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Envisaging a world with greener cities

Modelling of short range puff dispersion

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Motivation

- Funded by the ADMLC.
- Gaussian plume models provide very fast approximations of the average concentrations due to the dispersion of continuous releases.
- Have also been extended to model puff releases for simple cases.
- However these models are not designed for short time and length scale problems.
- Some assumptions made may not be valid at short time scales.

Objectives

- To review the strengths and limitations of Gaussian modelling for use at short time and length scales.
- Derive criteria defining the practical limits of applicability of Gaussian models at short time and length scales.
- To assess the performance of LES for modelling puff releases.

Methods

- Models used:
  - Wind tunnel
  - Fluidity
  - ADMS
- **Task 1: Neutral boundary layer, open terrain.**
- **Task 2: Single building downwind of a release under neutral boundary conditions.**
- **Task 3: Uncertainties and sensitivities under neutral boundary conditions.**
- Task 4: Stable and unstable boundary layer simulations.

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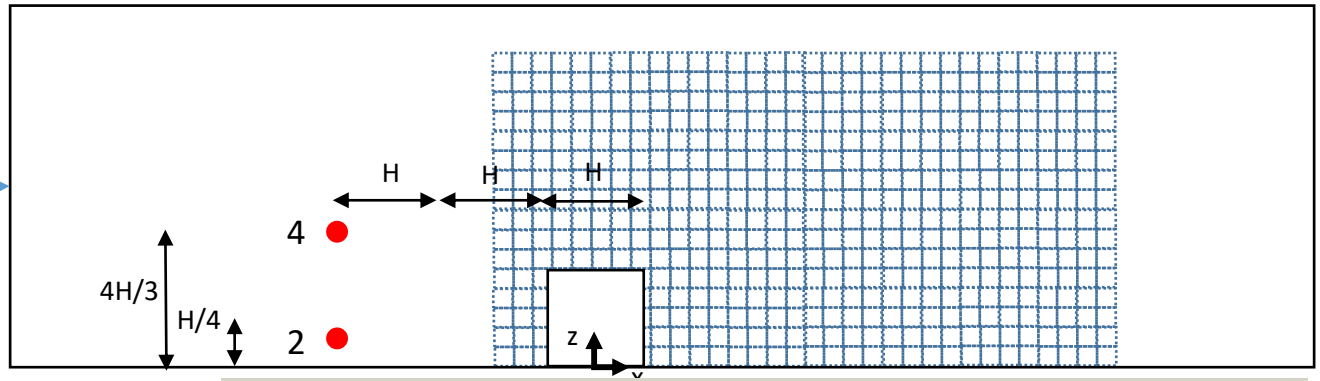
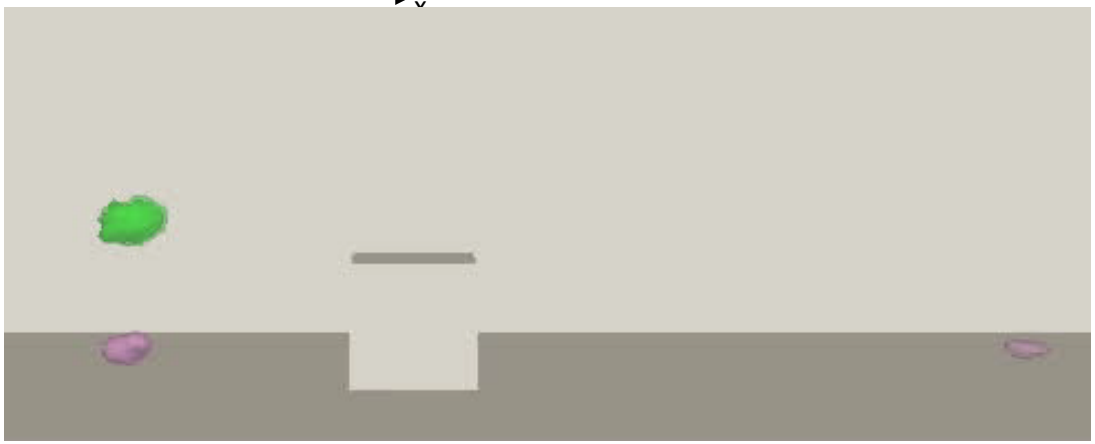
Single building downwind of a release

- Two release points used: R2 at Zs/H=1/4, R4 at Zs/H=4/3.
- Continuous releases and 60s puff releases.

U(z), uu(z), vv(z), ww,(z) Lu(z), Lv(z), Lw(z)



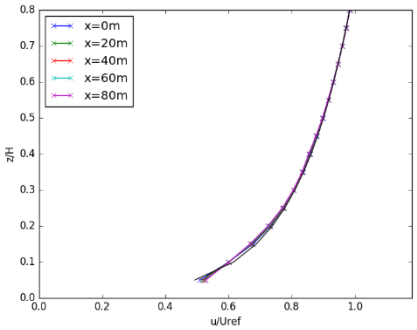
60 second release every 250 seconds.



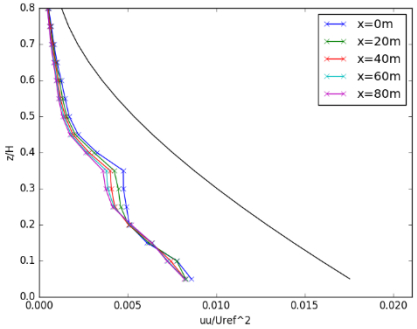
Flow profiles for empty domain

Task 1: Neutral boundary layer, open terrain.

U/Uref



uu/Uref^2



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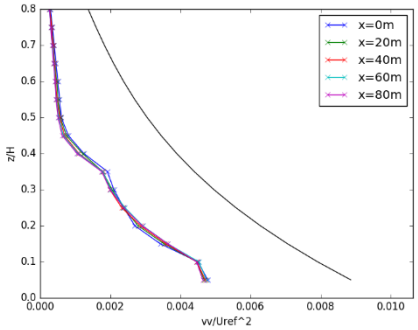
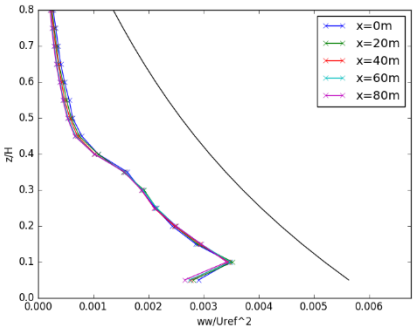


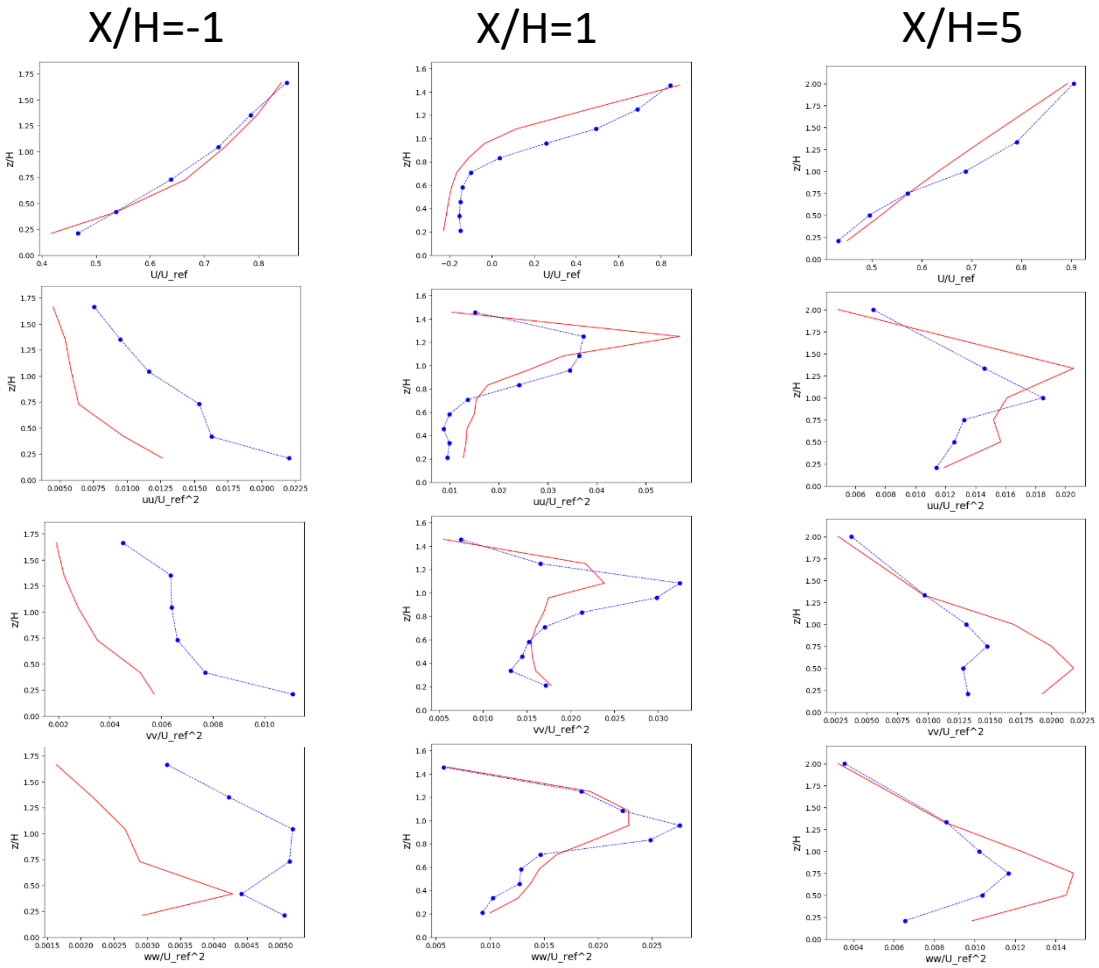
ww/Uref^2



	No. tracer fields	No. nodes	No. cores	Run time
Empty	3	1m	18	250 sec/day
Normal building	5	1.14m	24	276 sec/day
45deg building	5	1.15m	24	280 sec/day

Wind tunnel vs Fluidity flow around building

Task 2: Single building downwind of a release under neutral boundary conditions.



