Development of a multiscale high-resolution wind and dispersion model for simulation of catastrophic CO2 leakages

The Risks of CO2 Sequestration Workshop
11 October – 12 October 2011

Fue-Sang Lien, Kun-Jung Hsieh, Jim Kuo

Catastrophic CO2 leakages in Lake Nyos in Cameroon in 1986

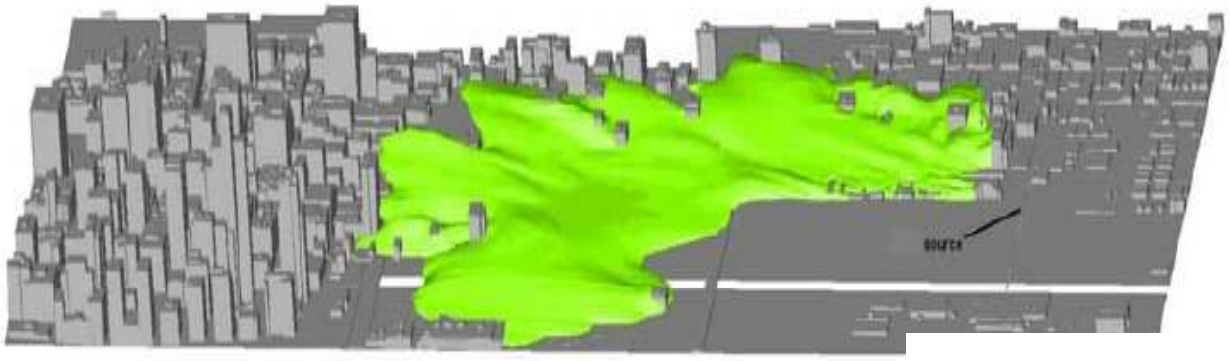
1. Due to CO2 that rises from volcanic activity
2. About 1.4 million tonnes of CO2 released to air within hours
3. 1,800 people killed

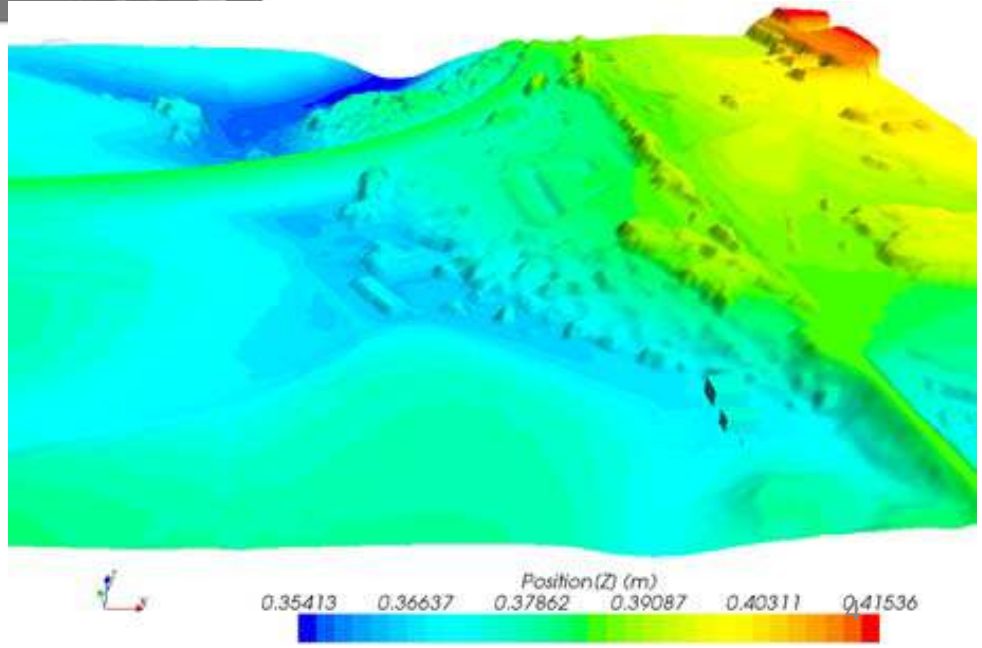
What if due to CO2 pipeline rupture?

European FP7 project: **CO2PipeHaz**

"Quantitative failure consequence hazard assessment for next generation CO2 pipelines"

(2009-2013)





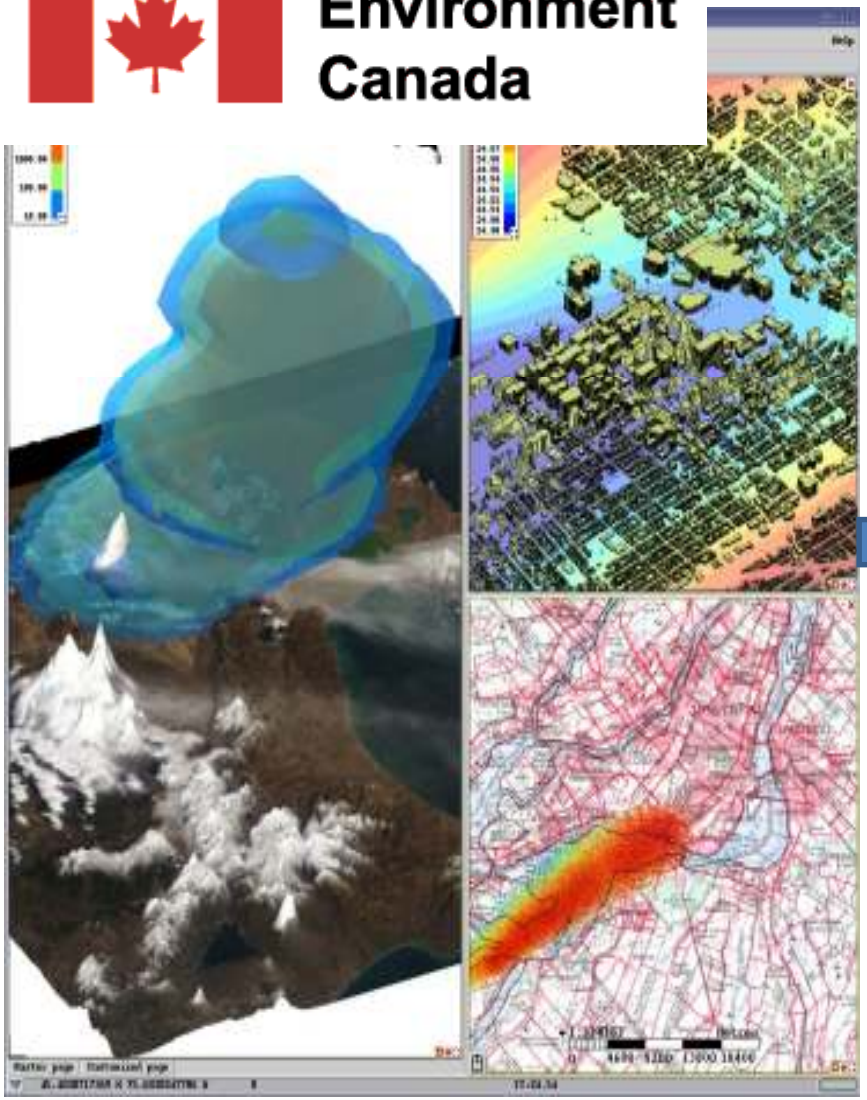
- 7 partners from 5 different countries
- **2.73 million Euro**

