Numerical modelling of a passive tracer dispersion from a continuous point source in a steady thermally driven slope wind

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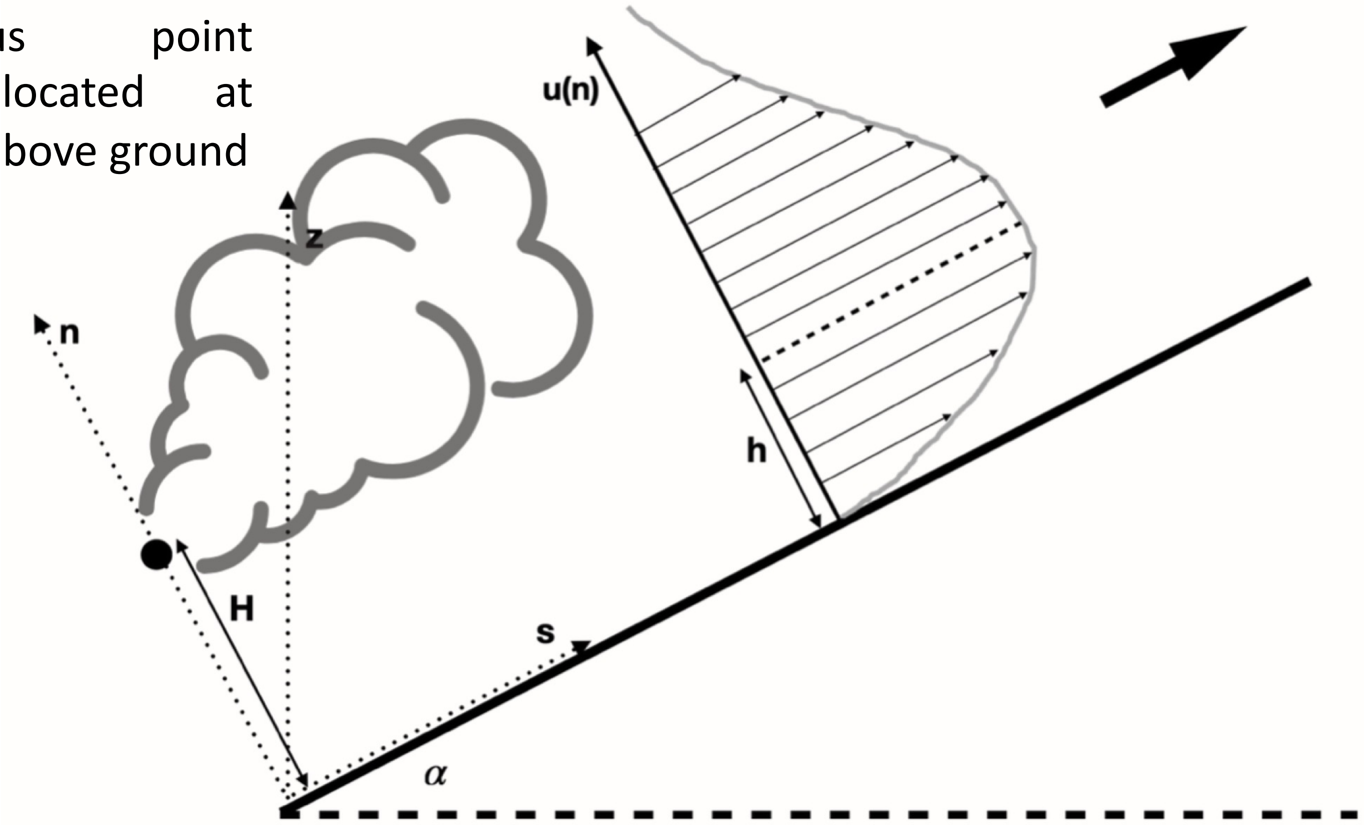
PASSIVE TRACER DISPERSION BY A SLOPE WIND

Slope wind developing over sloping terrain, characterized by a jet at height **h**