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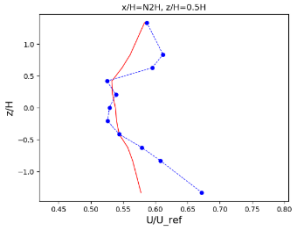
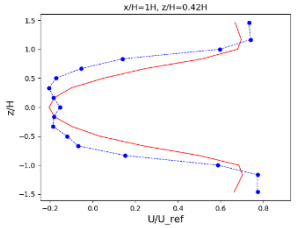
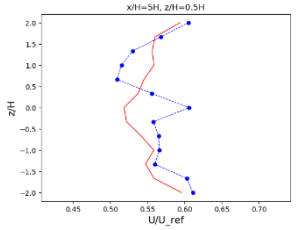
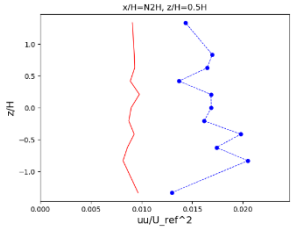
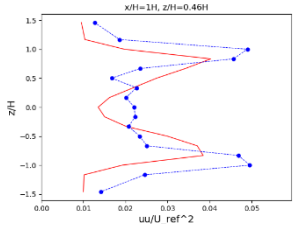
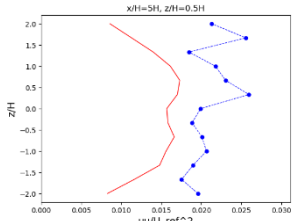
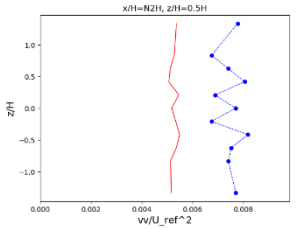
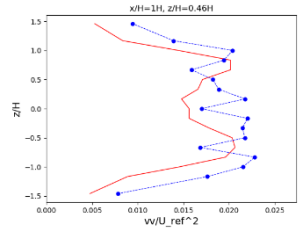
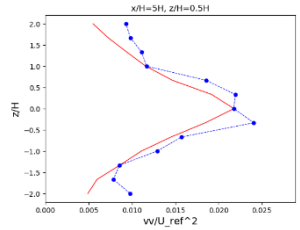
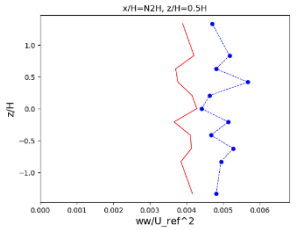
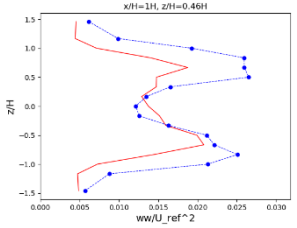
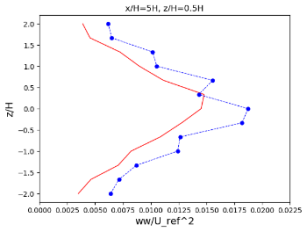
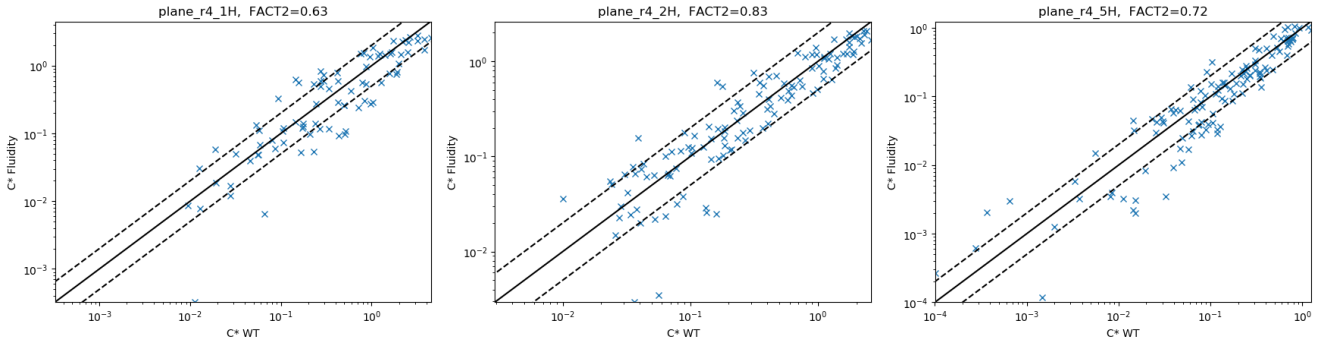
Wind tunnel vs Fluidity flow around building

Task 2: Single building downwind of a release under neutral boundary conditions.

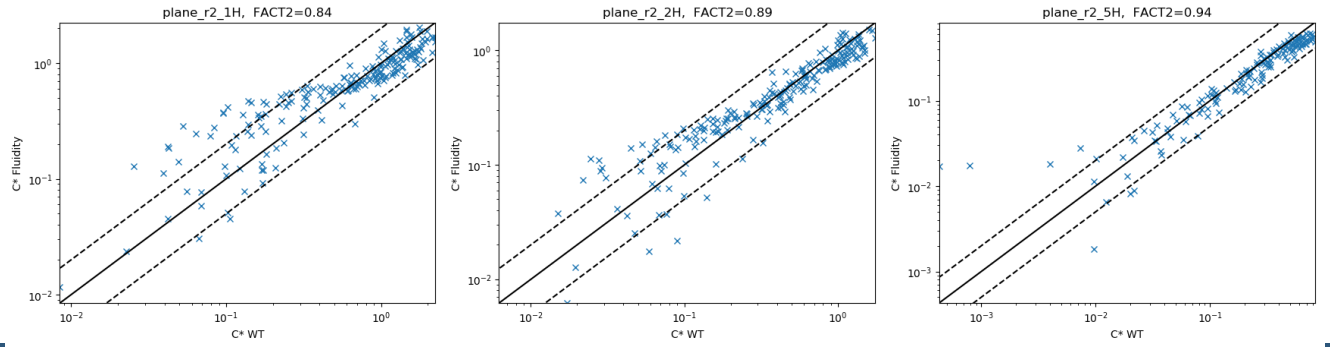
	X/H=-1	X/H=1	X/H=5
U/Uref			
uu/Uref^2			
vv/Uref^2			
ww/Uref^2			

WT vs Fluidity concentrations

- **Continuous release (plume).**
- Comparison of concentrations downwind of building (Zs/H=4/3)

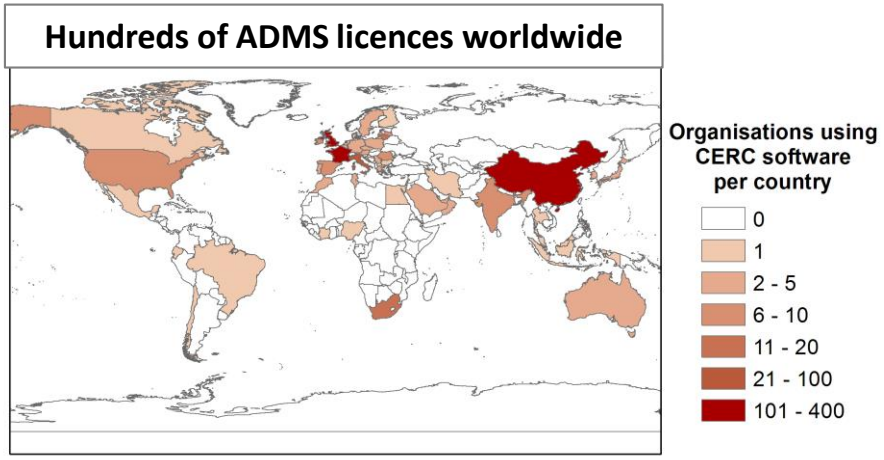


- Comparison of concentrations downwind of building (Zs/H=1/4)



