Evaluation of wind field and dispersion models in the presence of complex terrain

14th Harmo Conference

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Outline

- Context
- Presentation of the tested models
- Presentation of the methodology of evaluation
- Evaluation of wind flow models
- Evaluation of dispersion models
- Conclusion

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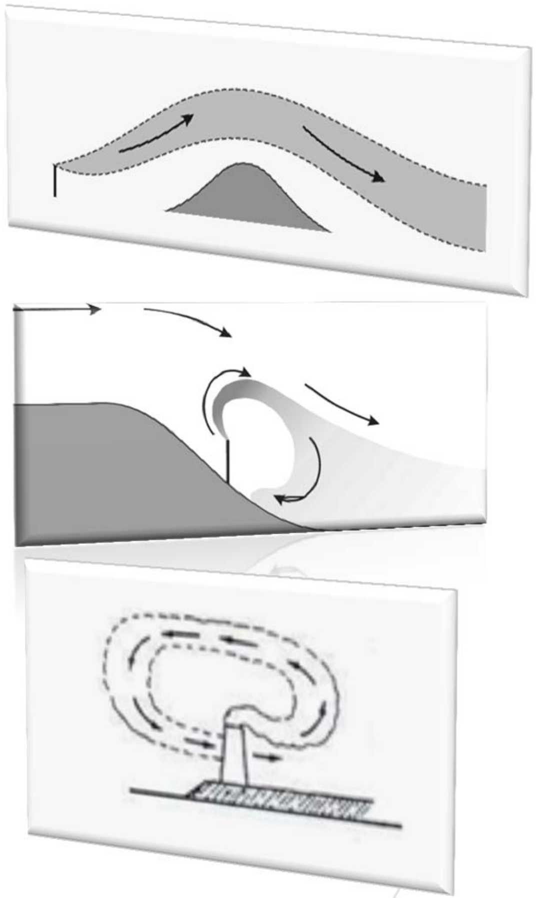
Context

Motivation:

- Importance of correct wind flow modeling in the presence of **complex terrain** for **local scale dispersion (1-10km)**

Objectives:

- Evaluate wind flow models and study their limitations in complex terrain
- Evaluate dispersion models
- Test each wind flow/dispersion coupling approach



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Tested models

Wind flow models

- **Fluent:** well-known CFD code, with a RANS k-ε turbulence model with Duynkerke constants
- **Flowstar:** linearized analytical model based on the theory of Jackson and Hunt (1975) and Hunt *et al.* (1988)

Dispersion models

- **SLAM:** a Lagrangian dispersion model developed at the Ecole Centrale de Lyon (recently validated by Vendel *et al.* , 2011)
- **ADMS:** well-known Gaussian plume model, with possibility of use of a complex terrain flow model using Flowstar