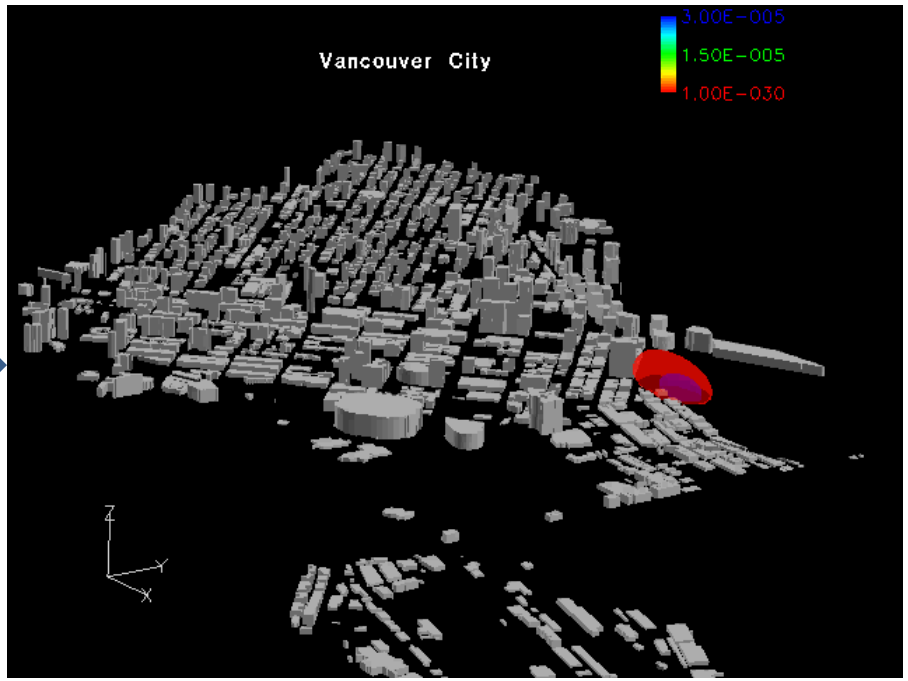
1. To provide tools for determining the **minimum distances** to populated areas
2. To allow **emergency response planning** in the event of (unlikely) pipeline failure

- **Concentration of 10%: unconsciousness in 1 min**
- **Concentration of >20%: instantaneously fatal**

Multiscale high-resolution wind & dispersion model

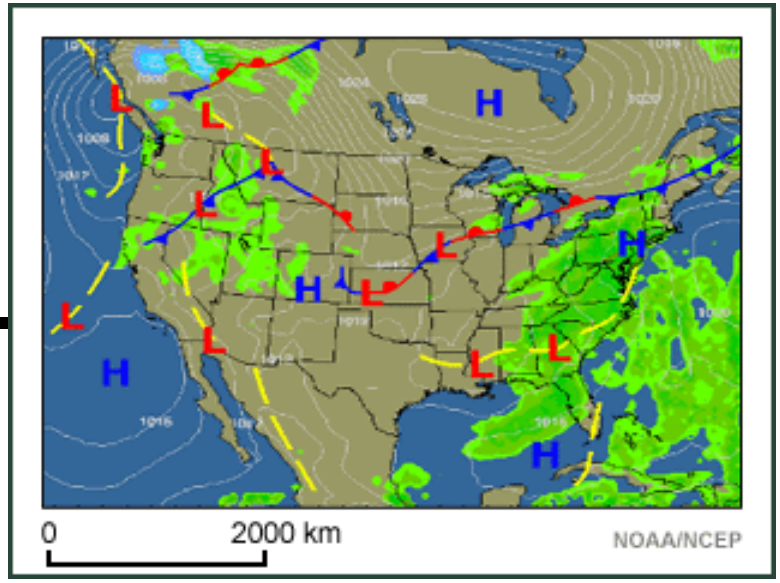
Environment Canada





University of Waterloo

Nested grids

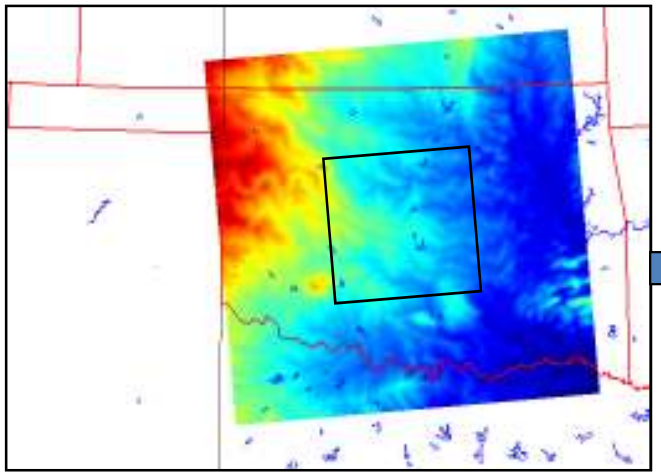


Synoptic scale
(>2000 km)

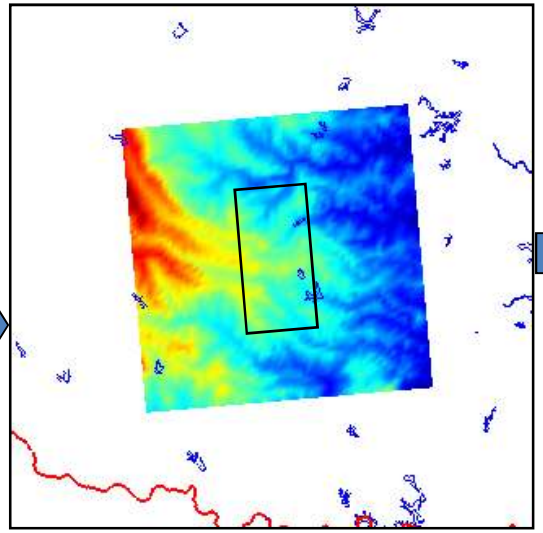
15-km
GEM Regional

Mesoscale (nested grid)