ADMS 5

- ADMS 5 is a Gaussian type plume air dispersion model used to model the air quality impact of existing and proposed industrial installations
- Typical applications include:
  - Planning and permitting
  - Stack height assessment
  - Odour modelling
  - Environmental impact assessments
  - Safety planning



ADMS 5

- Generally used to calculate annual statistics (average, percentiles etc.) for comparison to Air Quality Limits and Guidelines

- Applicable to around 60 km downwind of the sources and provides useful information up to around 100 km

- Contains a number of modules to account for the different effects on dispersion

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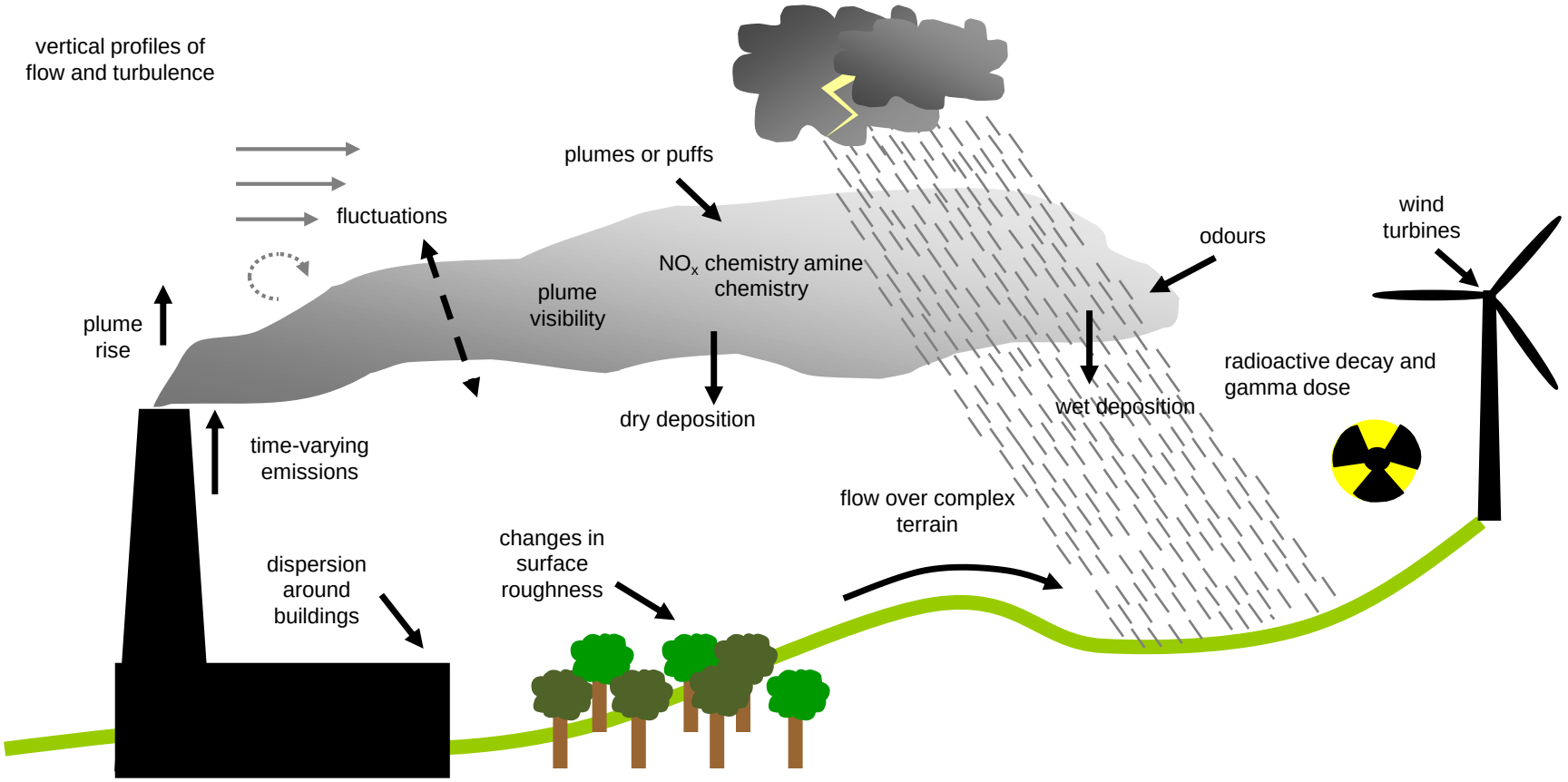
ADMS 5



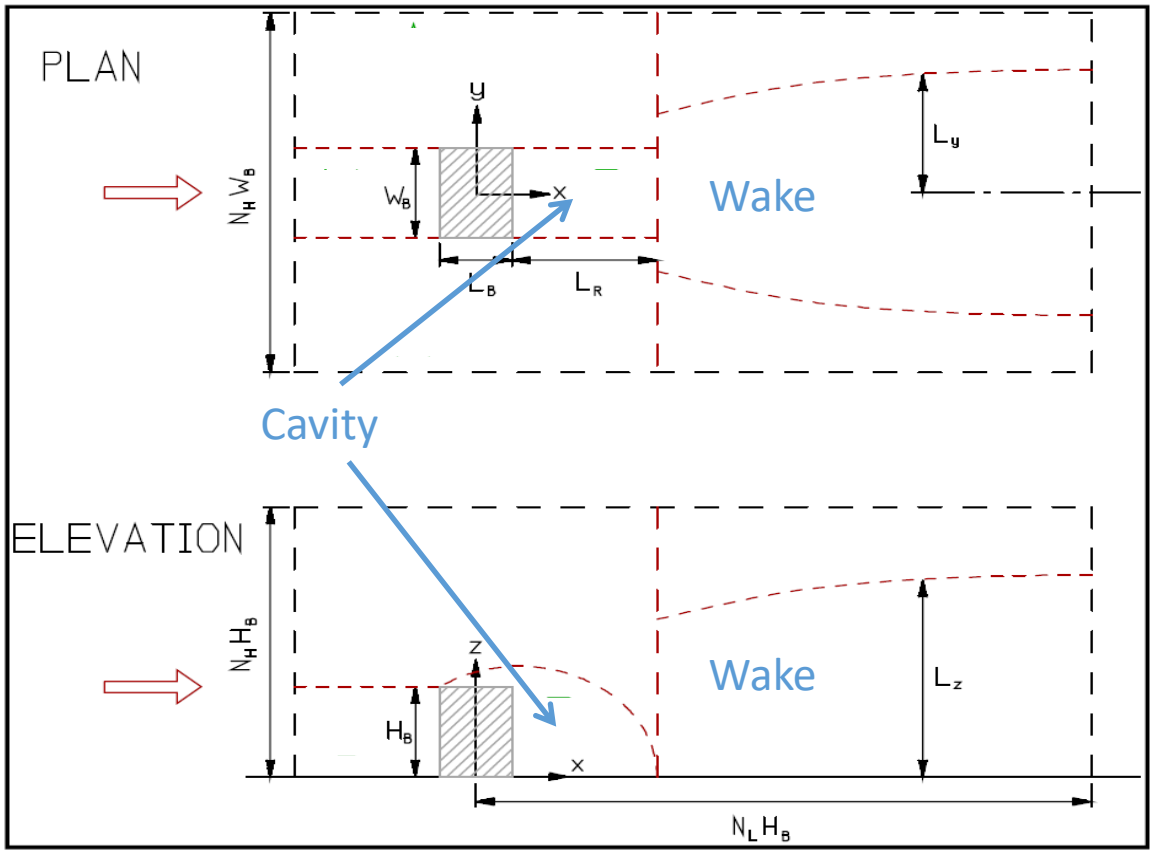
Buildings: Treatment in ADMS

- The buildings effects module is activated if a source lies within the building effects region