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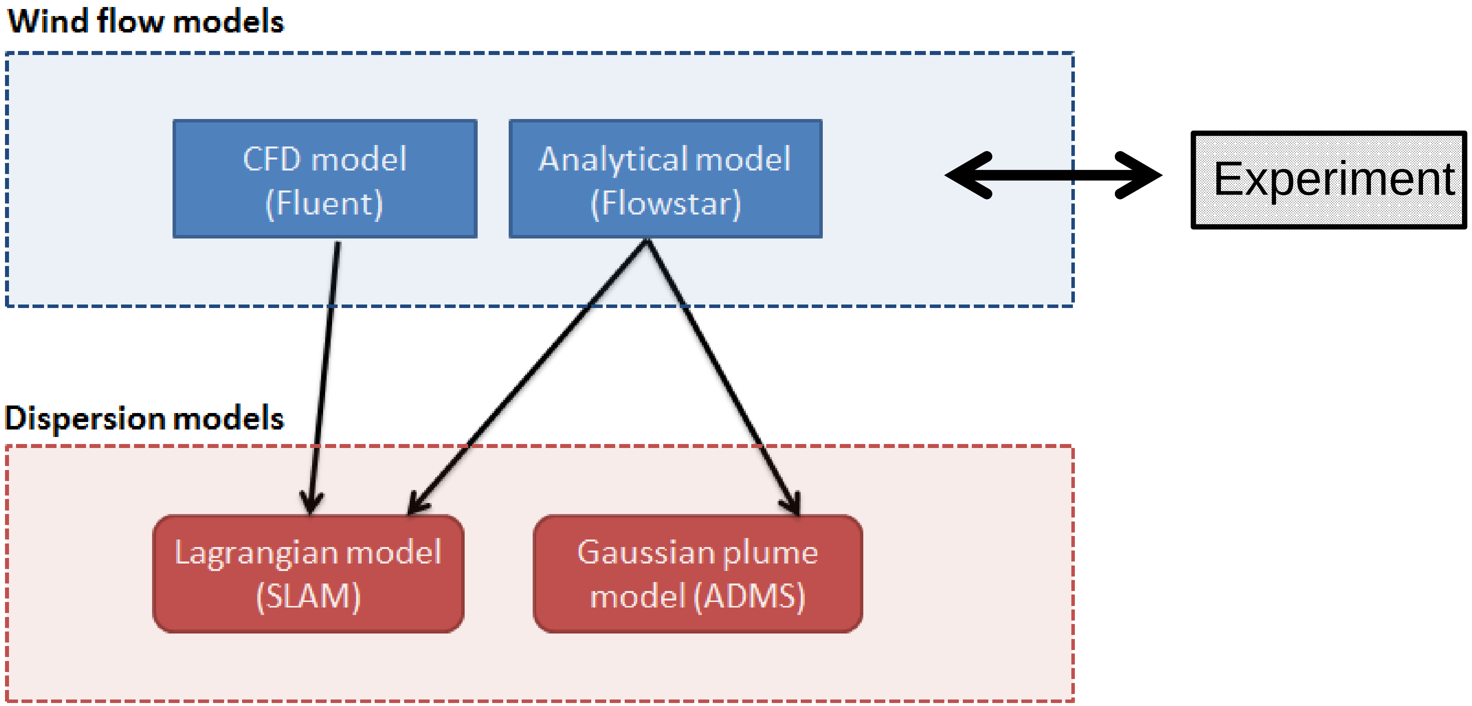
Methodology

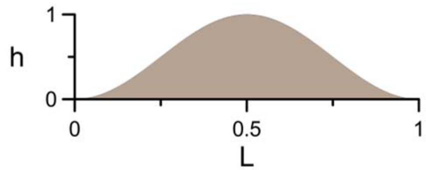


- Comparison of the wind flow models with wind tunnel experiments in the presence of hills and valleys of different steepness and roughness

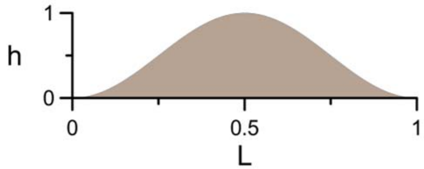
Description of the experiments

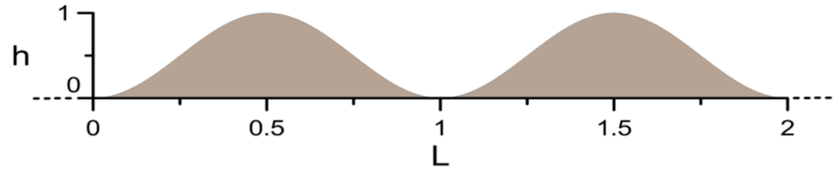
Wind tunnel experiments in neutral atmospheric conditions:

- **EPA RUSHIL experiment (Khurshudyan et al. , 1981):** three 2D hills with various ratios of h/L



- **Almeida et al. (1992) experiment** : isolated or several consecutive 2D steep hills -> valleys





Hill	h (m)	L (m)	h/L	u_* (m/s)	u_∞(m/s)	z_0 (m)
RUSHIL H8	117	1872	**0.0625**	0.178	4	0.157
RUSHIL H5	117	1170	**0.1**	0.178	4	0.157
RUSHIL H3	117	702	**0.166**	0.178	4	0.157
Almeida	280	1080	**0.259**	0.079	2.147	0.015

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Parametrisation of the wind flow models

- Specified roughness length **for both models**

- Theoretical wind profile in neutral boundary layers as input **for both models:**

$$u(z) = \frac{u_*}{\kappa} ln\left(\frac{z}{z_0}\right)$$

- Theoretical turbulent kinetic energy and dissipation rate profiles **for the CFD code Fluent** (k-ε model)