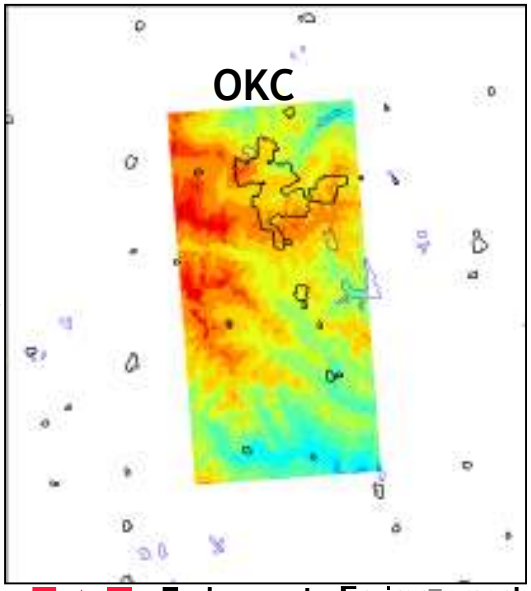
GEM-LAM 2.5 km



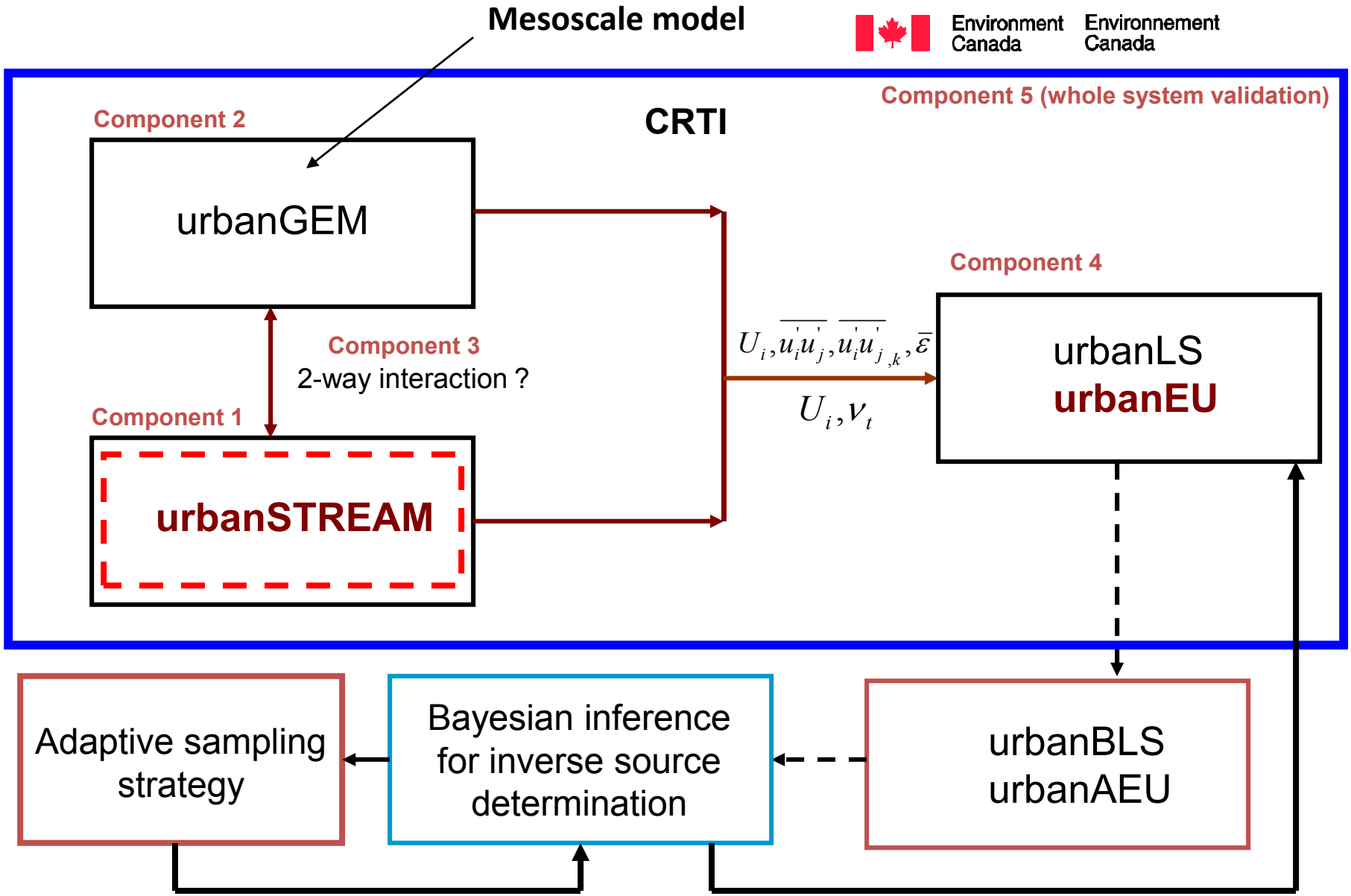
GEM-LAM 1 km



GEM-LAM 250 m



Environment Canada
Environnement Canada

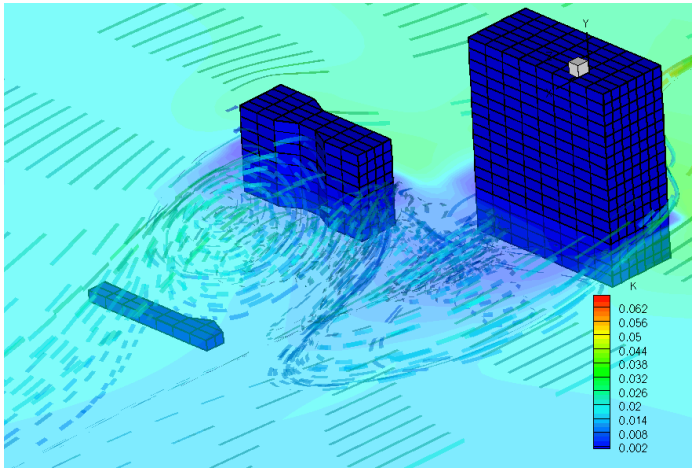

Mesoscale model
Environment Canada
Environnement Canada
Component 5 (whole system validation)
CRTI
Component 2
urbanGEM
Component 3
2-way interaction ?
Component 1
urbanSTREAM
Component 4
$U_i, \overline{u_i' u_j'}, \overline{u_i' u_j'}_{,k}, \bar{\varepsilon}$
U_i, ν_t
urbanLS
urbanEU
Adaptive sampling strategy
Bayesian inference for inverse source determination
urbanBLS
urbanAEU

CFD (computational fluid dynamics) software

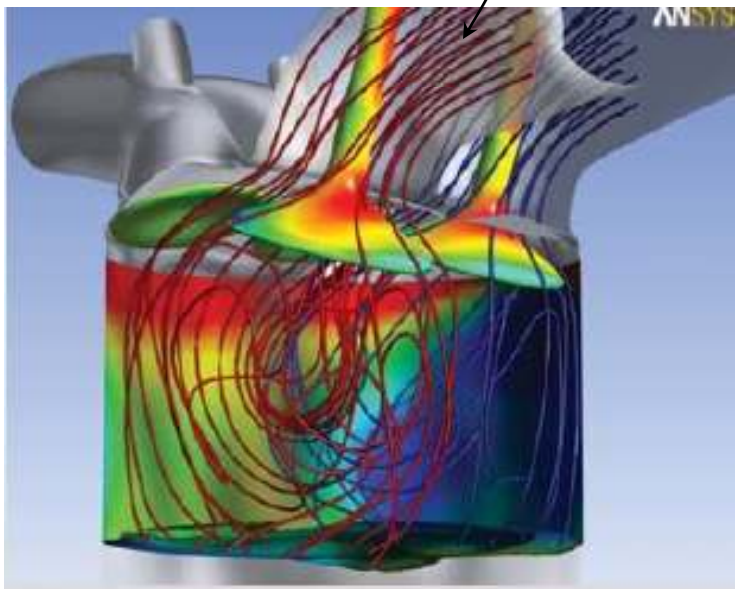
ANSYS FLUENT is a *commercial* flow modeling software