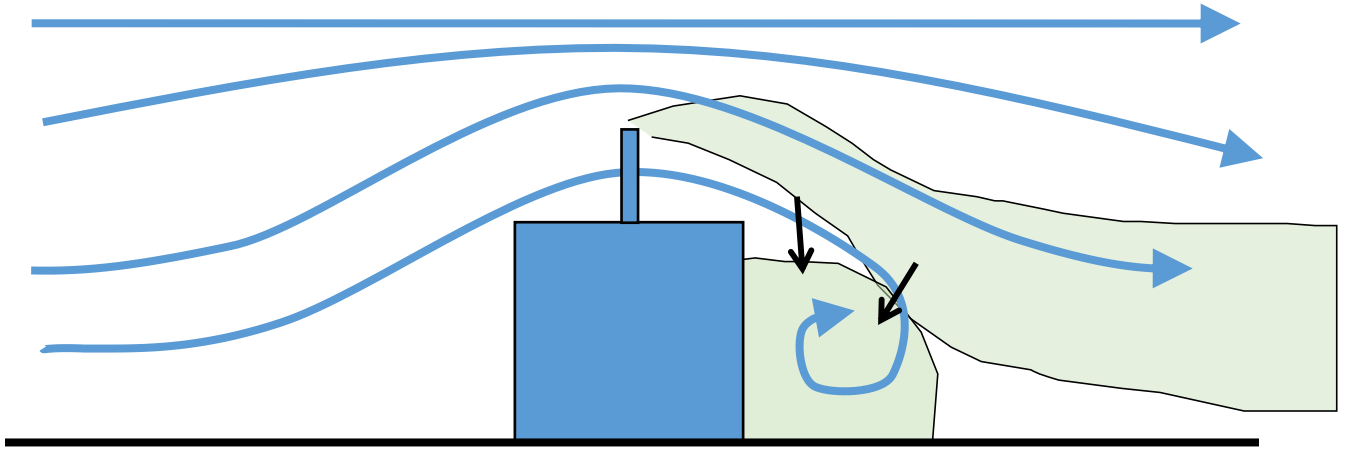
- The extent of this region depends on
  - the building dimensions
  - the source location
  - met conditions

- The main features are a recirculation region (cavity) and a turbulent wake region

Buildings: Effects region



Buildings: Effects on dispersion

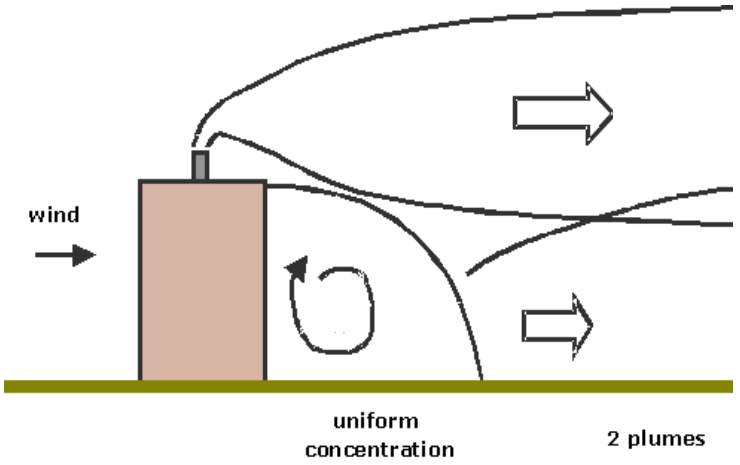


- Deflect wind flow and therefore the route followed by dispersing material
- This deflection increases levels of turbulence, often enhancing dispersion
- Material can be entrained in the recirculating flow region

Buildings: Dispersion

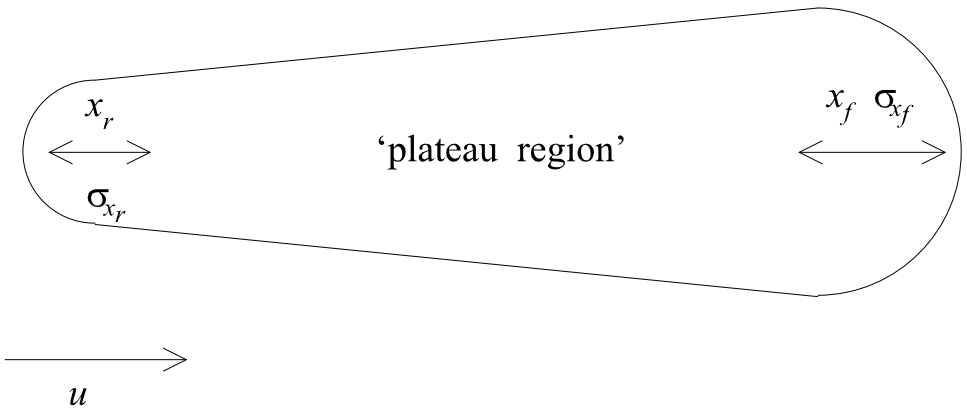
- Recirculation region concentrations assumed to be uniform
  - Based on size of region and the fraction of the release entrained
- Two-plume concentration further downwind
  - Ground level plume from recirculation region
  - Elevated plume for non-entrained material

- Turbulent wake – increases plume spread



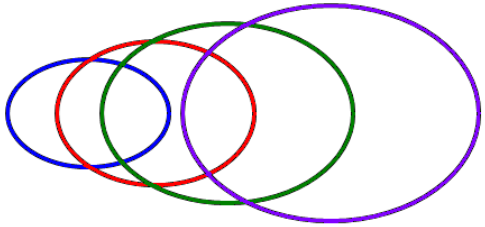
Puffs

- Puffs module for calculating concentrations due to finite release
- Puffs in ADMS 5 assume steady met conditions but release has finite duration
- Concentration depends on time since release and puff has a defined front and rear

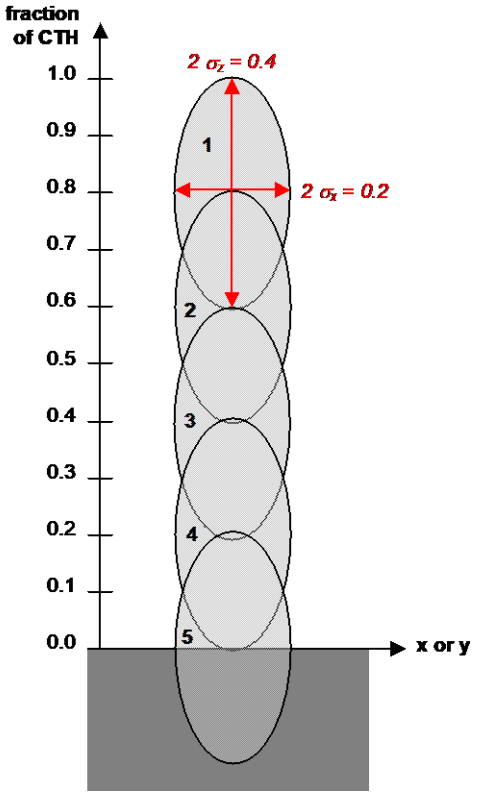


ADMS-STAR

- ADMS-STAR is a Lagrangian puff model for accidental releases
- Models finite and explosive releases
- Finite releases modelled as a sequence of puffs
- Explosive releases modelled as a set of 5 puffs stacked vertically
- Incorporates temporally and spatially varying meteorology

