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PREDICTING THE INDIVIDUAL EXPOSURE FROM AIRBORNE HAZARDOUS RELEASES BY RANS- CFD MODELS

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THE FUNDAMENTAL QUESTION

Can RANS CFD Models ‘predict’ individual exposure over any exposure times (especially the short ones) ?

THE PROBLEM

- A hazardous substance is released in the atmosphere at a constant release rate at a certain point for a certain time
- The turbulent flow field is assumed stationary for the time of the release
- The precise (instantaneous) flow conditions of the time of the release are not known (by definition)

THE TOOL

- A RANS – CFD model able to predict at all positions the
  - the mean concentration
  - the concentration variance
  - the time scale of turbulence

Individual exposure estimation

- Individual exposure over Δτ:

$$D(\Delta\tau) = \int_0^{\Delta\tau} C_{real}(t)\cdot dt \le \left[\int_0^{\Delta\tau} C_{stationary}(t)\cdot dt\right]_{\max} = D_{\max}(\Delta\tau)$$

- Maximum Individual Exposure

$$D_{\max}(\Delta\tau) = \Delta\tau \cdot C_{\max}(\Delta\tau)$$

$$C_{\max}(\Delta\tau) = \frac{1}{\Delta\tau}\left[\int_0^{\Delta\tau} C_{stationary}(t)\cdot dt\right]_{\max}$$

$C_{\max}(\Delta\tau)$ the peak time-averaged concentration

The peak time averaged concentration

- Bartzis et al (2007)

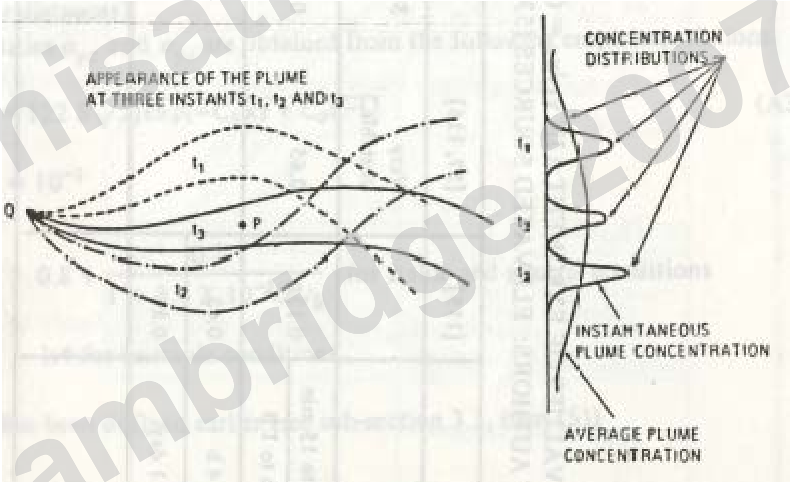
$$\frac{C_{\max}(\Delta\tau)}{\overline{C}} = f\left(I, \frac{\Delta\tau}{T_L}\right) \qquad I = \frac{\sigma_C^2}{\overline{C}^2}$$

- The first correlation

$$\frac{C_{\max}(\Delta\tau)}{\overline{C}} = 1 + 1.5 \cdot I \cdot \left(\frac{\Delta\tau}{T_L}\right)^{-0.3}$$

Previous Work-I

IAEA Safety Guide, Safety Series, Atmospheric Dispersion in Nuclear Power Plant Siting, No. 50-SG-S3, Vienna, IAEA, 1980.



Previous Work -II

IAEA Safety Guide, Safety Series, Atmospheric Dispersion in Nuclear Power Plant Siting, No. 50-SG-S3, Vienna, IAEA, 1980.

TABLE A5. VALUES OF EXPONENT n IN $\chi_1/\chi_2 = (T_{s1}/T_{s2})^{-n}$ FOR VARIOUS PERIODS ACCORDING TO DIFFERENT AUTHORS: GROUND SOURCES [53]

Authors:		[86]*	[118]*	[119]	[110]
Atmospheric stability					
Values for durations of	3 min to 15 min	0.2		0.35	
	15 min to 1 h				0.5
	1 h to 4 h		0.3		0.4
	4 h to 1 day				
Influence of distance		No variation	Increase with distance	None between 200 and 800 m	Slight increases with distance between 1 km and 4 km

* Expressions of $\chi = f(T_s)$ taken as a power law.