http://www.ansys.com/products/fluid-dynamics/fluent/

urbanSTREAM is an *in-house* CFD code developed at U of Waterloo

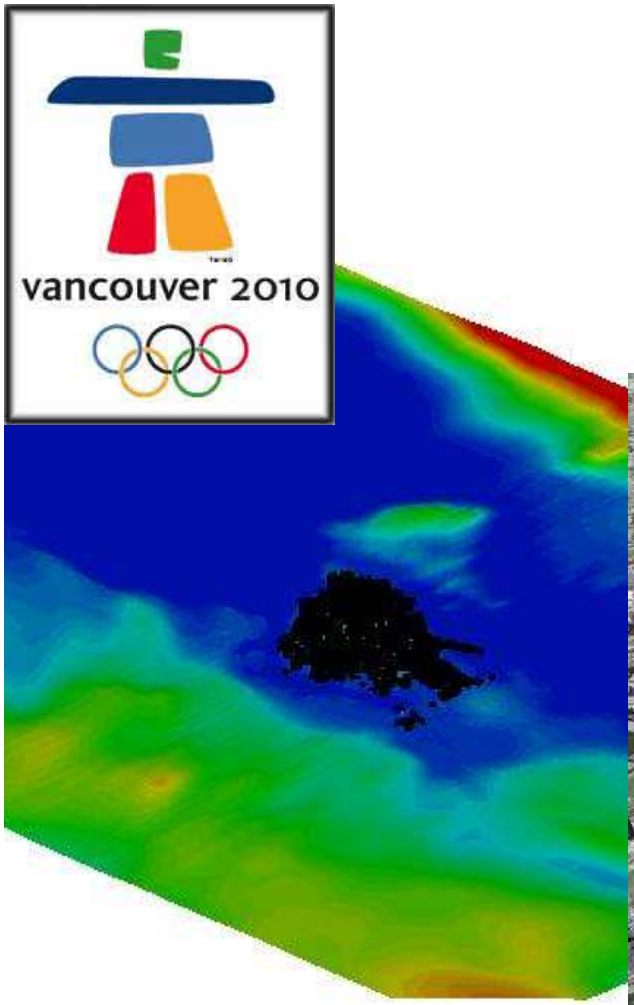


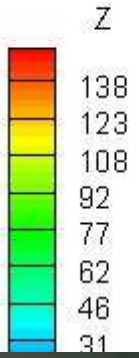
University of Waterloo



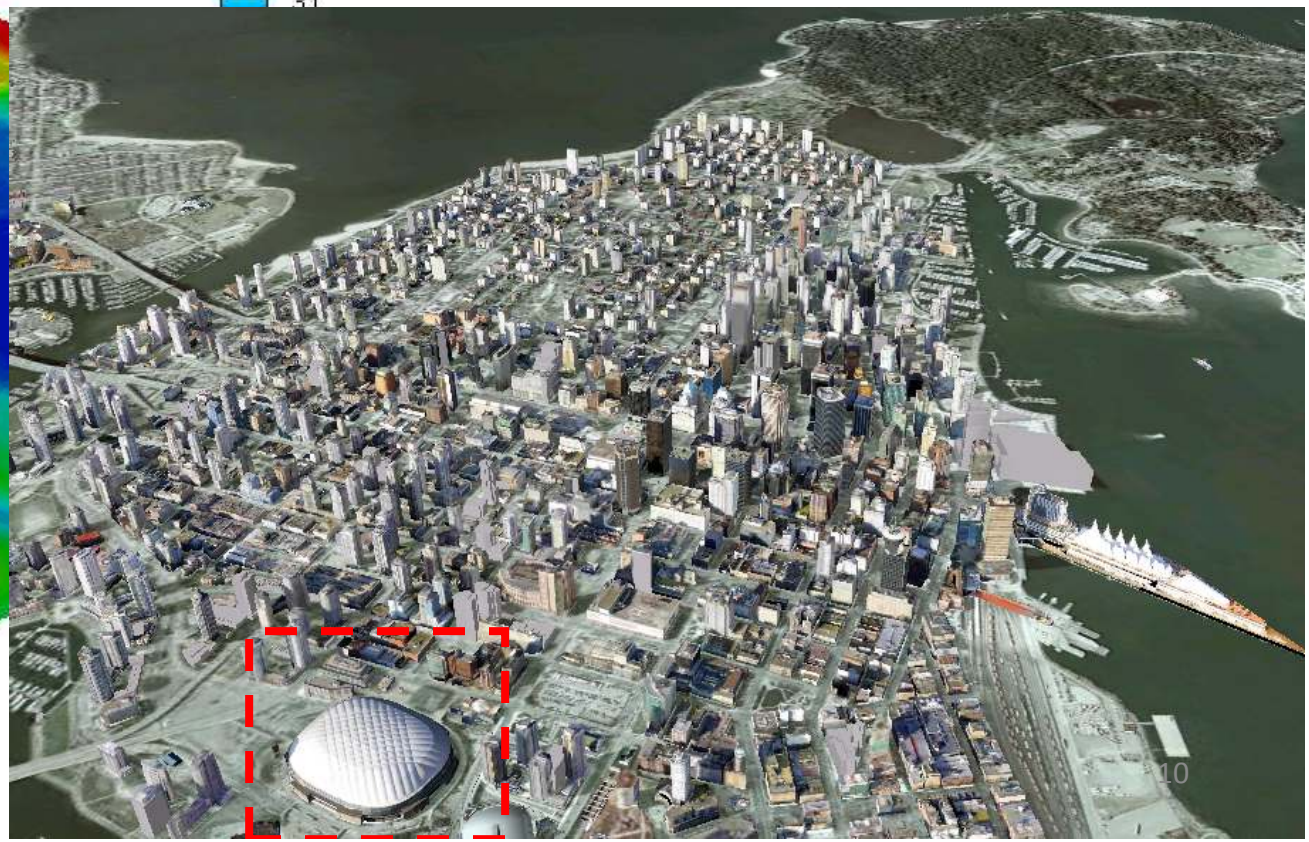
Internal combustion engine and the flow inside modeled using ANSYS FLUENT software