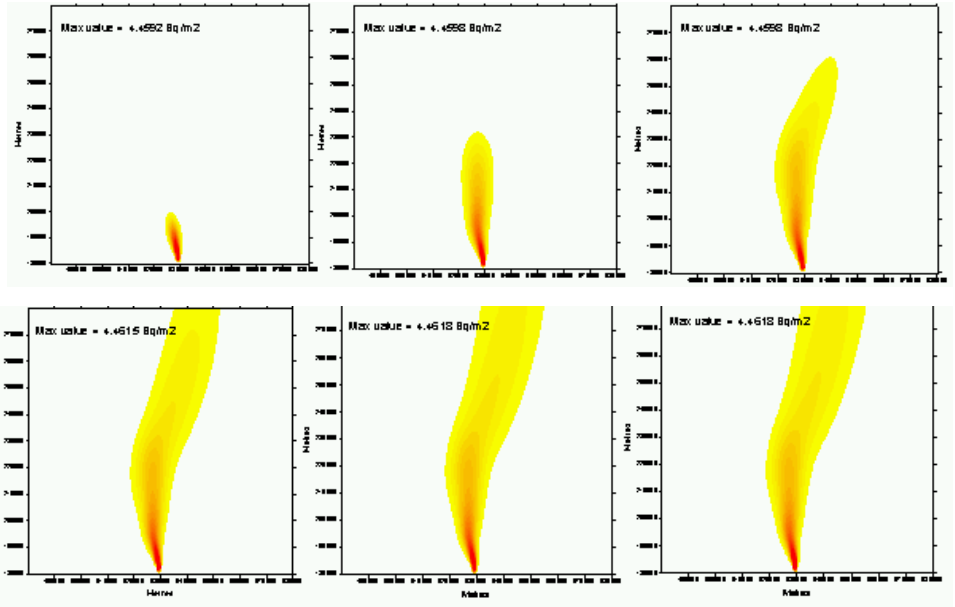


Part of a continuous release

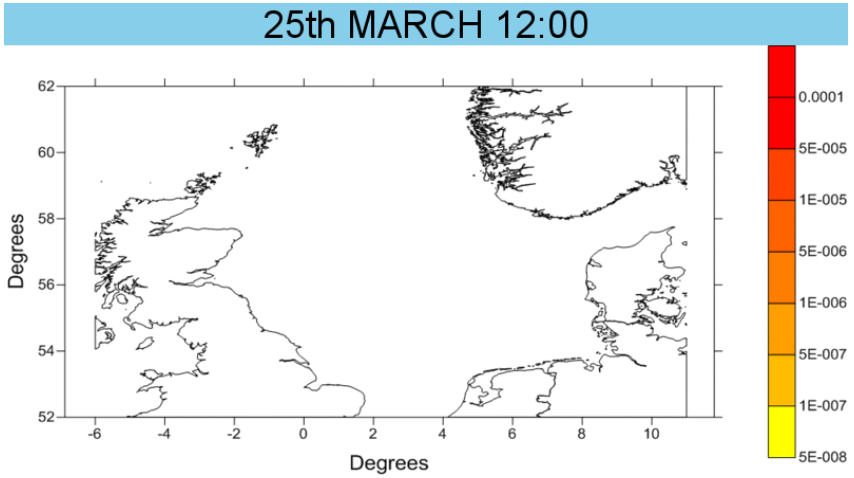


Initial stage of explosive release

ADMS-STAR



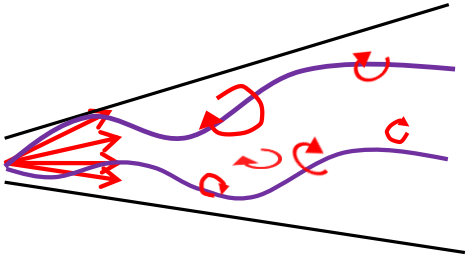
Deposition over a series of hours for a short duration release

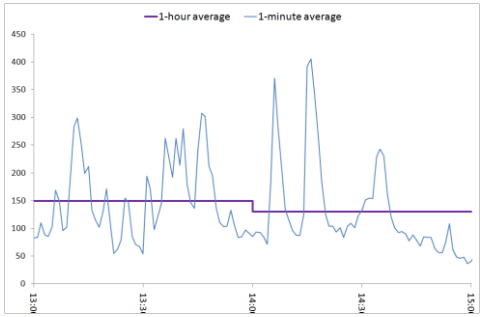


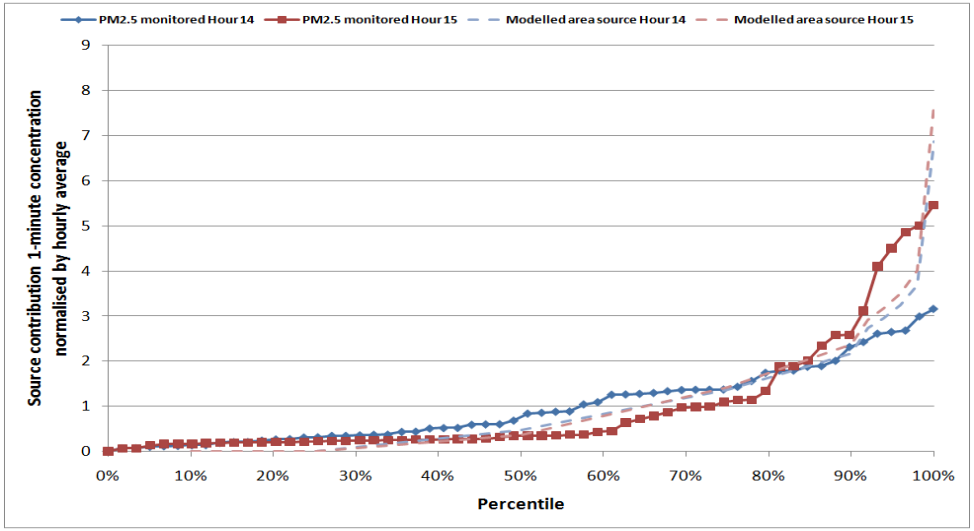
Concentration over a series of days – continuous release

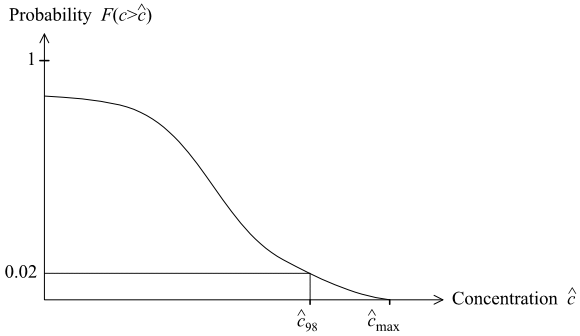
Fluctuations

- Fluctuations module produces statistics of fluctuations in concentration for short time periods.
- Accounts for both turbulence and changes in wind direction
- Calculates a probability distribution of concentration



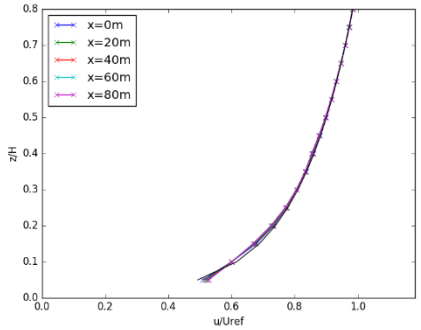


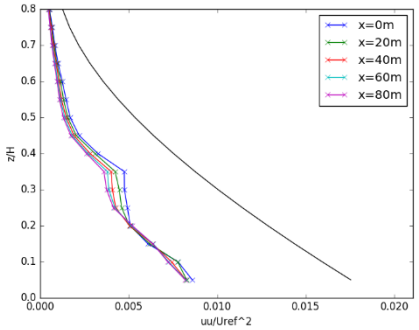


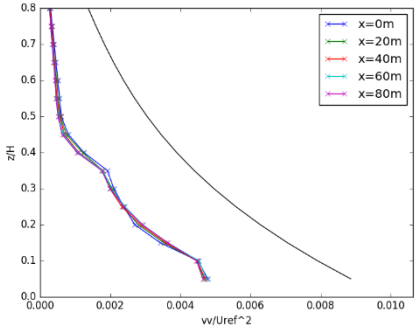


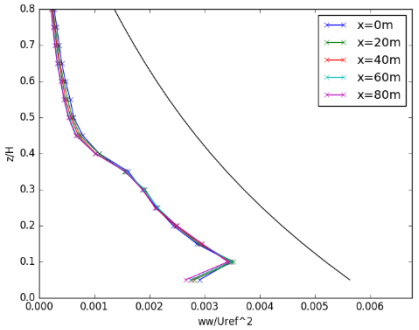
Flow profiles

Fluidity

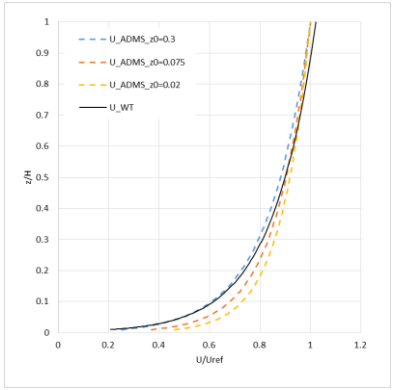


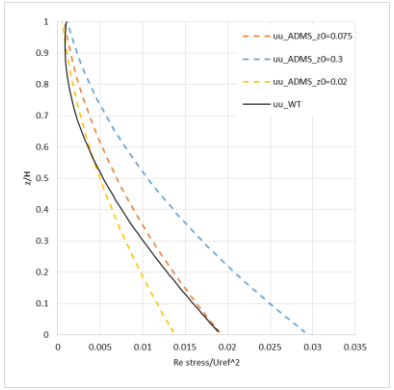


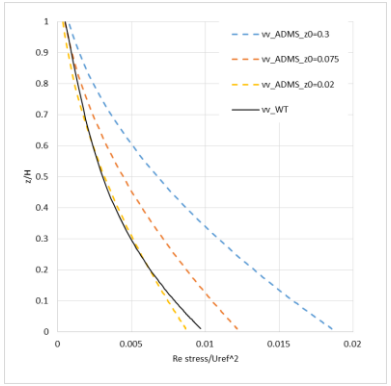


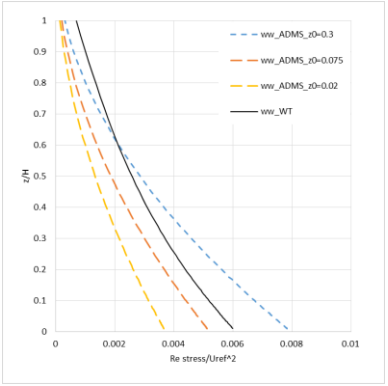


ADMS





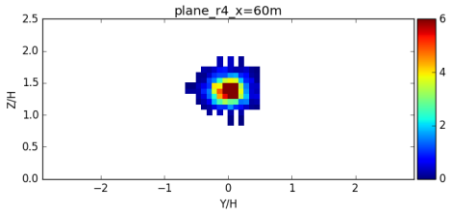




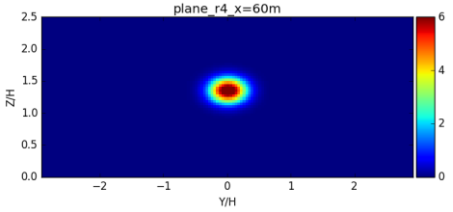
No building

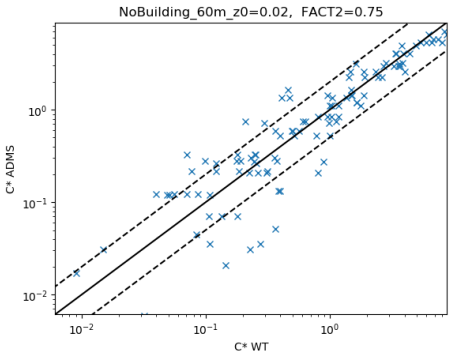
- Open terrain (no building), continuous source at height Z/H=4/3 (32m at full scale)