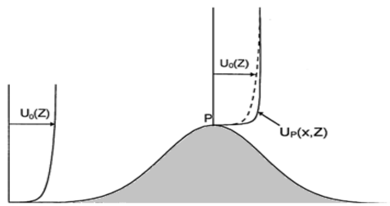
$$k(z) = \frac{u_*^2}{\sqrt{C_\mu}} \qquad \text{with } C_\mu = 0{,}033$$

$$\varepsilon(z) = \frac{u_*^3}{\kappa z}$$

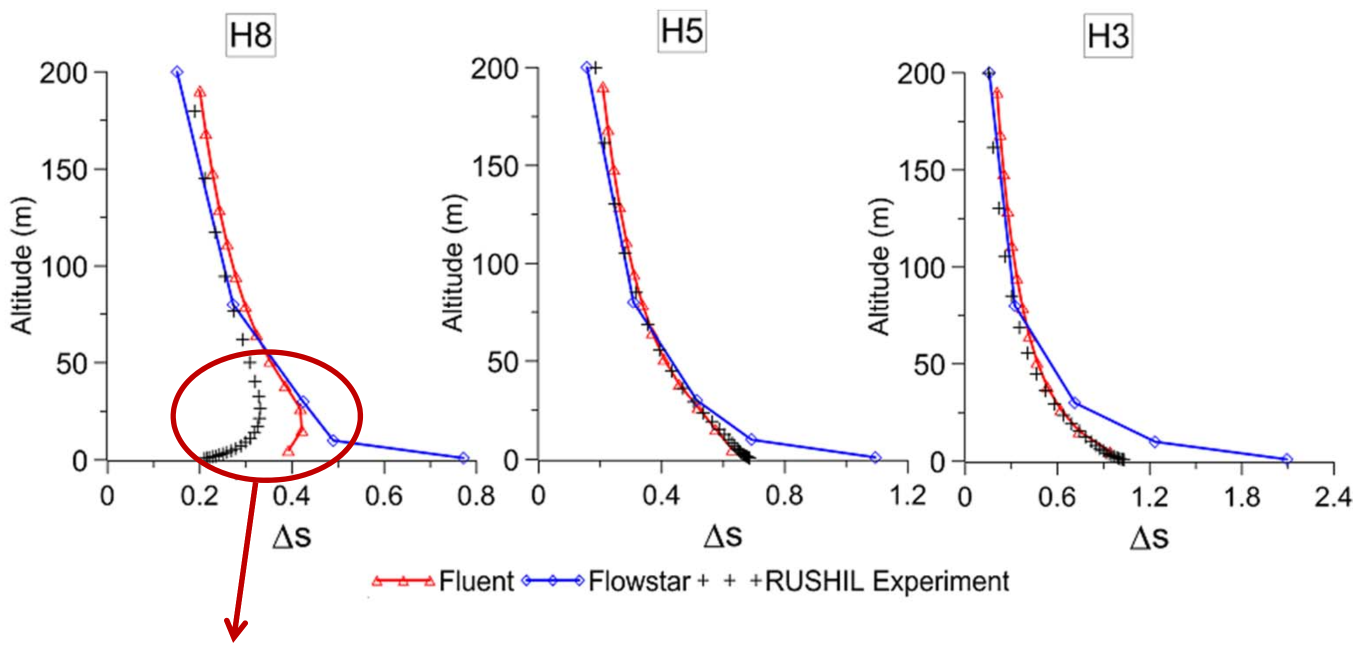
Wind flow results (RUSHIL experiment)

Comparison in terms of **speed-up** (relative acceleration):

$$\Delta S = \frac{u_p(z) - u_0(z)}{u_0(z)}$$



- H8 (h/L=0,06)
- H5 (h/L=0,1)
- H3 (h/L=0,17)