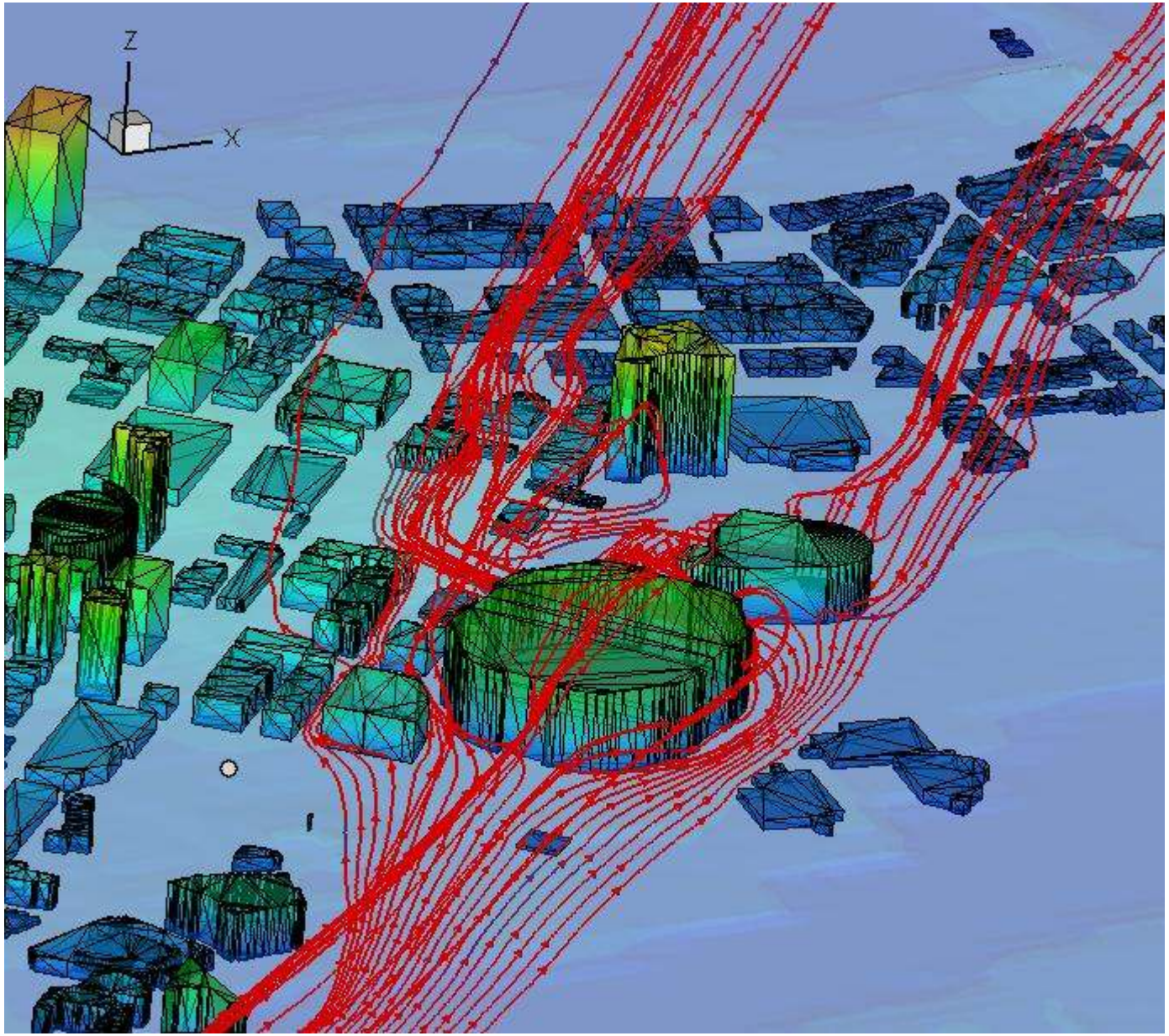
2010 Winter Olympics in Vancouver



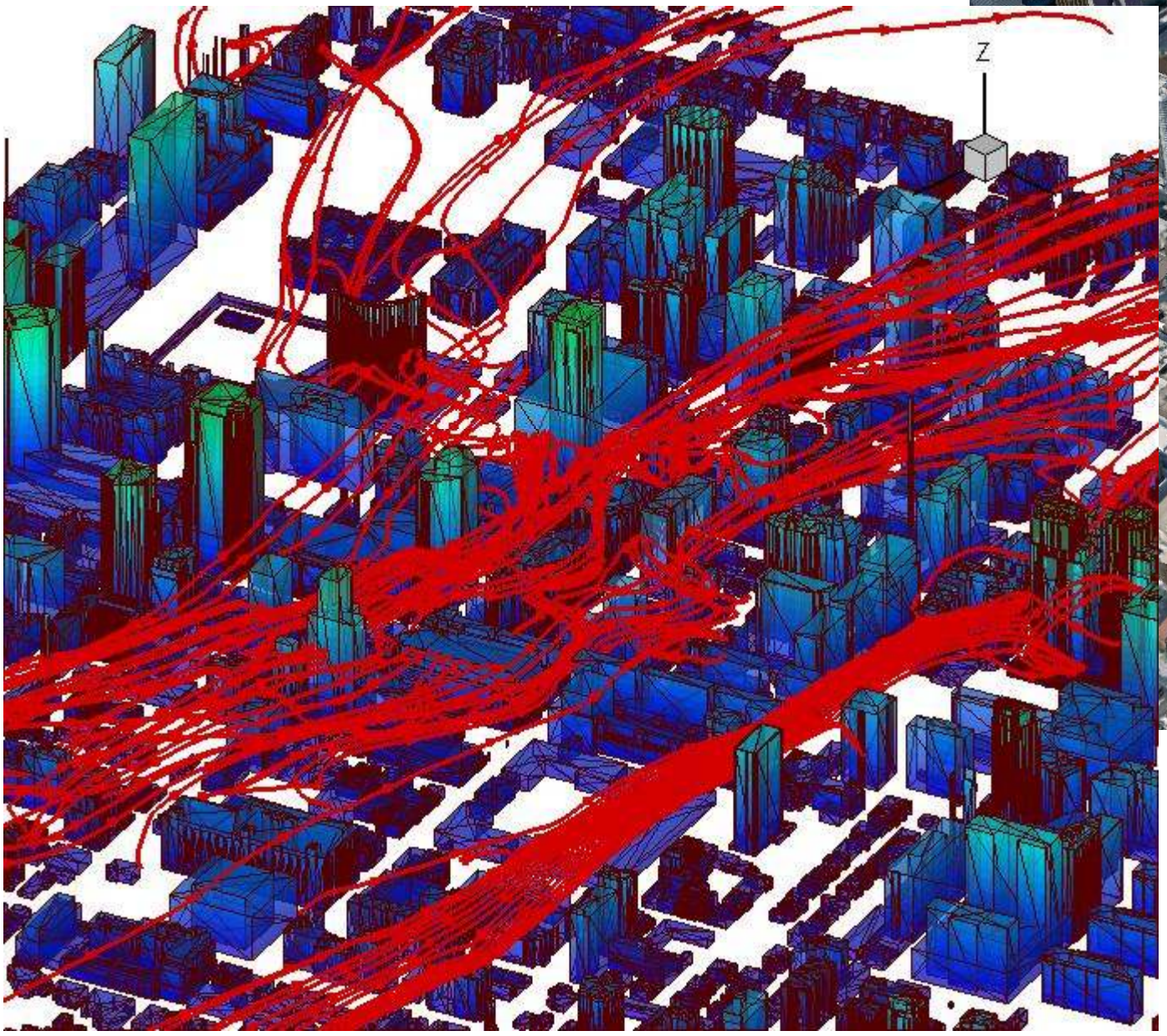


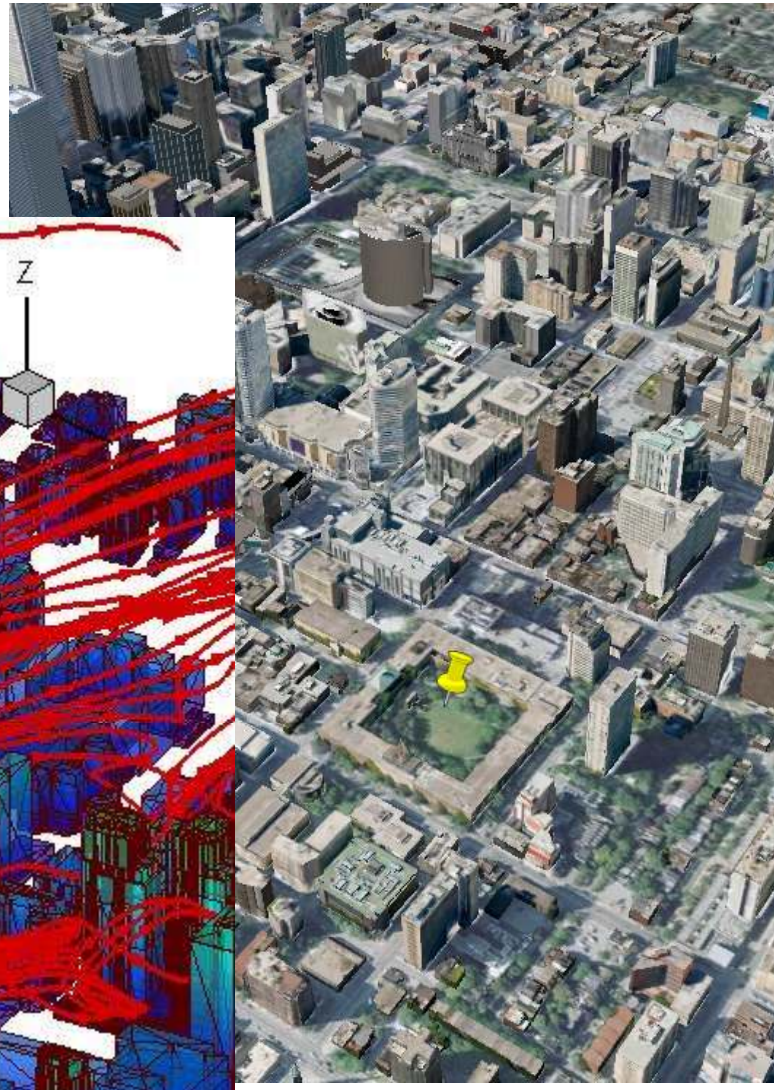
10 million nodes running on 16 CPUs



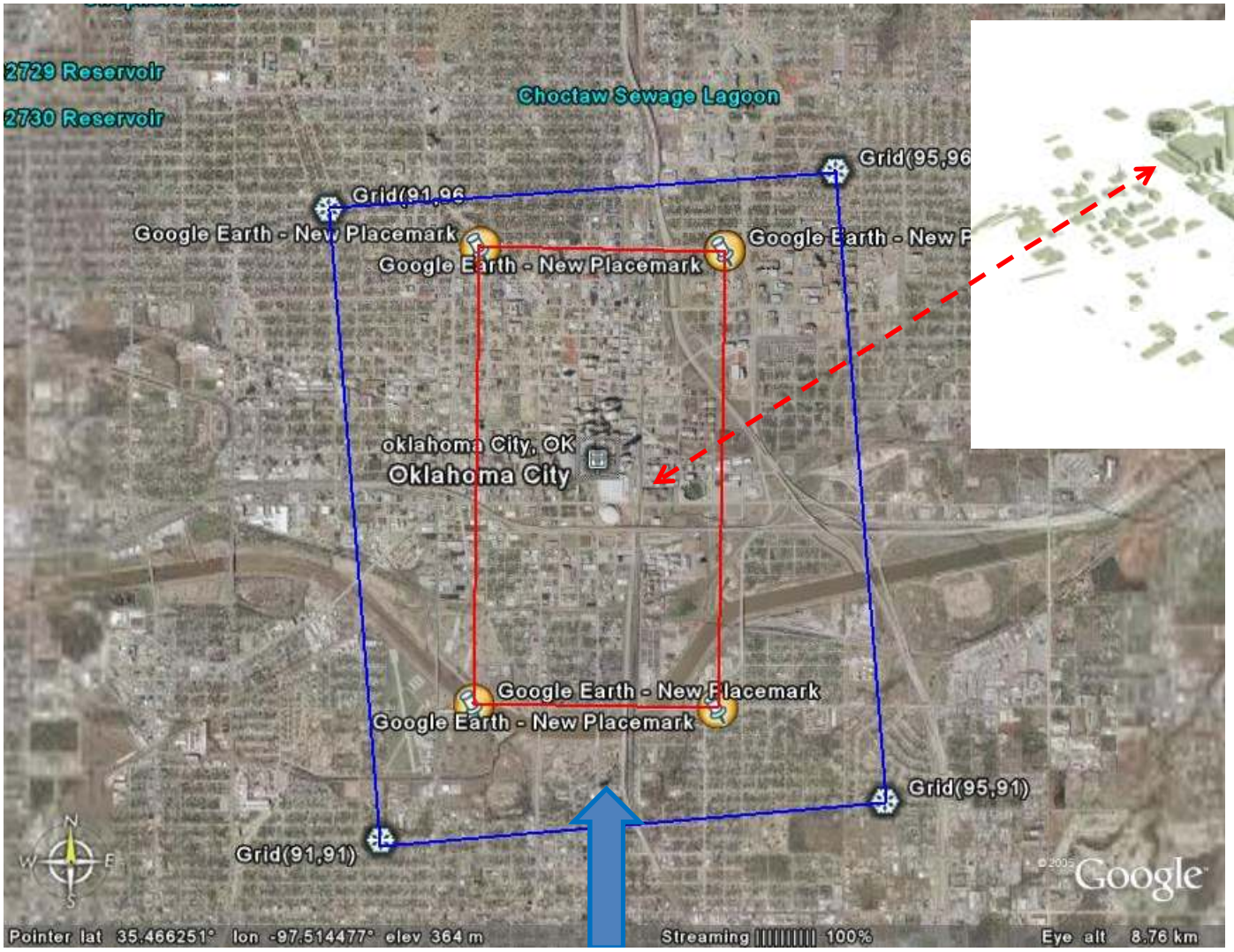