Wind tunnel

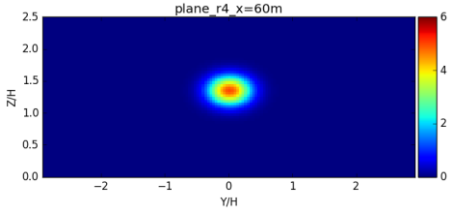


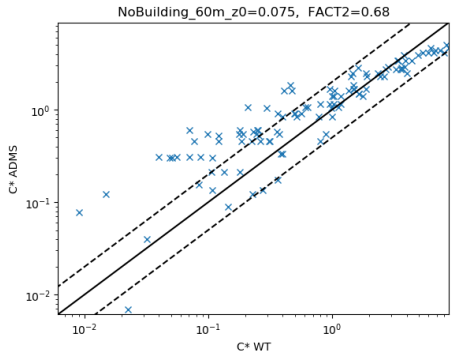
ADMS z0 = 0.02m



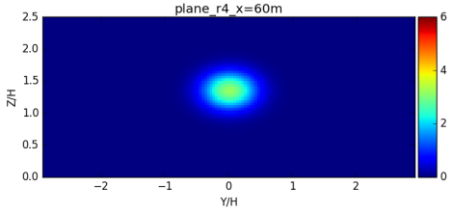


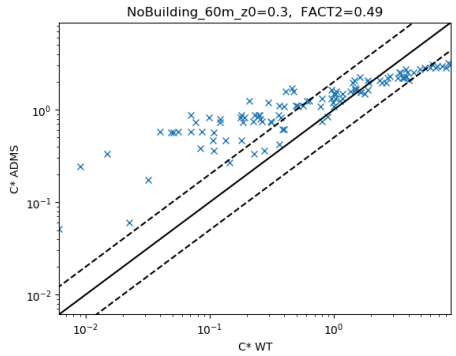
ADMS z0 = 0.075m





ADMS z0 = 0.3m





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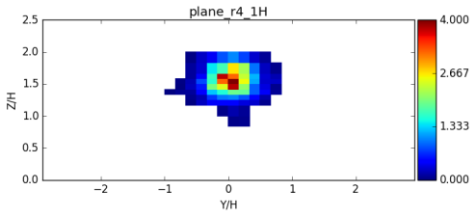
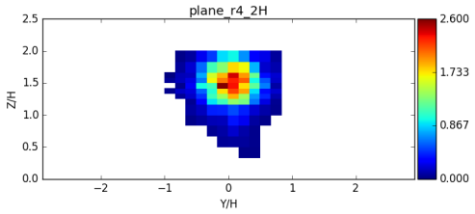
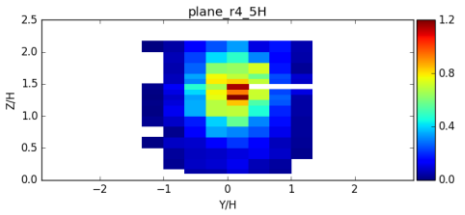
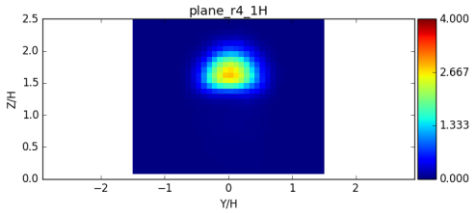
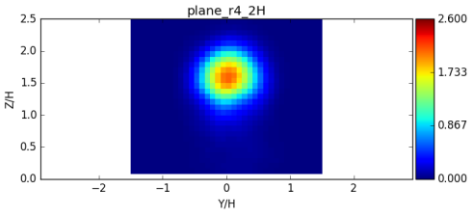
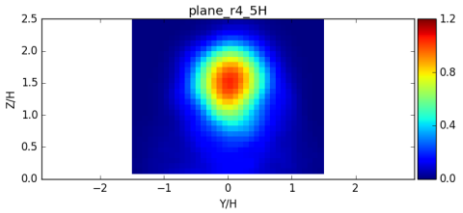
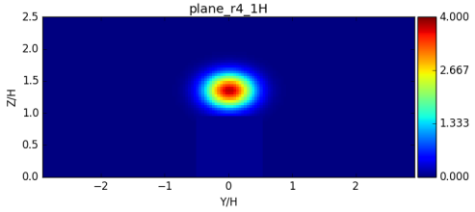
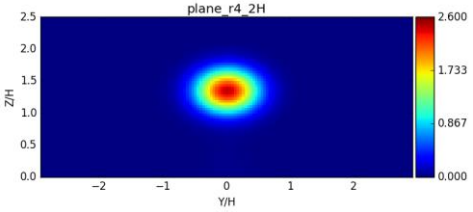
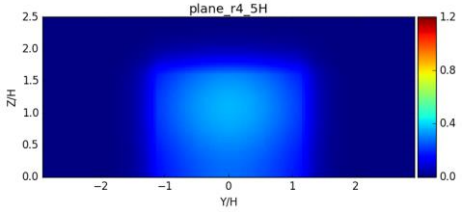
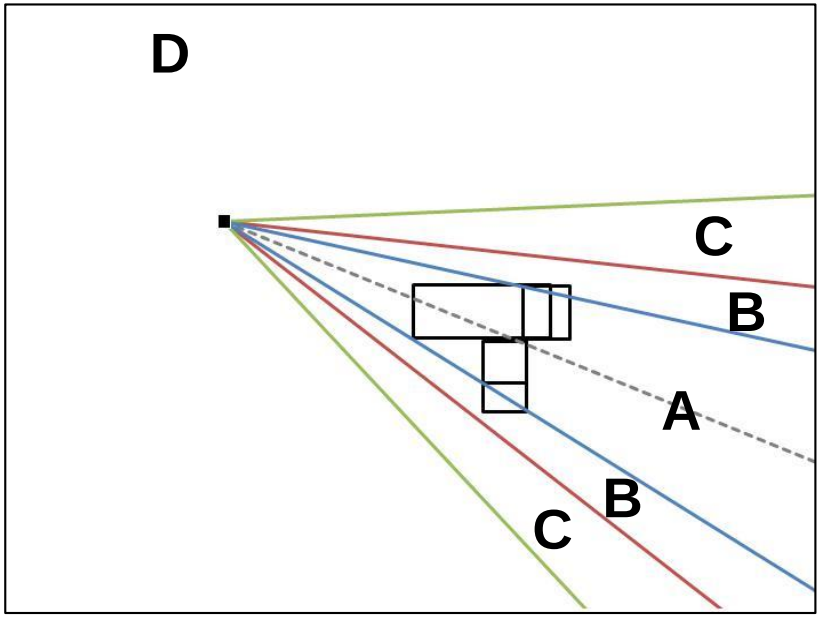
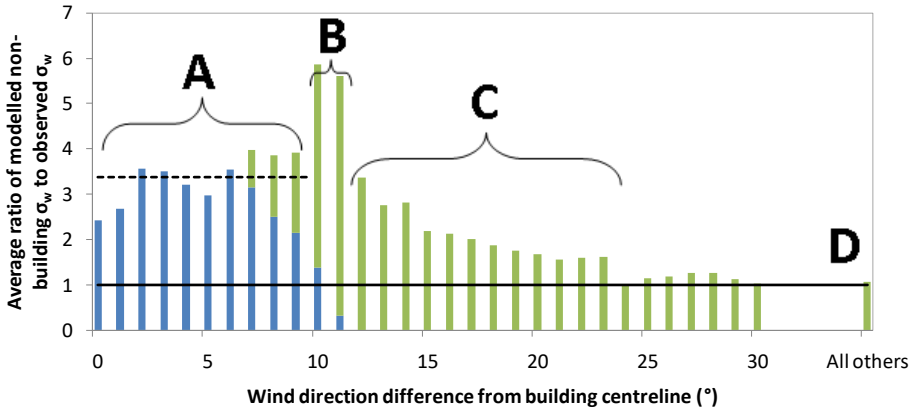
Concentrations downwind of normal facing building (Zs/H=4/3)