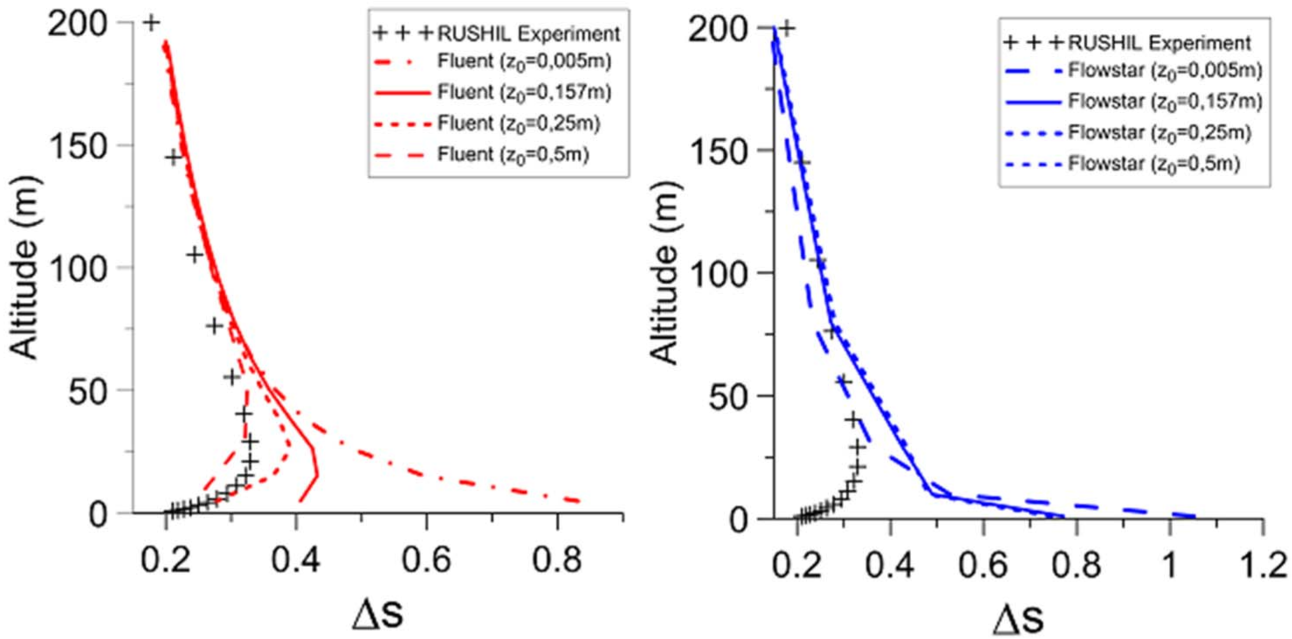


➢ Roughness effect not well captured by Flowstar

Wind flow results (RUSHIL experiment)

Sensitivity test to the roughness length z_0 for hill H8 (h/L=0.06):

- h/L=0,06

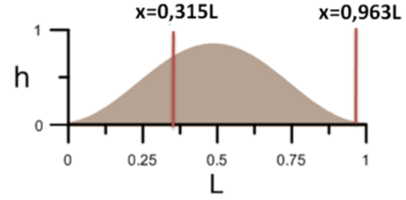


- Considerable differences between the two models with increased roughness length
- No sensitivity to the value of z_0 when z_0>0,157m with Flowstar