Previous Work-III

IAEA Safety Guide, Safety Series, Atmospheric Dispersion in Nuclear Power Plant Siting, No. 50-SG-S3, Vienna, IAEA, 1980.

TABLE A4. VALUES OF EXPONENT n IN $\chi_1/\chi_2 = (T_{s1}/T_{s2})^{-n}$ FOR VARIOUS PERIODS ACCORDING TO DIFFERENT AUTHORS: ELEVATED SOURCES [53]

Refs:		[115]	[57, 116]			[117]*		[97]	[86]*
Atmospheric stability			Very unstable	Stable	Neutral	Unstable	Stable		
Values for durations of	3 min to 15 min	0.12	0.65	0.52	0.35	0.4	0.25	0.3	0.7
	15 min to 1 h							0.5	
	1 h to 4 h	0.43							
	4 h to 1 day	0.86							
Influence of distance								Increase with distance	Decrease with distance

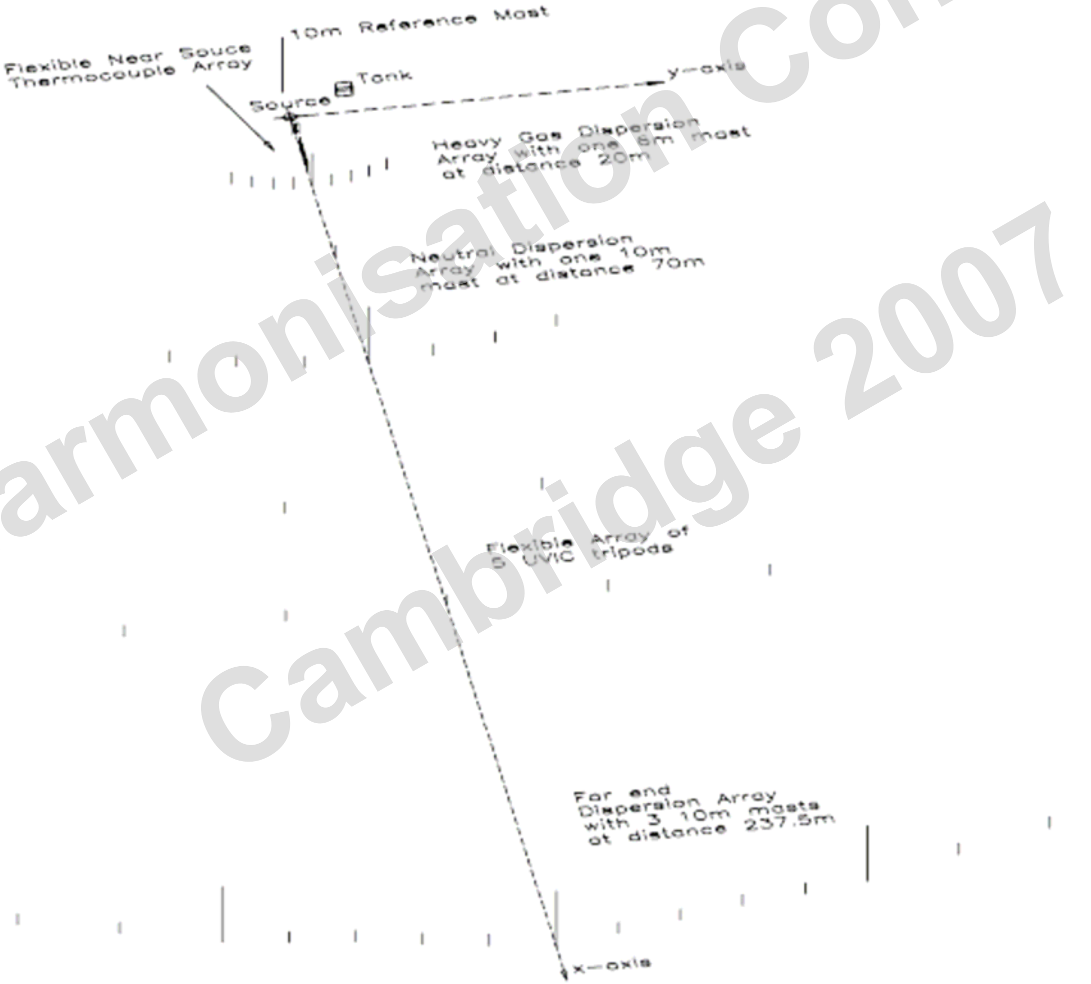
* Expressions of $\chi = f(T_s)$ taken as a power law.