	X/H=1	X/H=2	X/H=5
Wind tunnel			
Fluidity			
ADMS			

Real world turbulence values near a building



A. ADMS models building-induced turbulence for the majority of wind directions
B. The measurements show a significant increase in turbulence, not modelled by ADMS
C. The turbulence decays away from an elevated value due to the presence of the buildings down to ambient values, not modelled by ADMS
D. Ambient values of turbulence



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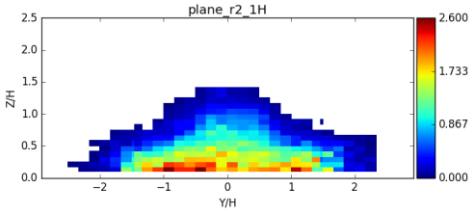
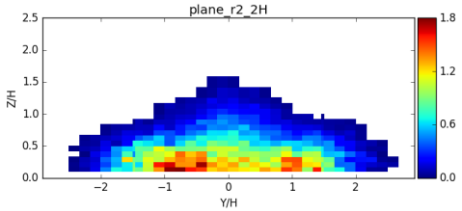
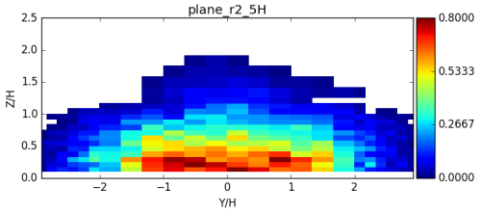
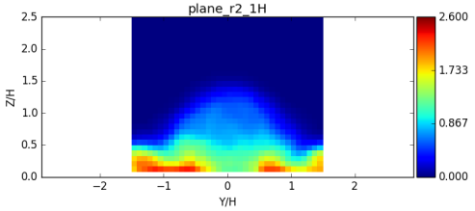
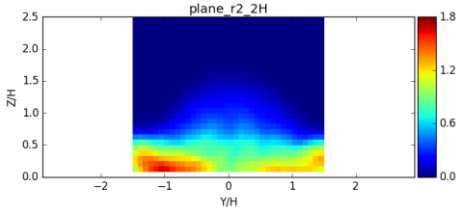
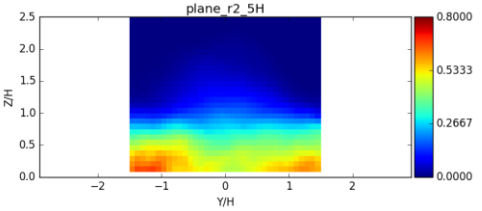
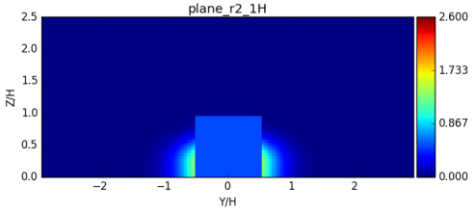
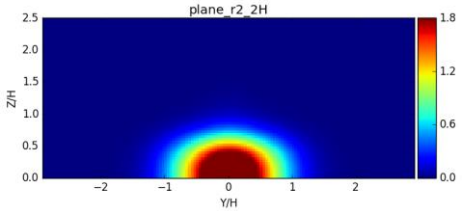
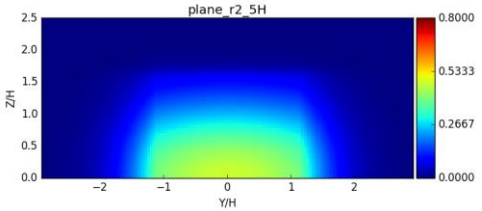
Concentrations downwind of normal facing building (Zs/H=1/4)

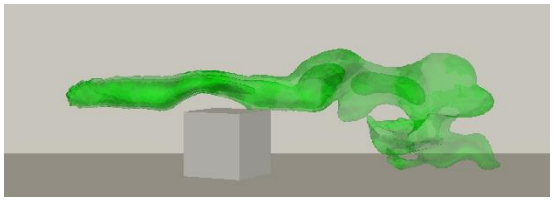
	X/H=1	X/H=2	X/H=5
Wind tunnel			
Fluidity			
ADMS			

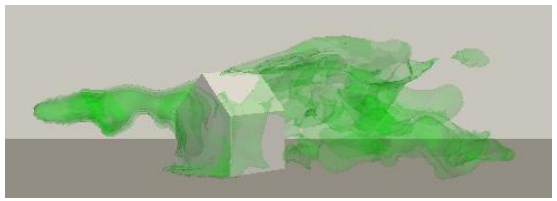
Task 3: Uncertainties and sensitivities

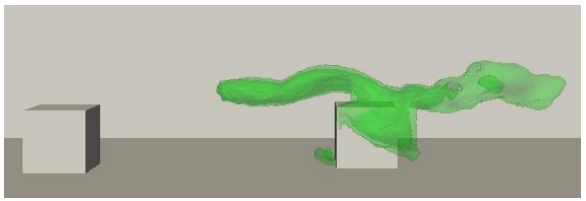
Building at 30deg

Building at 45deg with pitched roof

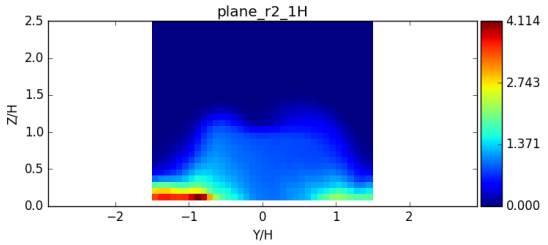
Upwind building at X/H=-5, Y/H=1/2

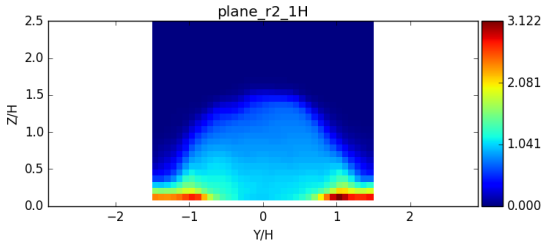


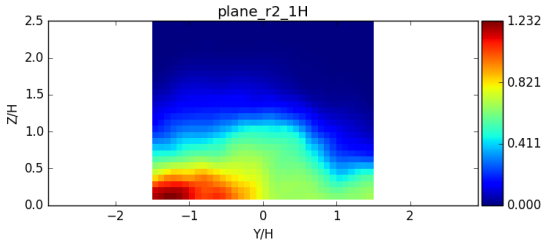




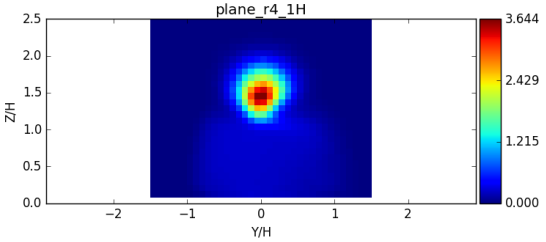
Zs/H=1/4

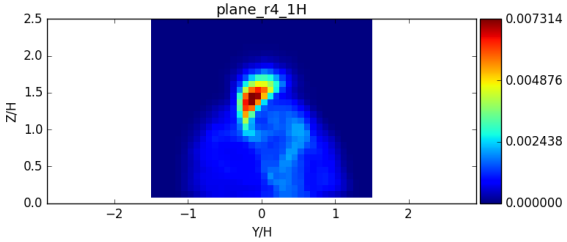


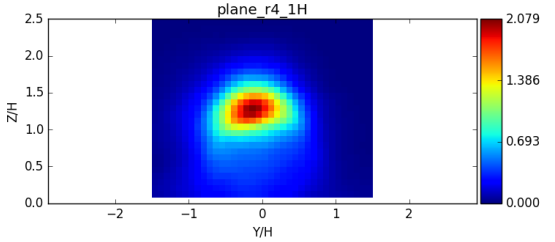




Zs/H=4/3



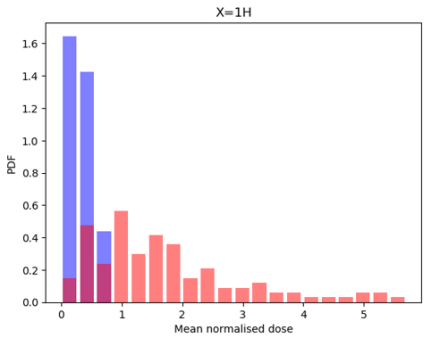




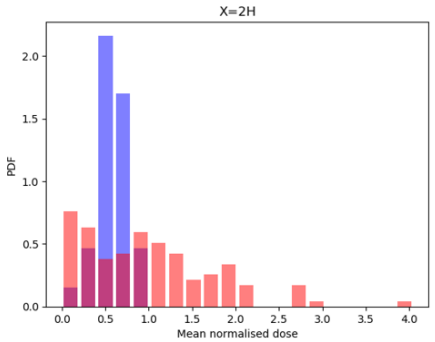
Puff releases - PDFs

- 60 second (at full scale) puff releases at Zs/H=4/3.
  - Fluidity: ~30 puffs.
  - Wind tunnel: 150-200 puffs.
- Fluidity did not capture the variation in doses seen in the wind tunnel.