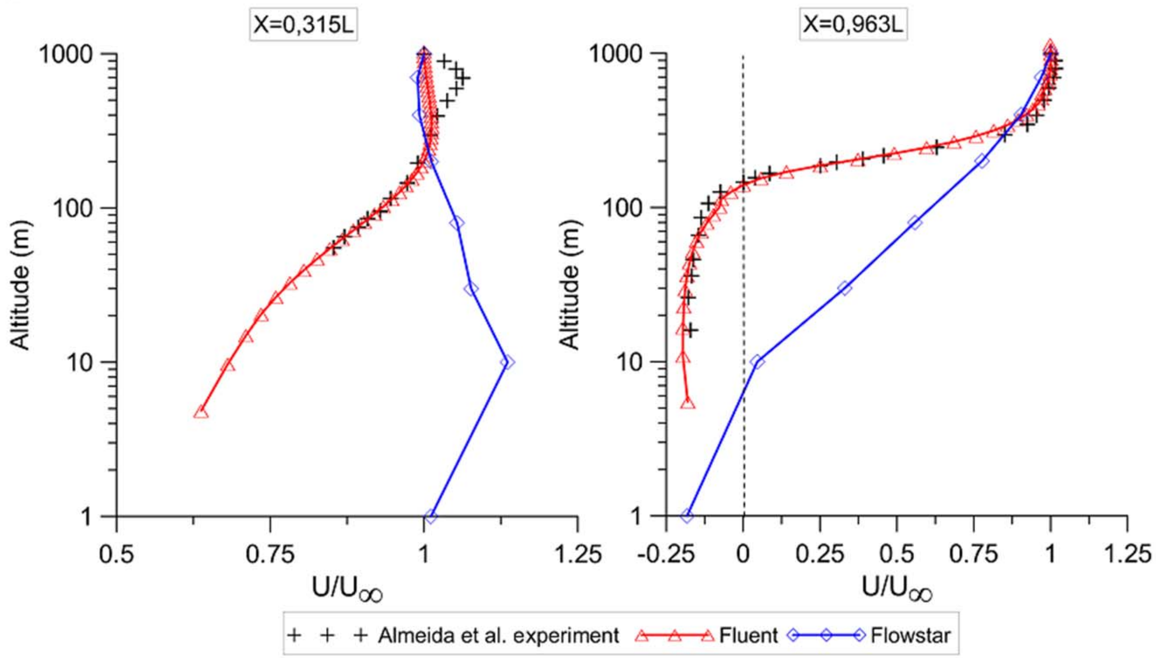
Wind flow results (Almeida experiment)

Single hill case

Comparison of velocity profiles (U) at two locations:



- h/L=0,26



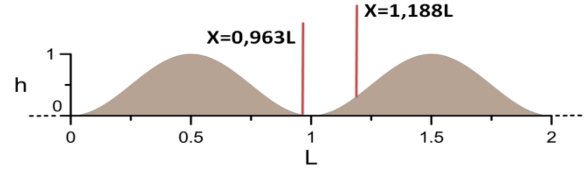
➢ Recirculation region well predicted by Fluent

➢ The recirculation length is 1,2L in Fluent and 1,3L in the experiment

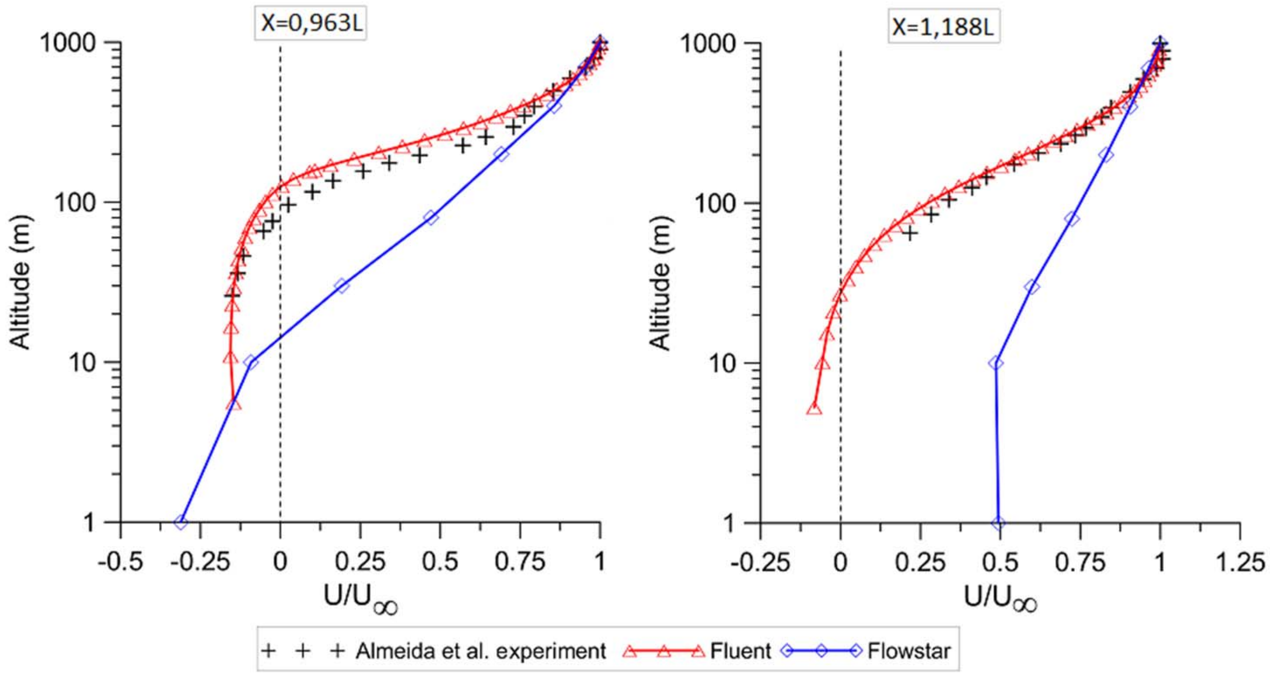
Wind flow results (Almeida experiment)

