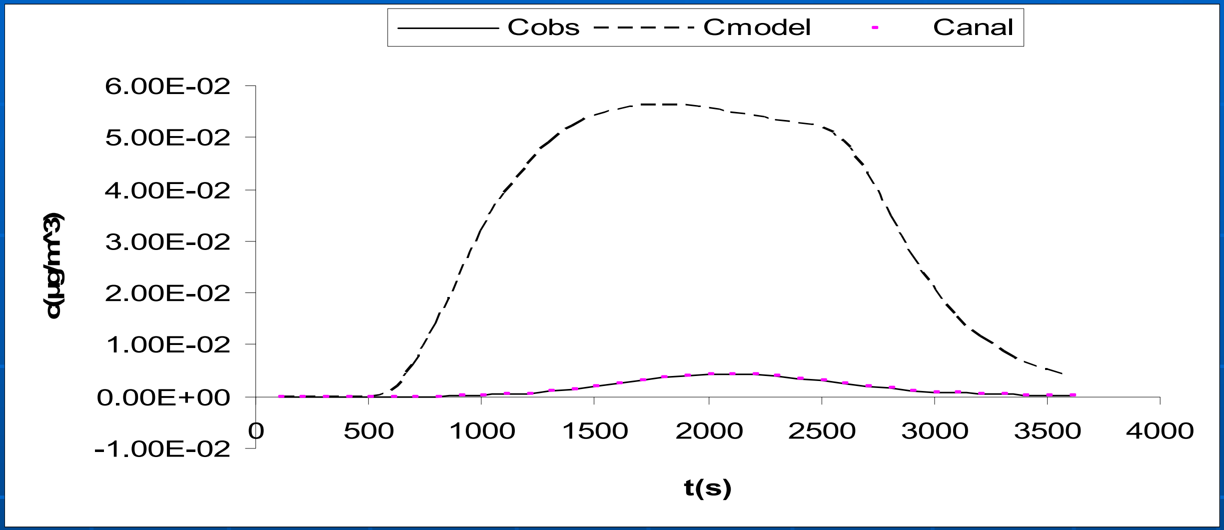
- constant source function
- three measurement points

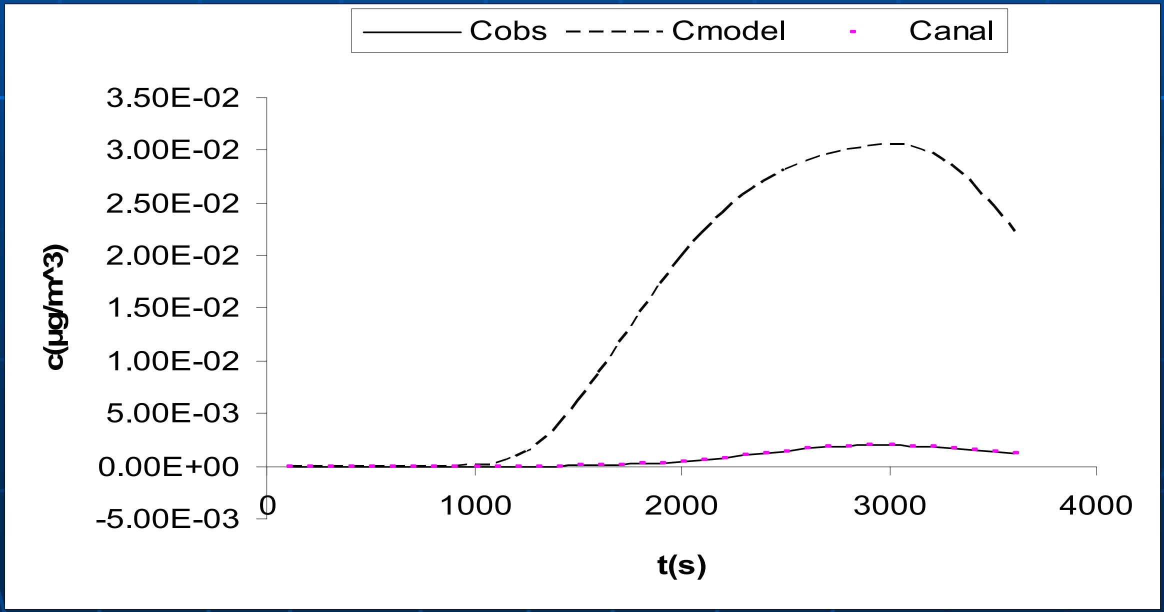


- variable source function
- three measurements points



Results for the Concentration after Data Assimilation





Future Work

Future work involves the application of the method to more realistic situations and required optimisations