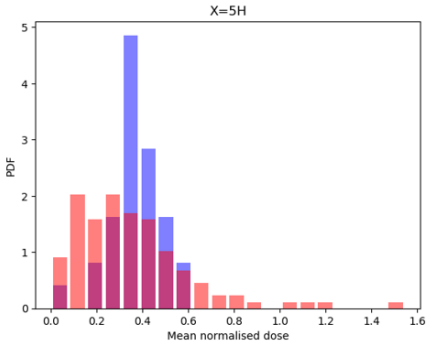
X/H=1



X/H=2



X/H=5



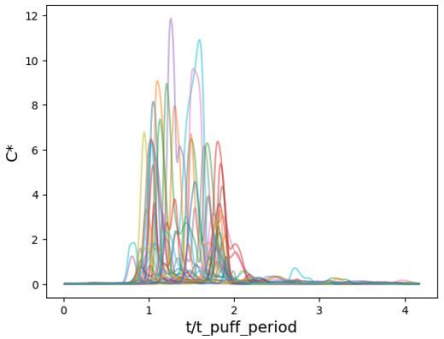
Puff releases – time series

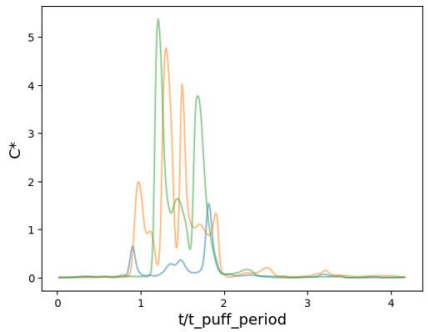
- Fluidity "smooths" the puff concentrations.
- Leads to lower maximum concentrations and smaller range in puff dose.

- Fix:
  - refine the mesh!
  - Or use mesh adaptivity?

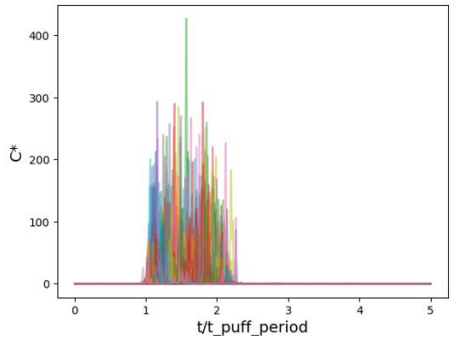
Time series of concentrations at X/H=1H, release height Zs/H=4/3

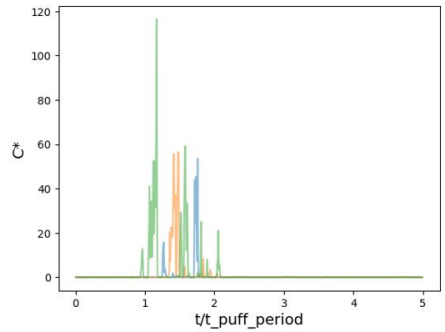
Fluidity





Wind tunnel





Puff releases - statistics

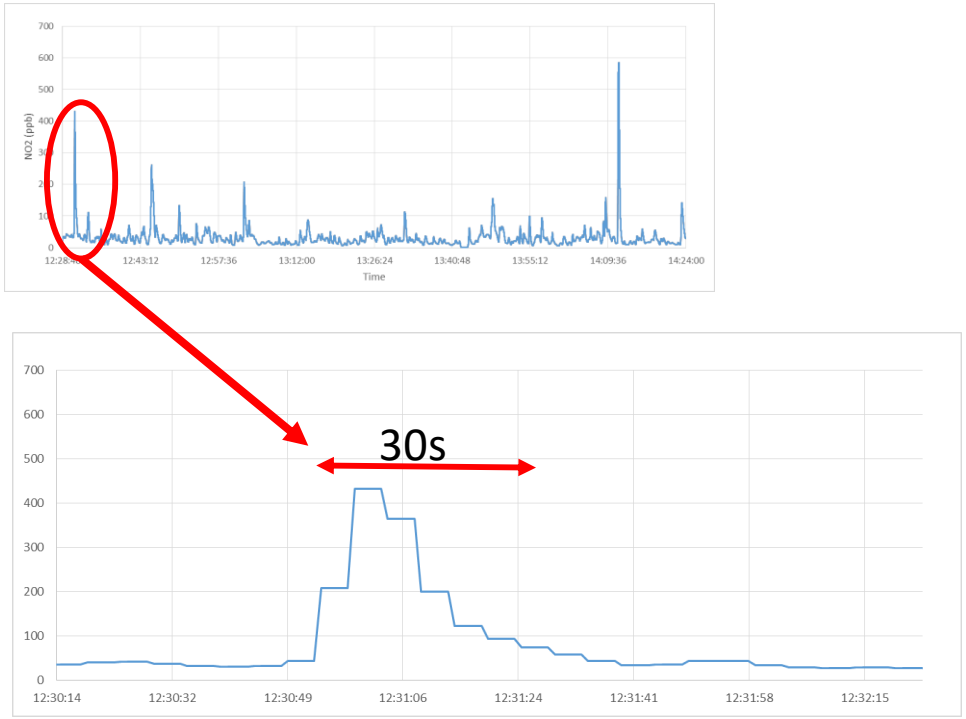
- Fluidity currently under predicts the standard deviation of puff dose.
- Agreement is somewhat better for mean dose.
- Agreement between the two models improves with distance downwind.
- Wind tunnel results may indicate linear relationship between mean dose and standard deviation.

	Fluidity			Wind tunnel		
Location	**1H**	**2H**	**5H**	**1H**	**2H**	**5H**
Mean dose	0.19	0.35	0.22	0.85	0.5	0.17
Dose Std. Dev	0.12	0.11	0.07	0.62	0.38	0.13
Dose CV	0.62	0.32	0.3	**0.73**	**0.76**	**0.75**
5th %/mean	0.21	0.57	0.59	0.19	0.06	0.12
95th %/mean	2.21	1.49	1.41	**2.56**	**2.24**	**2.29**

Roadside peak concentrations

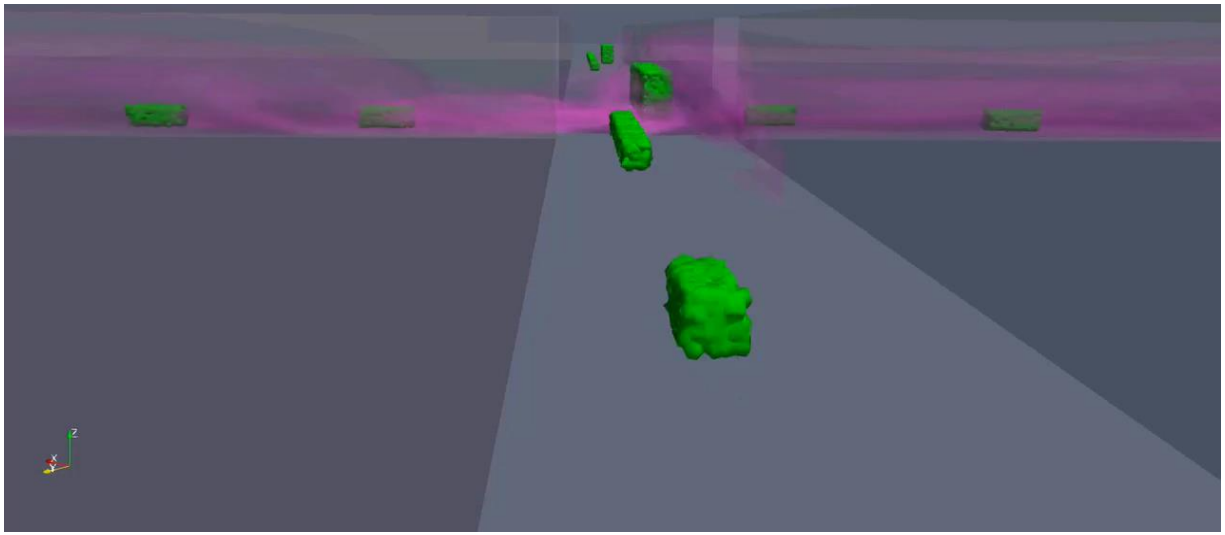
- What time scales are relevant for exposure analysis?

Roadside NO2 measurements at 1s time resolution.



ADMS Urban and Fluidity's traffic model

- For urban scenarios ADMS-Urban would be used.
- Can we use Fluidity to improve some of the parameterizations used for the street canyon model.



Next steps

- Can we make use of Fluidity's mesh adaptivity to improve modelling of puff releases?
- Is it possible to extend the ADMS fluctuations and puff modules to cases with buildings?
- What is the limit of applicability of Gaussian plume models in terms of time scale?
- Modelling unstable and stable boundary layers.

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Thank you.
Any questions?