Continuous point source located at height **H** above ground



Objectives

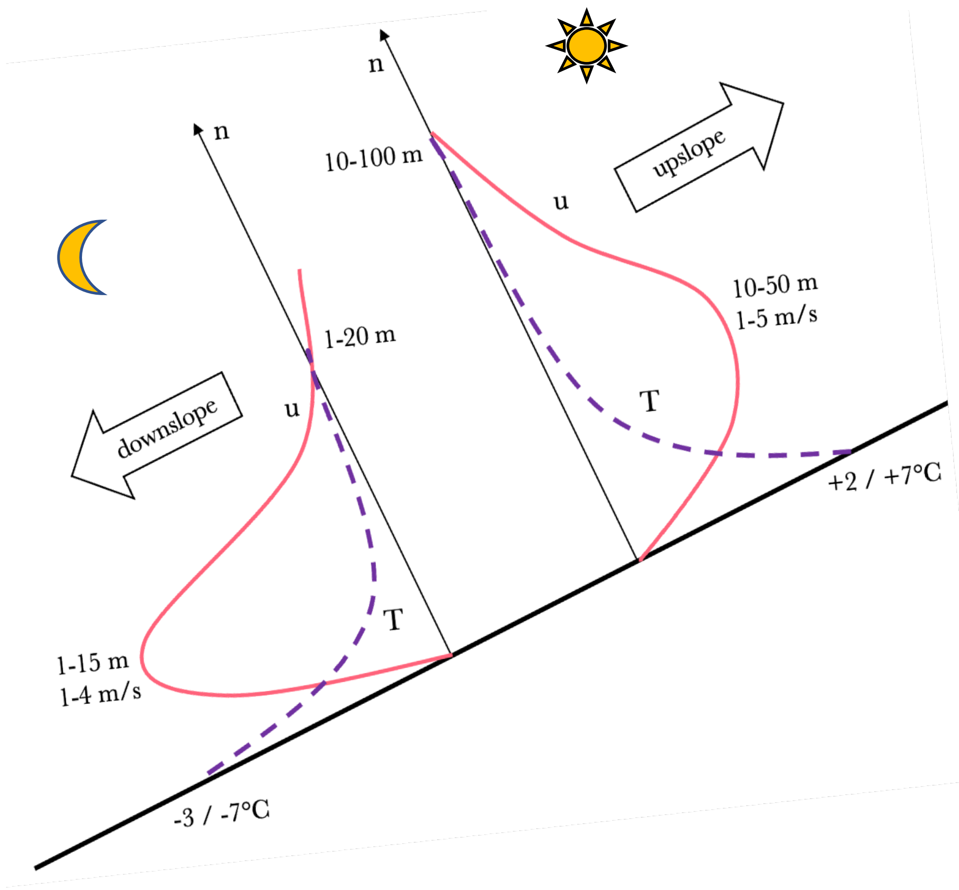
- Test the available solutions for a fast and accurate forecast of the concentration field.
- Parameterize the eddy diffusivity coefficient for turbulent transport.
- Identify the key variables for the final ground concentration field.

Applications

- Transport of biogenic particles (i.e. pollens)
- Transport of chemicals over agricultural terrain (i.e. pollutants, pesticides..)
- Transport of water vapour and convection initiation.

MODELLING THE WIND FIELD: SLOPE WINDS

main features



$$\begin{cases} \dfrac{\partial \bar{u}}{\partial t} = \bar{\theta}\dfrac{N^2}{\gamma} \sin\alpha - \dfrac{\partial}{\partial n}\overline{u'w'} \\ \dfrac{1}{\rho_0}\dfrac{\partial \bar{p}}{\partial n} = \bar{\theta}\dfrac{N^2}{\gamma} \cos\alpha - \dfrac{\partial}{\partial n}\overline{w'^2} \\ \dfrac{\partial \bar{\theta}}{\partial t} = -\bar{u}\gamma \sin\alpha - \dfrac{\partial}{\partial n}\overline{\theta'w'} \end{cases}$$

$$\begin{cases} \overline{u'w'} = -K_m \dfrac{\partial \bar{u}}{\partial n} \\ \overline{\theta'w'} = -K_h \dfrac{\partial \bar{\theta}}{\partial n} \end{cases}$$