Z
X

City of Toronto
2010 G8/G20 Summit

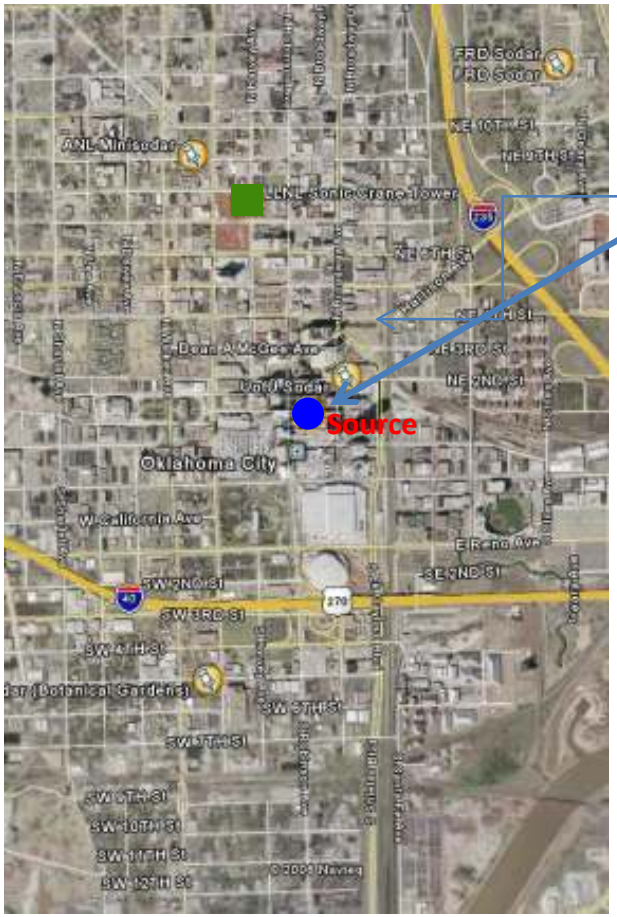

Z



JU2003 Database: Oklahoma City

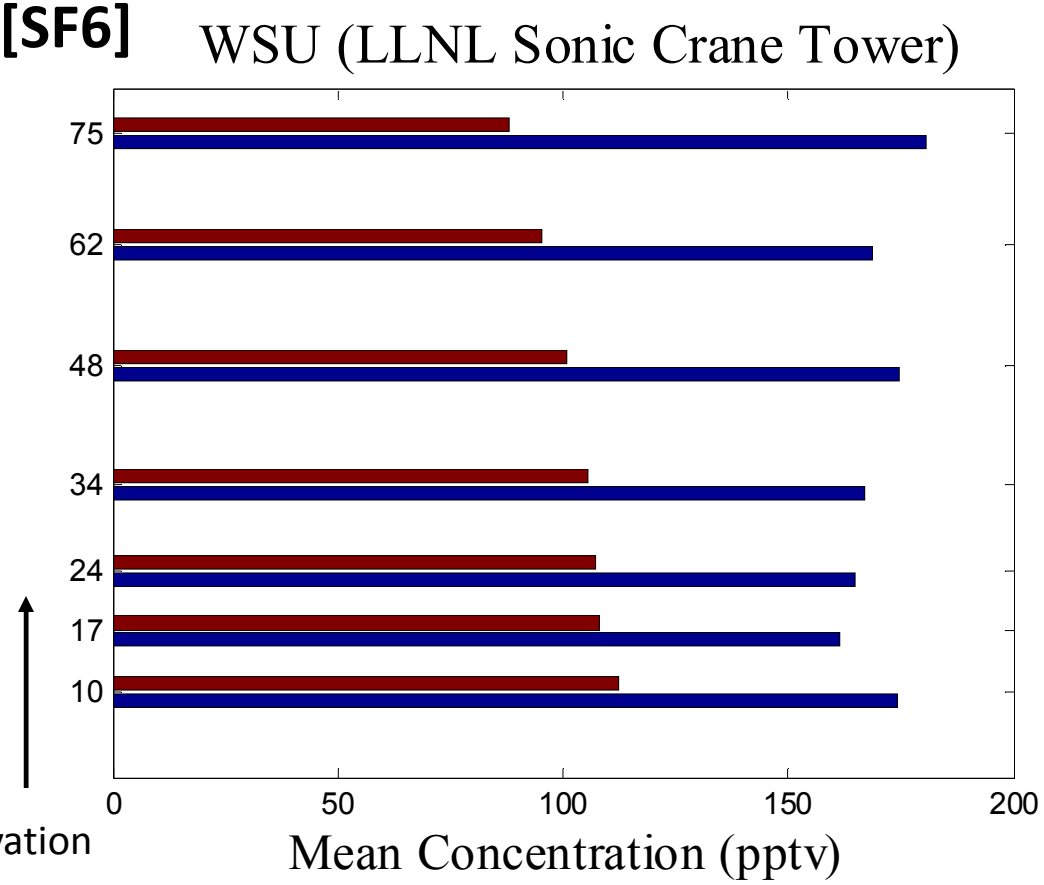


Concentration Prediction for Oklahoma City



2 g/s [SF6]