Multiple hill case

Comparison of velocity profiles (U) at two locations:



- h/L=0,26

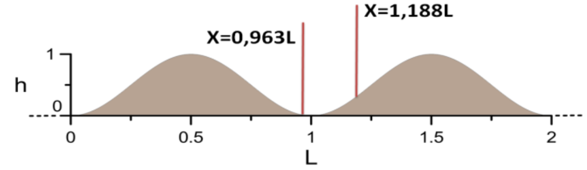


➢ Valley effect and recirculation region well predicted by Fluent

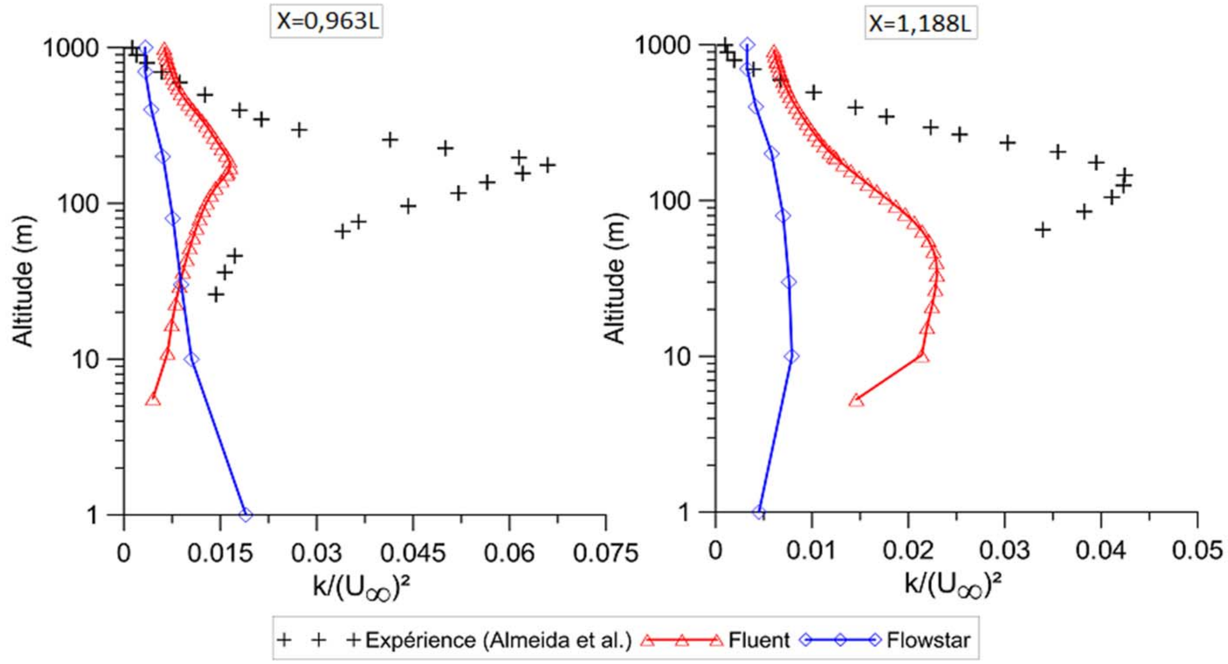
Wind flow results (Almeida experiment)

Multiple hill case

<u>Comparison of turbulent kinetic energy (k) profiles at two locations:</u>



- h/L=0,26



➢ Both models under-predict turbulent kinetic energy

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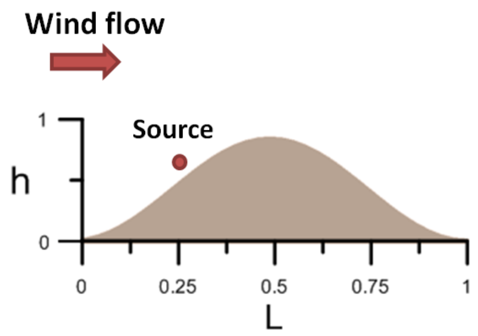
Parametrisation of the dispersion models