↓

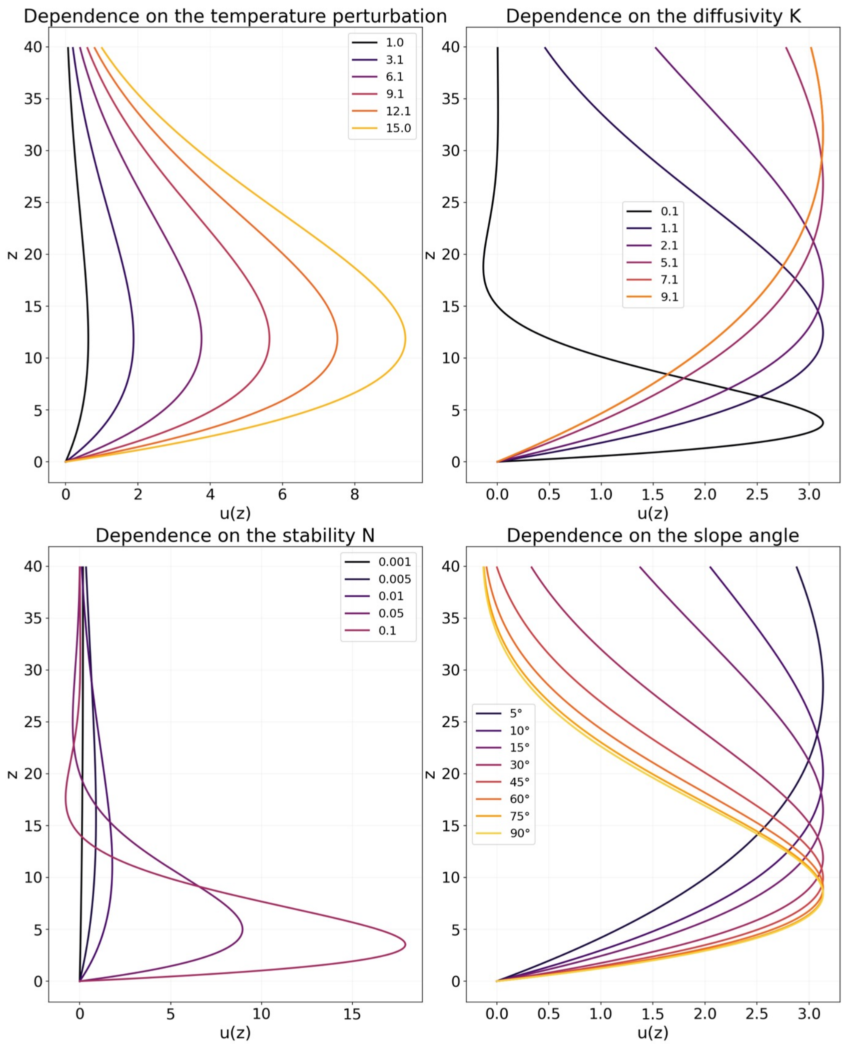
$$\begin{cases} \bar{u} = \Theta \dfrac{N}{\gamma} Pr_t^{-1/2} e^{-n/l} \sin(n/l) \\ \bar{\theta} = \Theta e^{-n/l} \cos(n/l) \end{cases}$$

$$l = \left(\frac{4K_m K_h}{N_\alpha^2}\right)^{1/4}$$

$$Pr_t = K_m/K_h$$

Prandtl (1942) model

sensitivity analysis



MODELLING DISPERSION PROCESSES

$$\frac{\partial \overline{c_i}}{\partial t} + \overline{u_i}\frac{\partial \overline{c_i}}{\partial x_j} - \frac{\partial \overline{u'_j c'_i}}{\partial x_j} = \overline{R_i} + \overline{E_i} - \overline{S_i}$$

$$\frac{\partial \bar{c}}{\partial t} + \bar{u}\frac{\partial \bar{c}}{\partial x} = \frac{\partial}{\partial x_j}K_{jj}\frac{\partial \bar{c}}{\partial x_j} + E$$