Vertical profile of mean concentration

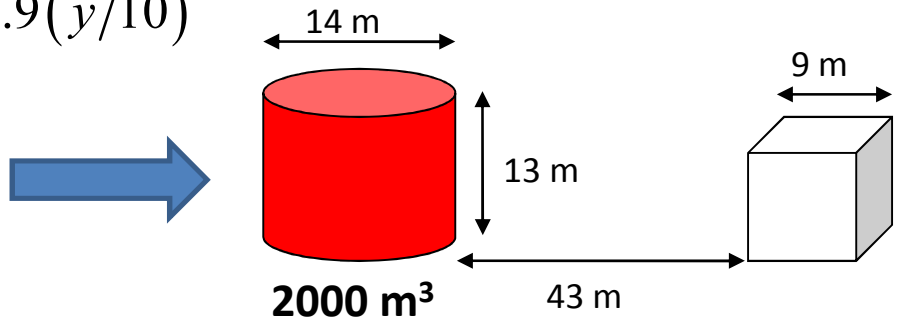


Experimental

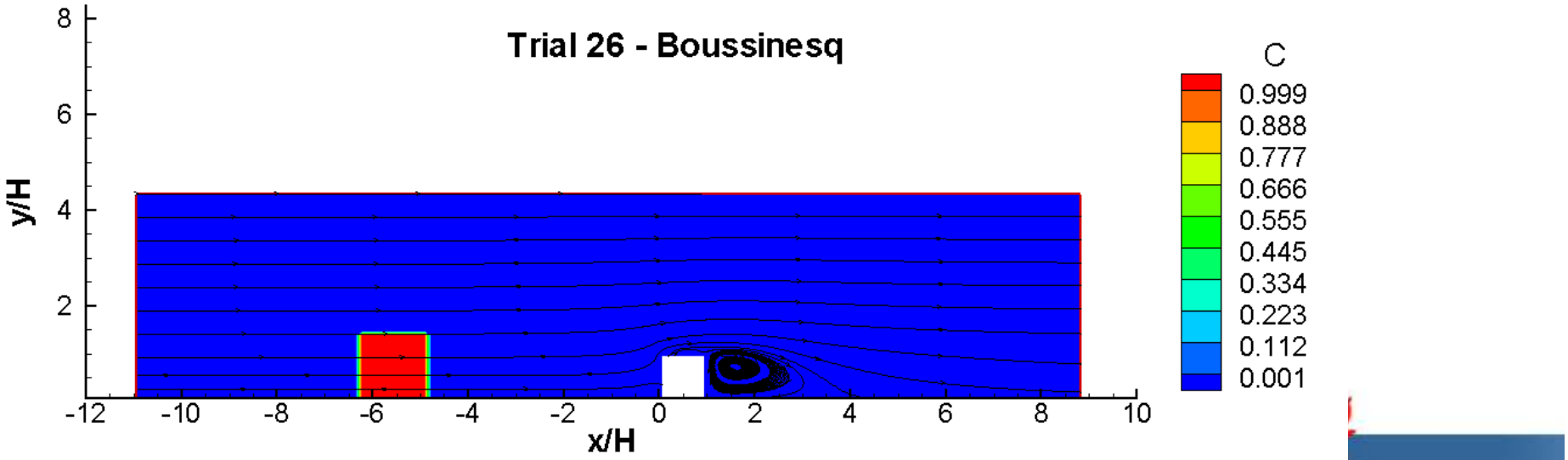
urbanEU

Heavy gas capability

$$\overline{u}_{in}(y) = 1.9(y/10)^{0.07}$$

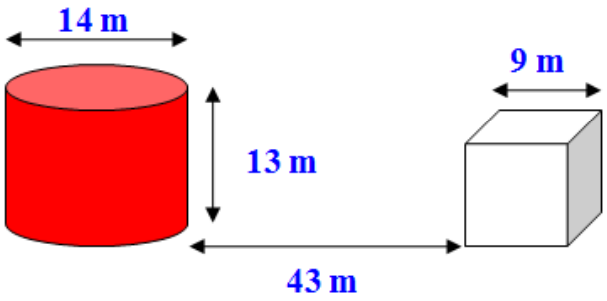


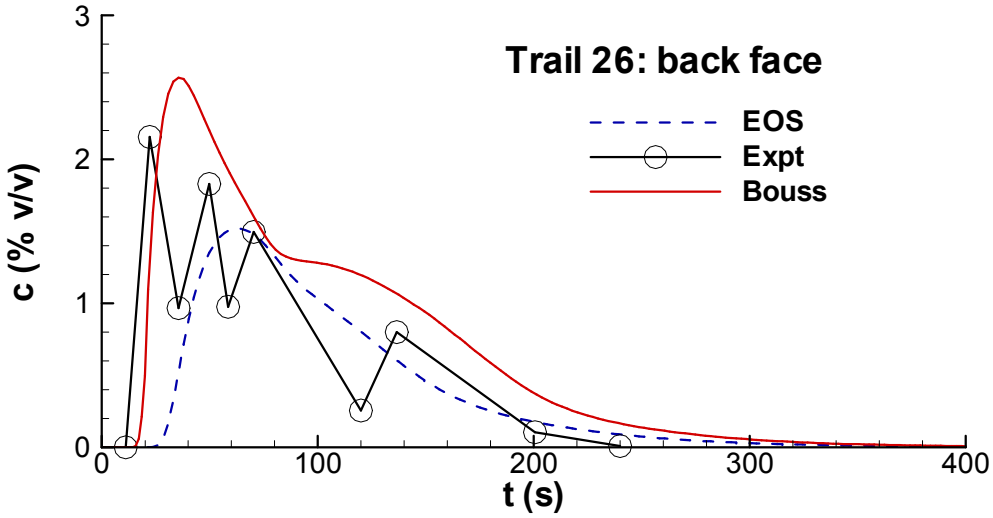
68.4% nitrogen and 31.6% Freon-12 (w/w)

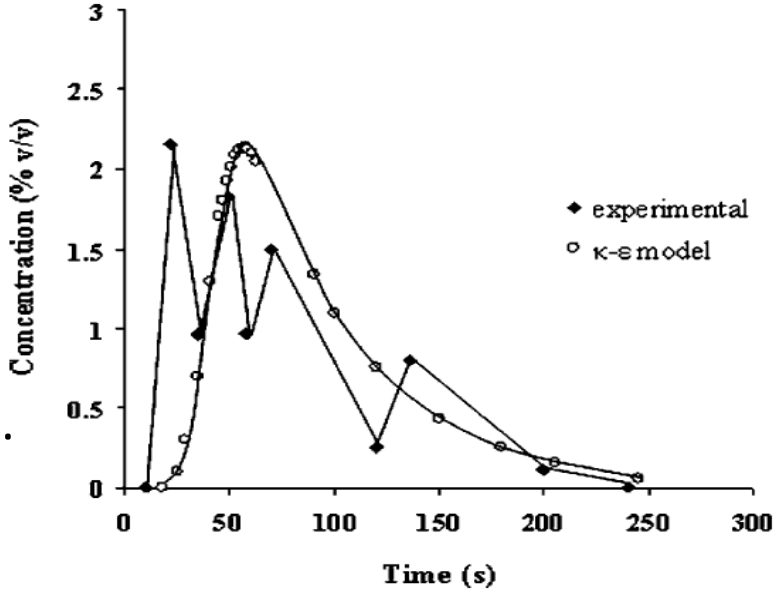


Natural Resources Canada
www.nrcan.gc.ca

Time history of gas concentration



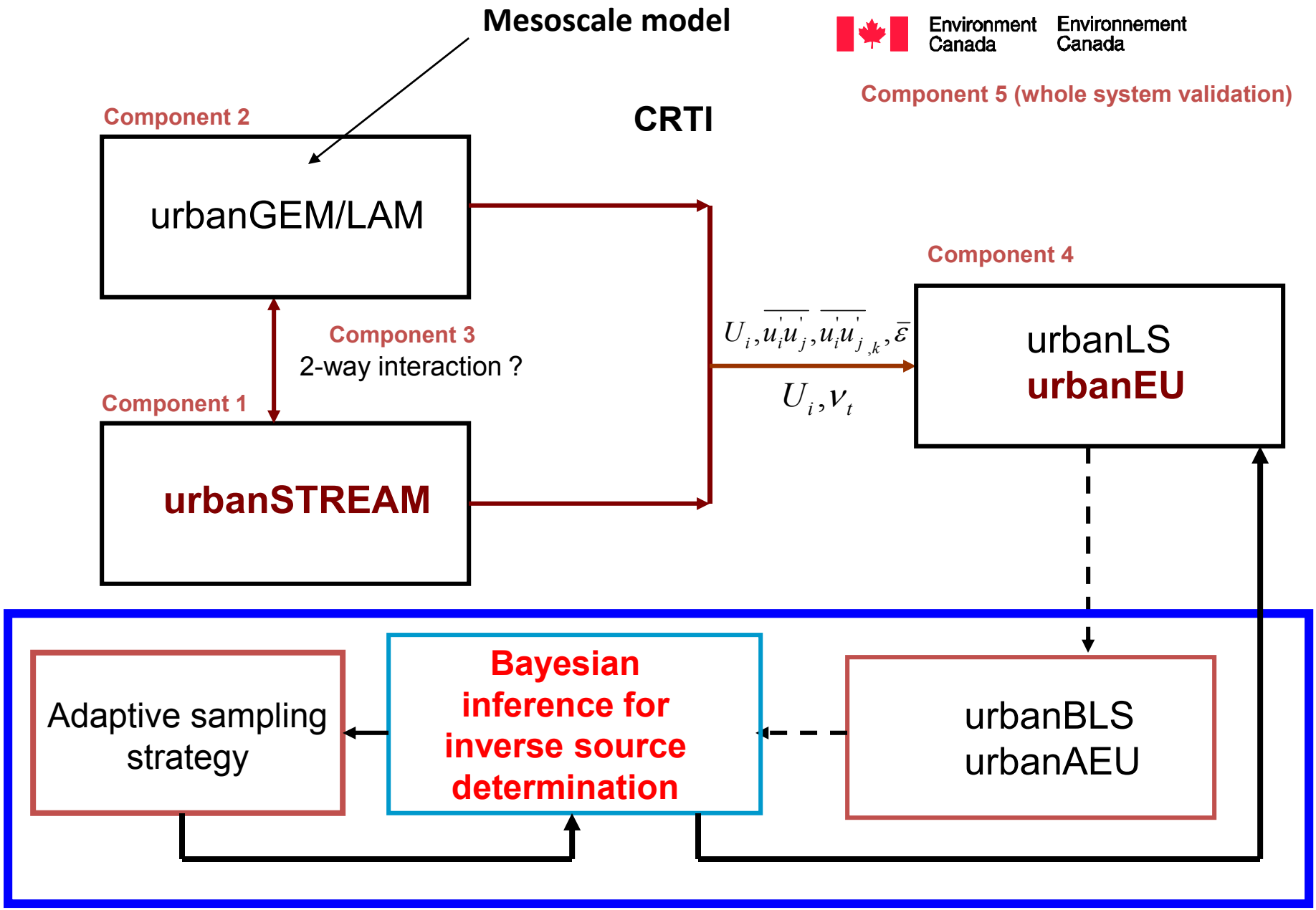




Sklavounos, S., Rigas, F. (2004), J. of Hazardous Materials, **108**, 9-20.