The Application:
The FLADIS T16 field Experiment

Ammonia flashing near ground release

- Release rate 0.27 kg/s
- Jet direction: horizontal
- Release duration 20 min
- Average wind speed at 10 m 4.4 m/s
- Near neutral conditions
- Ambient temperature 16 Celcius
- Relative humidity 62 %

Experimental site – sensor positions



The model ADREA

- **Mesoscale/local scale**
- Stable/unstable ambient conditions
- One equation and two equation turbulence modeling
- Induced turbulence from moving objects (e.g. vehicles)
- One (dense/buoyant) pollutant
- 3-D RANS finite volume, transient
  - one/two phase release and dispersion
  - instantaneous/continuous releases
  - jets of arbitrary orientation (e.g. pipe exhaust, pipe/tank rupture etc)
- N passive substances reactive or not
  - CBM – IV gas chemistry (up to 36 species)
  - radioactivity
  - moist atmosphere (dispersion on gas and water phase in the atmosphere)

The Modeling approach - I

- 3D domain 44x33x38
- Non-uniform logarithmic grid
  - X=287m Δx_{min}=1.64m, Δx_{max}= 29m
  - Y=211m Δy_{min}=2.00m, Δy_{max}= 14.5m
  - Z=47.2m Δz_{min}=0.15m, Δz_{max}= 5m

The Modeling approach - II

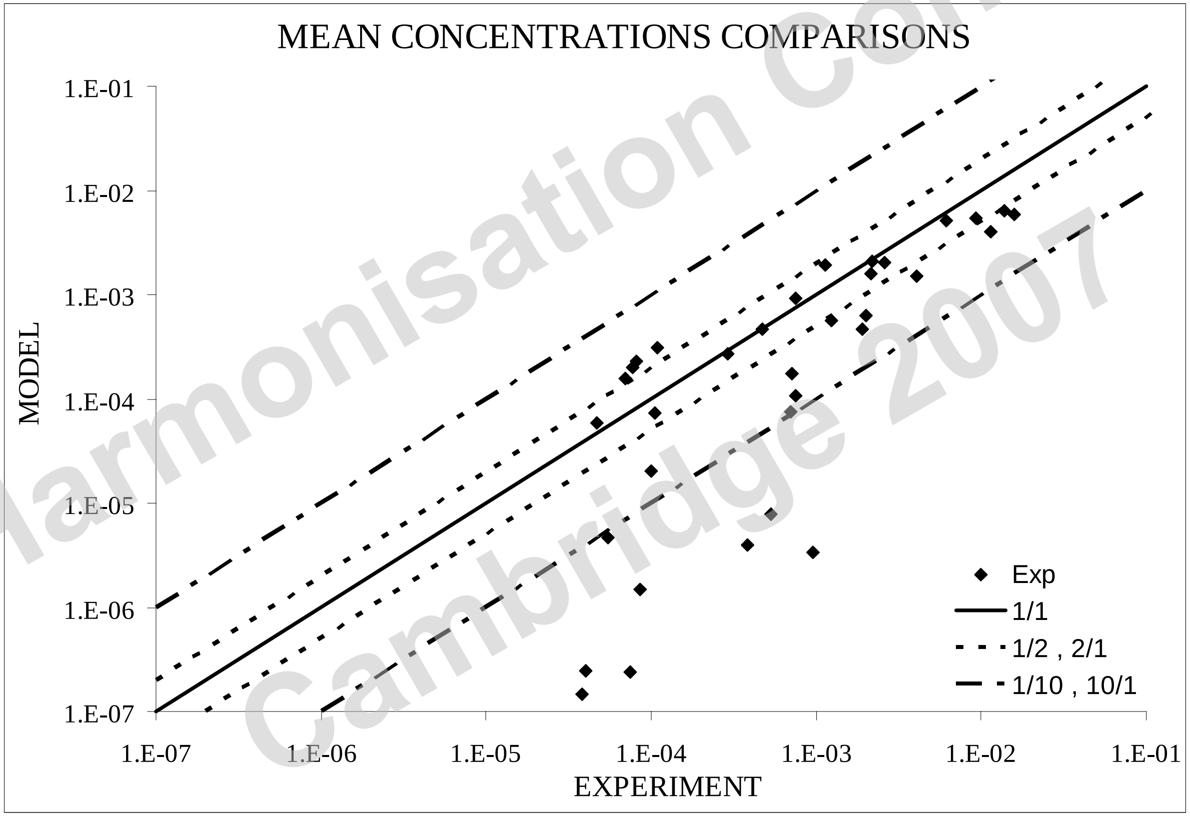
- **Concentration variance transport equation**
  (Andronopoulos et al ,2001)