PROPOSED PARAMETERIZATION

$$K = \frac{c^2 \Delta T_s^2 N}{\gamma^2 \sin\alpha}$$

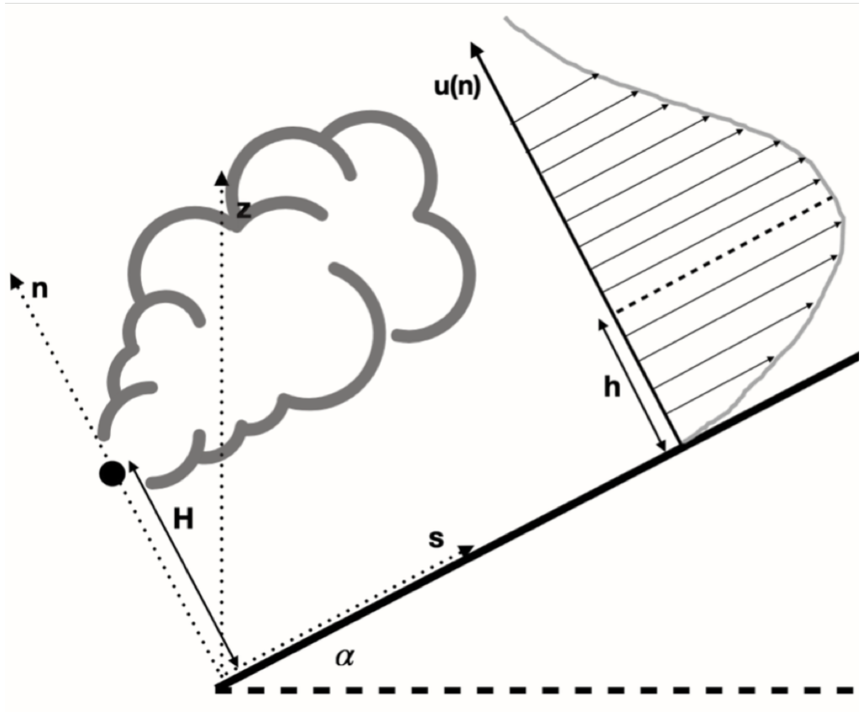
Keeping into account:
- environmental stability
- slope configuration
- thermal forcing

EDDY DIFFUSION COEFFICENT

$$\overline{u'_j c'_i} = -K_{jj}\frac{\partial \overline{c_i}}{\partial x_j}$$

K-CLOSURE

Coherent with preliminary experimental observations!



GAUSSIAN MODEL: analytical solution for a constant u profile

$$c(x,y,z) = \frac{Q}{2\pi U\sigma_y\sigma_z}e^{(-\frac{y^2}{2\sigma_y})}[e^{-\frac{(z-H)^2}{2\sigma_z^2}} + e^{-\frac{(z+H)^2}{2\sigma_z^2}}]$$