- Simulation of a single source of a NO_2 pollutant at 20m above ground level in the presence of Almeida hill



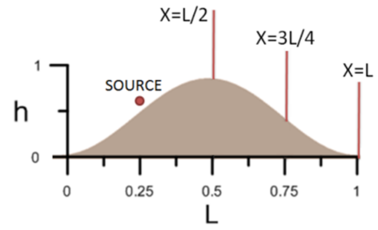
h=280m
L=1080m

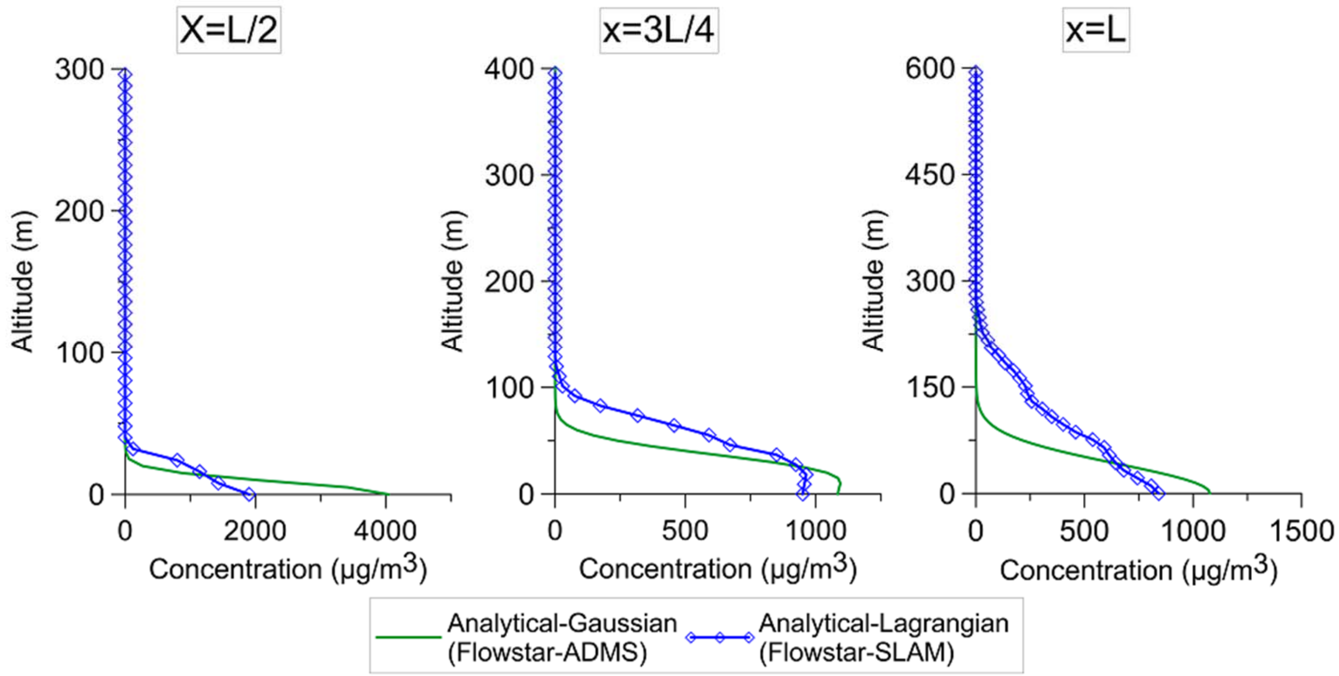
Gaussian Plume Model (ADMS)	✓ Point source ✓ No exit velocity ✓ An averaging time of 15 minutes
Lagrangian Model (SLAM)	✓ Point source ✓ No exit velocity ✓ A time step of 5s ✓ 1000 particles per time step ✓ A simulation time until a stationary state is observed

Results

Analytical flow model (Flowstar) as input

<u>Concentration profiles at three locations (hilltop and in the wake of the hill):</u>