- **Two Equation Turbulence (k – ζ) model**
  (Bartzis,2005)

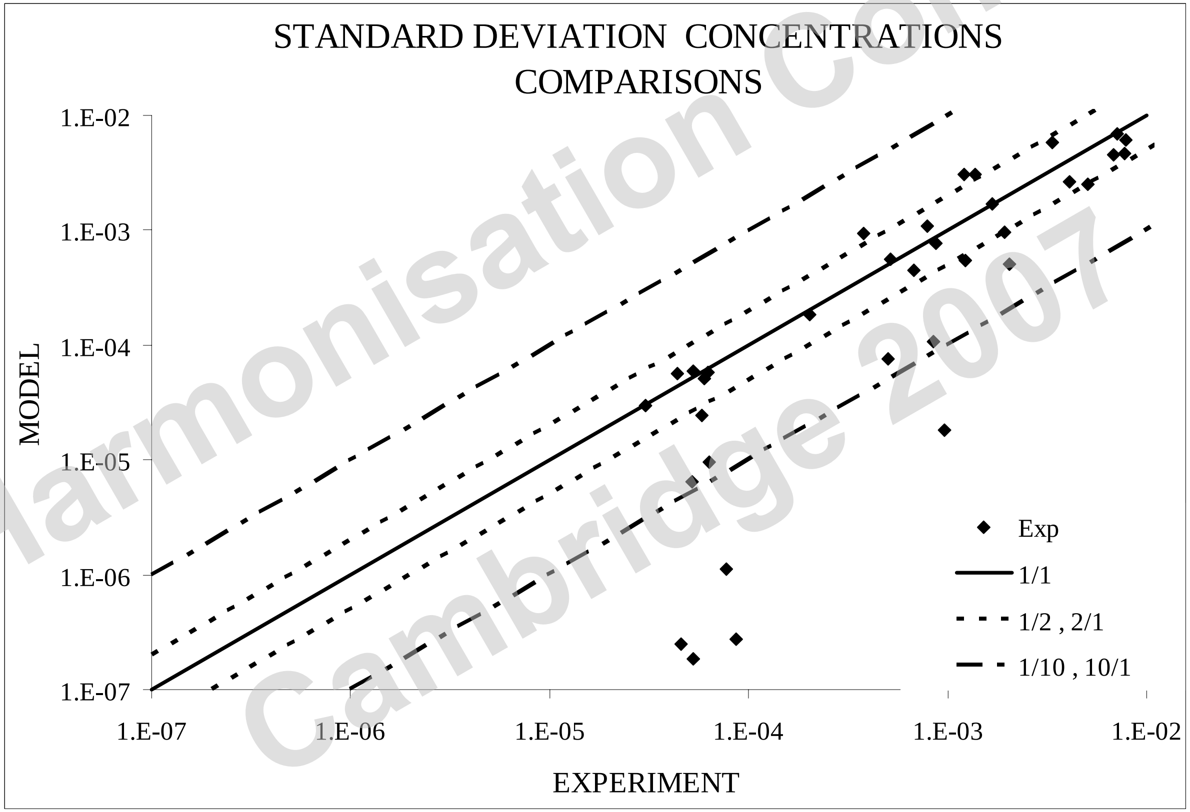
- **Turbulent time scale** :
  Taylor Hypothesis and correlation with the streamwise length scale as given by Bartzis(1990)