$$c(x,y_s,0) = \frac{Q}{2\pi U\sigma_y\sigma_z}e^{-\frac{H^2}{2\sigma_z^2}}$$

$$\sigma_z^2 = \frac{2K_z x}{U}, \sigma_y^2 = \frac{2K_y x}{U}$$

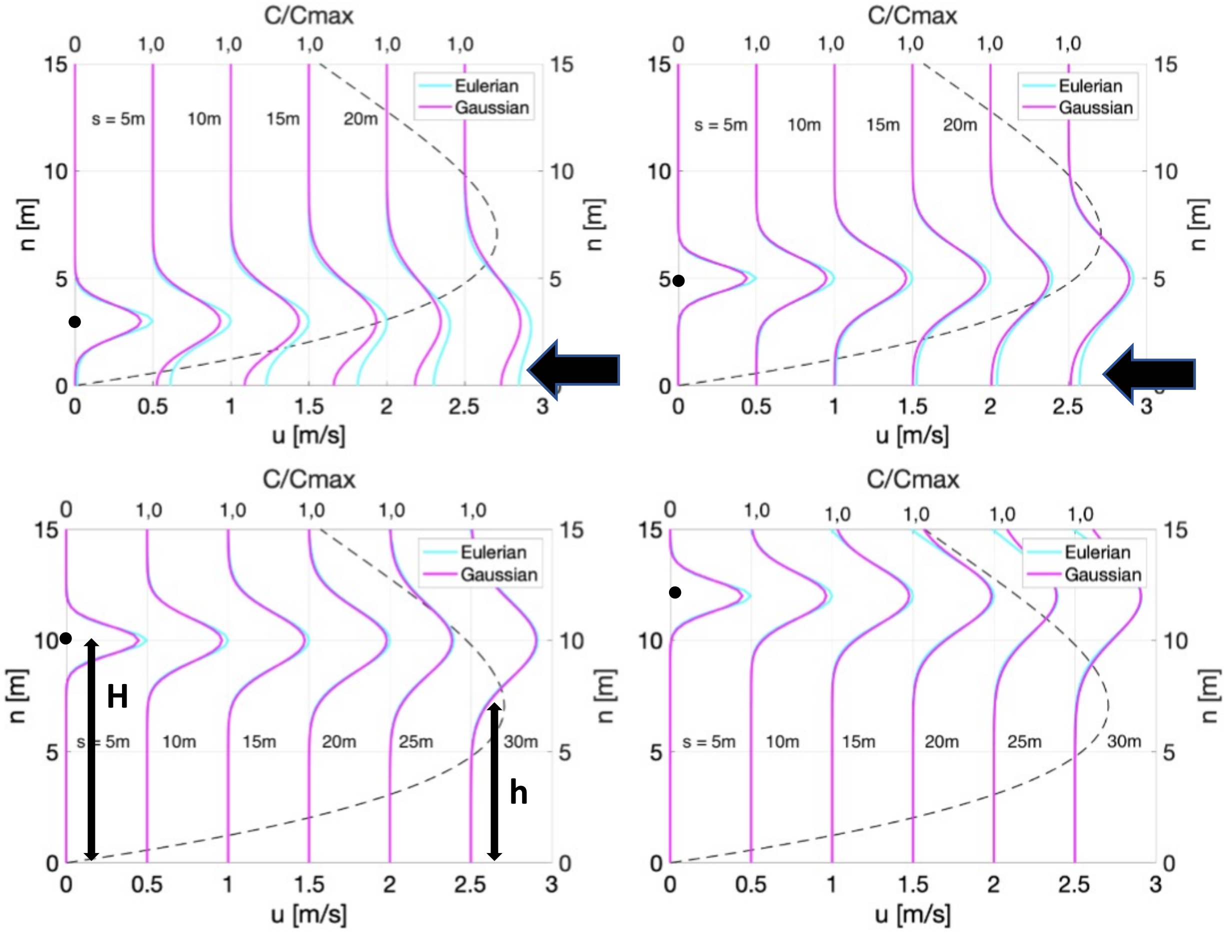
EULERIAN MODEL: numerical solution of the equation

$$\frac{\partial \bar{c}}{\partial t} + \bar{u}\frac{\partial \bar{c}}{\partial x} = \frac{\partial}{\partial x_j}K_{jj}\frac{\partial \bar{c}}{\partial x_j} + E$$