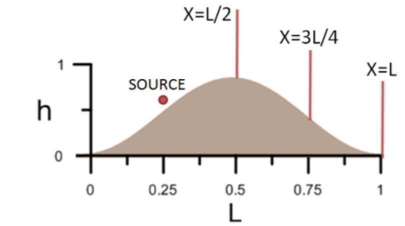


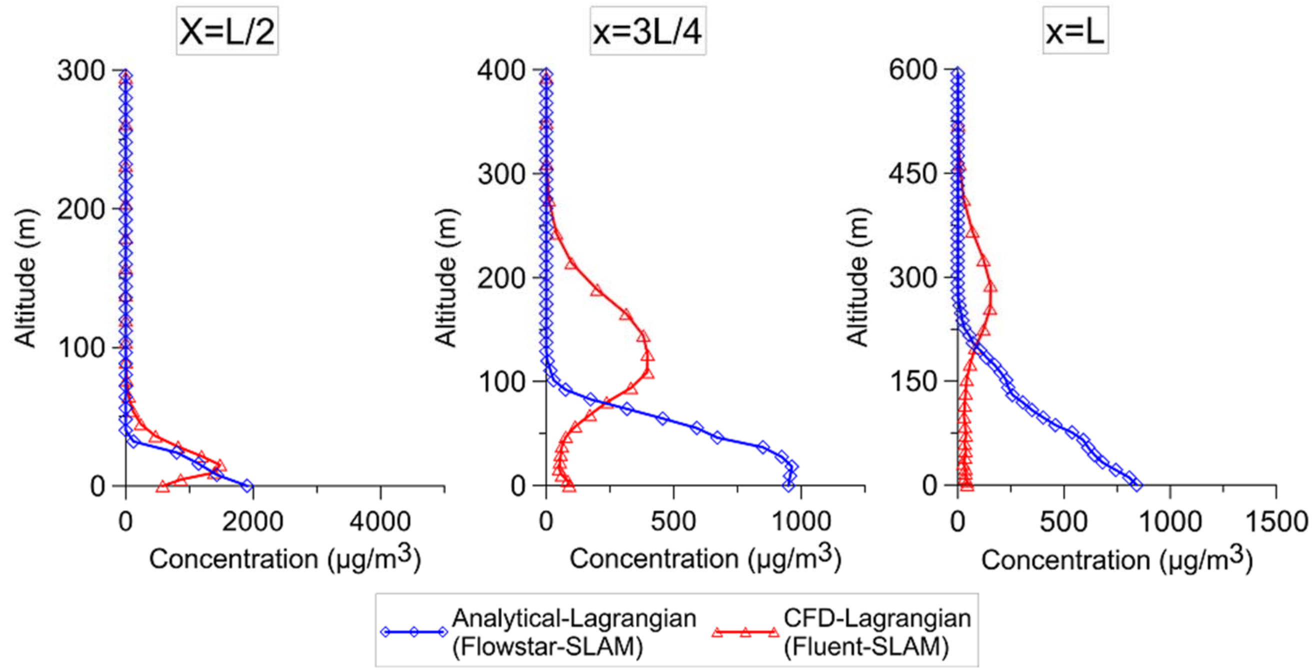
➢ Results are comparable between the Lagrangian and Gaussian dispersion models when a Flowstar field is used

Results

Analytical and CFD flow models as input

<u>Concentration profiles at three locations (hilltop and in the wake of the hill):</u>





- High differences are calculated when different flow models are used

Conclusions

Wind flow models

- A RANS k-ε CFD model can be used for simulations of regions of complex terrain at local scale

- The validity of Flowstar (hills of ratios up to 0,167) is not satisfactory
    - Speed-up for lower hills
    - Recirculation regions for steeper hills

Dispersion models

- The impact of the choice of the wind flow model on the dispersion is very high

Perspectives

- The CPU time of CFD models is high, when compared to analytical models (almost negligible)

Model	Flowstar	Fluent
CPU time (s) of the Almeida hill case	$\sim 1s$	$\sim 50s - 500s$

- The use of partially converged CFD calculations can be a way of reducing CPU time

➡ See poster presentation by Sadek *et al.* (H14-168)

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Thank you for your attention!

Questions?