- **Inlet conditions and geostrophic wind**
  The corresponding 1-D boundary layer(Wind speed velocity
  . at 10m about 4.4m/s. Neutral conditions)

The results -I



The results -II



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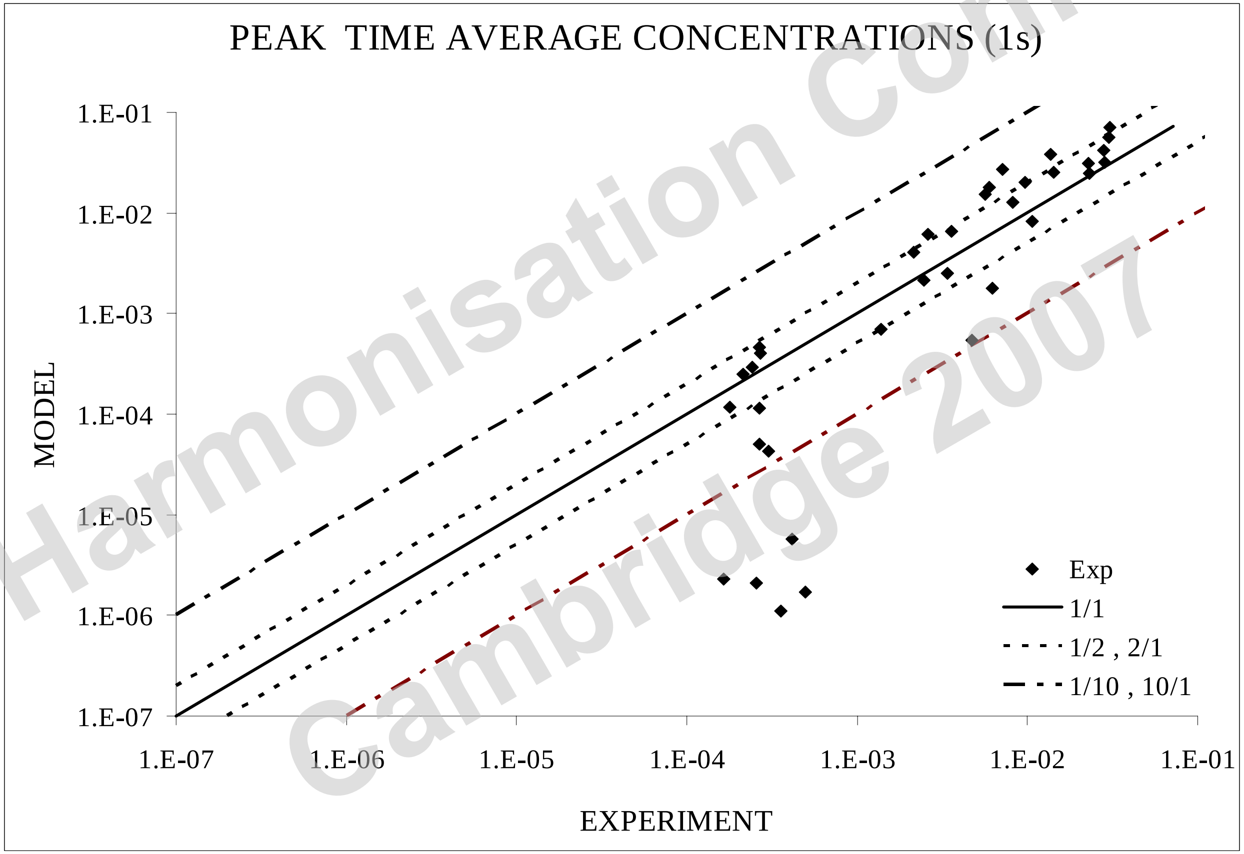
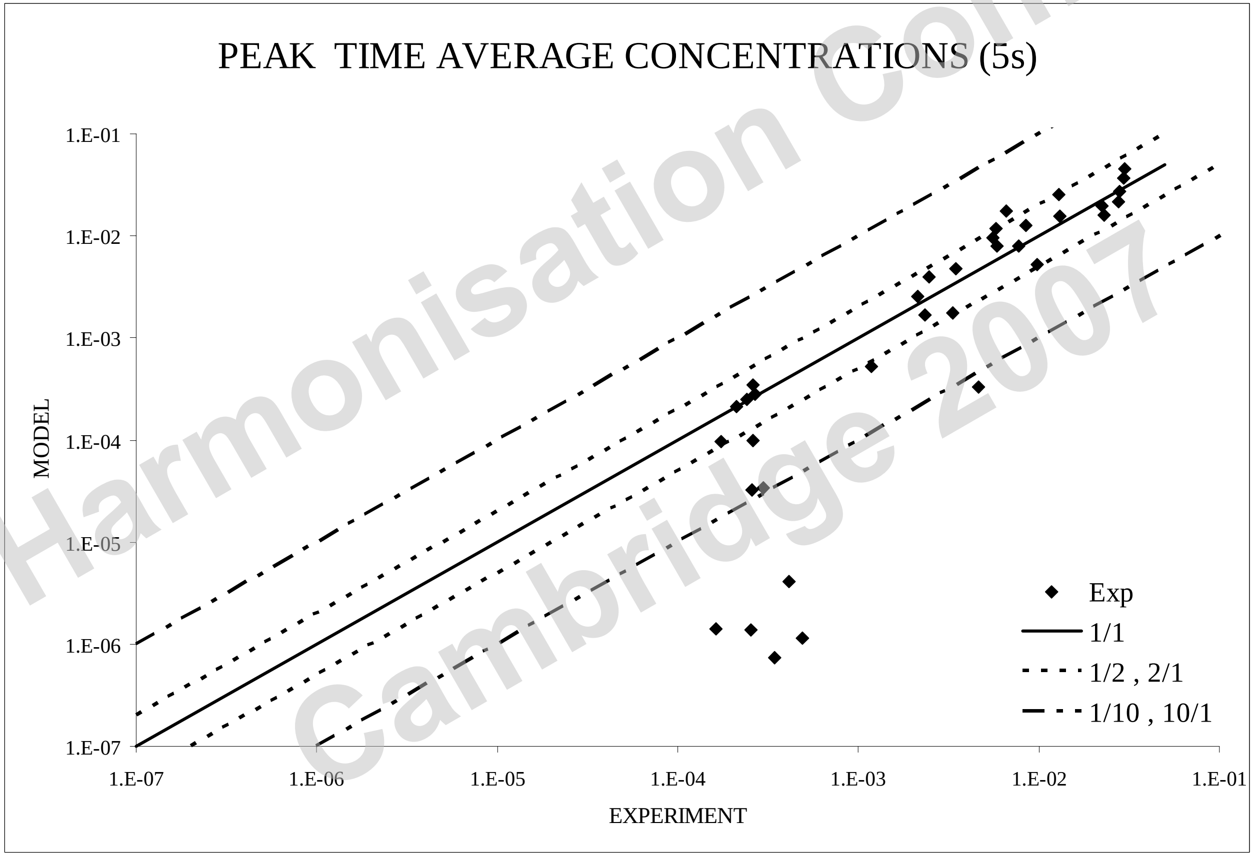
The Results - III



The results -IV



The Conclusions

- The present work represent the first attempt to estimate peak time averaged mean concentrations utilizing the RANS CFD models.
- The model results comparisons with the FLADIS T16 ammonia flashing release experiment are quite encouraging.
- The models will require in the future to be more refined in estimating concentration variance and turbulent integral scales.

The Final Conclusion

Question

Can RANS CFD Models ‘predict’ individual exposure over any exposure times (especially the short ones) ?

Answer

Yes . We need RANS CFD Models reliable in predicting mean concentration, concentration variance and turbulent time scales