Localization and Characterization of Leakage Sources (Bayesian Inference Engine)

To reconstruct the characteristics (location, emission rate) of the unknown CO2 source distribution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urbanLS
urbanEU
Component 1
urbanSTREAM
U_i, ν_t
Adaptive sampling strategy
Bayesian inference for inverse source determination
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urbanAEU

Oklahoma City (9 detectors)

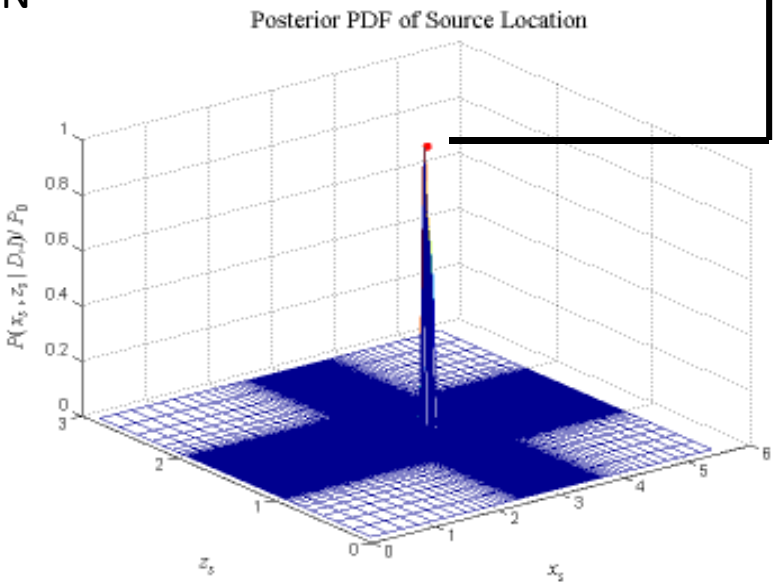
Detector

Source

N

Actual source location:

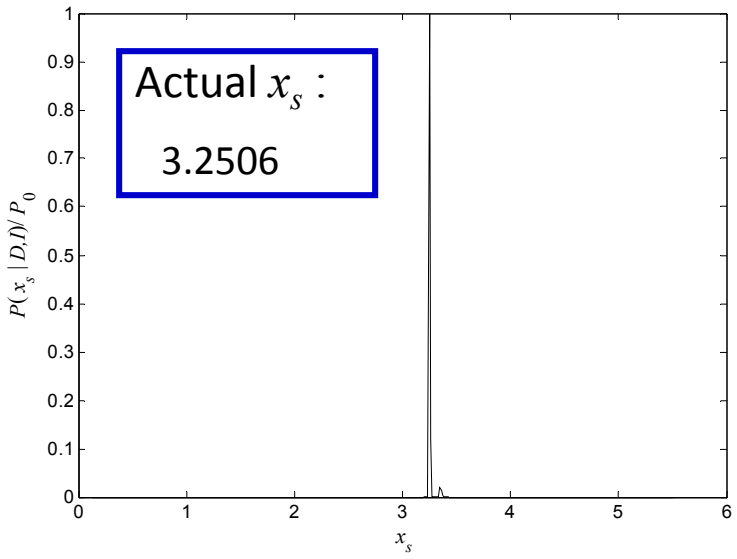
$(x_s\ ,\ z_s) = (3.2506, 1.5537)$

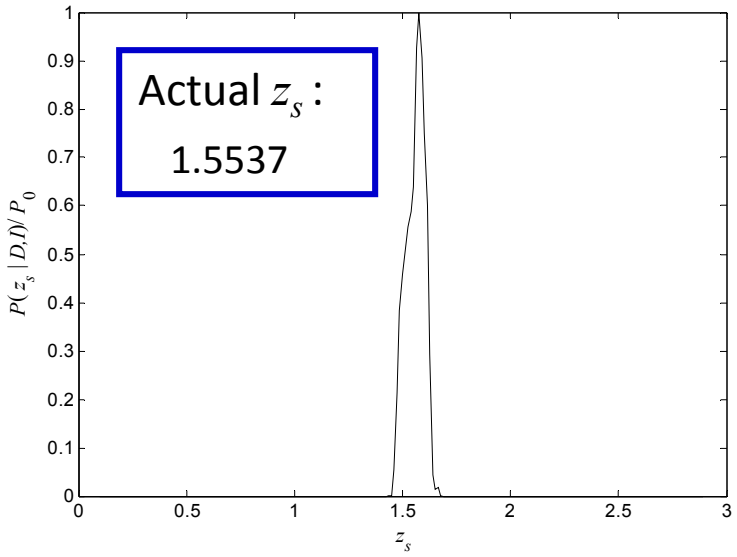


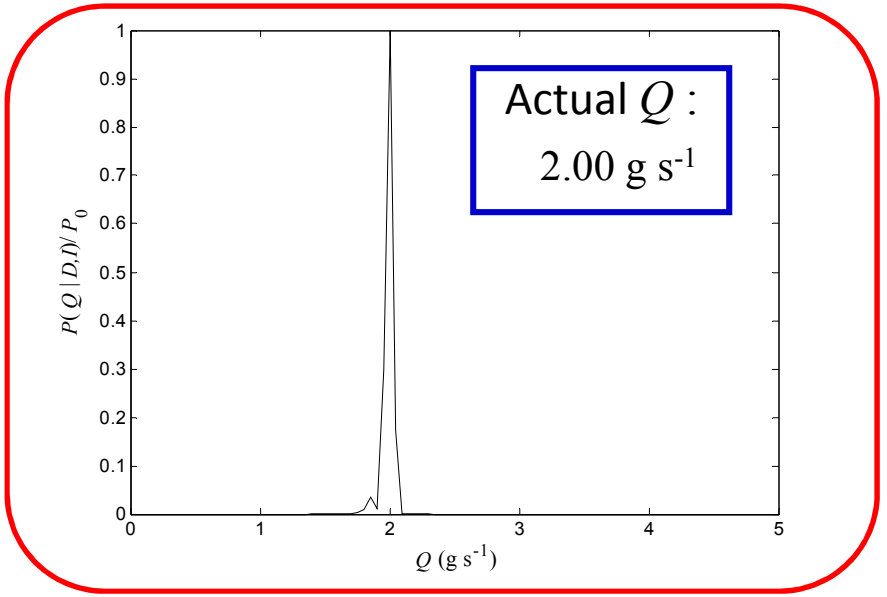
– estimated source location at one standard deviation:

$$(x_s)_{\text{est}} = \langle x_s \rangle \pm \sigma_{x_s} = 3.254 \pm 0.019,$$
$$(z_s)_{\text{est}} = \langle z_s \rangle \pm \sigma_{z_s} = 1.559 \pm 0.042$$

Emission rate







– estimated source parameters at one standard deviation:

$$(Q)_{\text{est}} = \langle Q \rangle \pm \sigma_Q = 1.990 \pm 0.041 \text{ g s}^{-1}$$

[Yee et al., 2006]

Note that a paper using a **Bayesian inversion technique** for determining the rate and location of fugitive **CO2 emission** has been submitted in 2011 by researchers in CSIRO (Commonwealth Scientific and Industrial Research Organization) in Australia