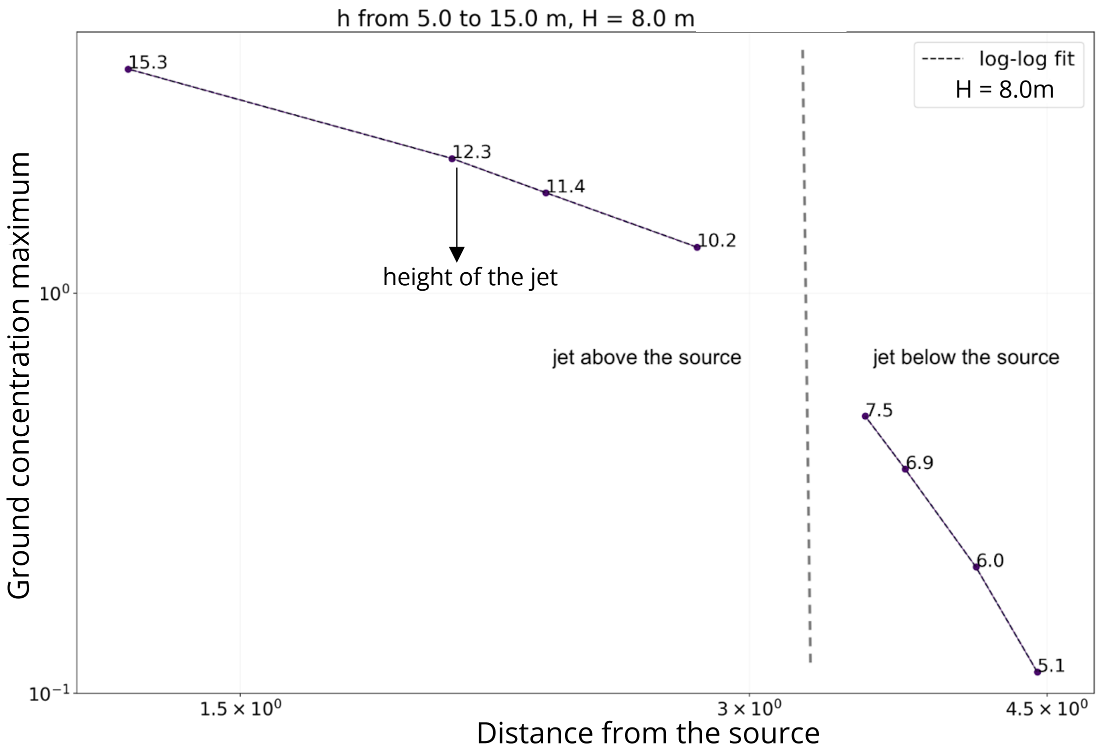
Numerical integration through finite differences after the definition of:
- the initial concentration field
- the boundary conditions
- the wind field

RESULTS

Comparison between the concentration fields obtained with a Gaussian model for u=u(H) and with the Eulerian for constant upslope wind profile and varying source height H.



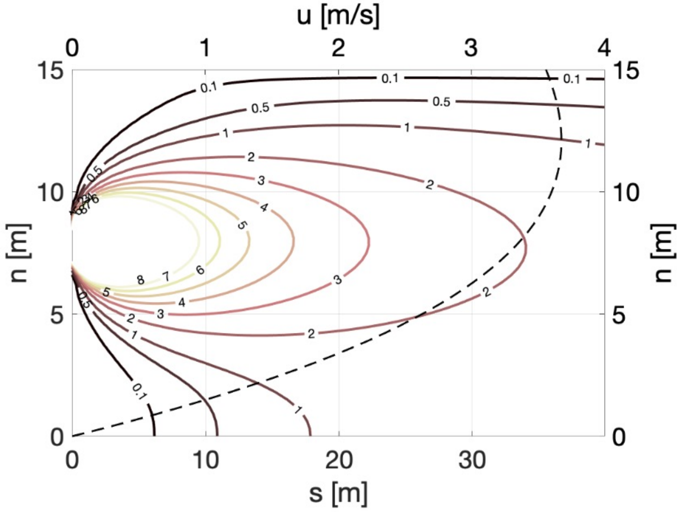
Study on the relation between position and intensity of ground concentration for different combinations of H and h and fit of the results with a logarithmic profile.



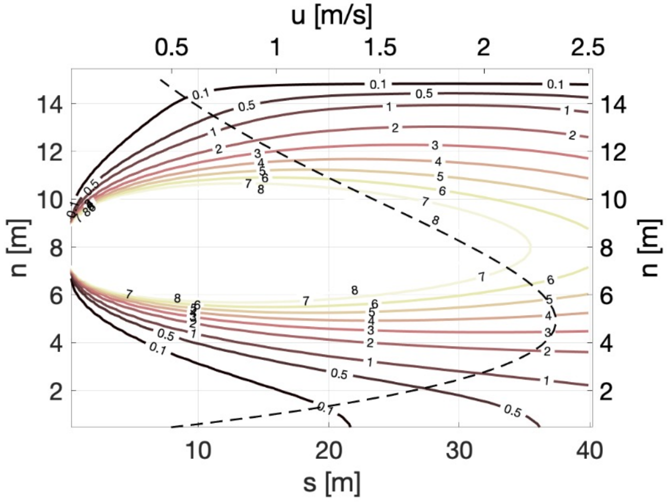
Regime H<h **Regime H>h**

The crucial factor is **H-h**.

RESULTS

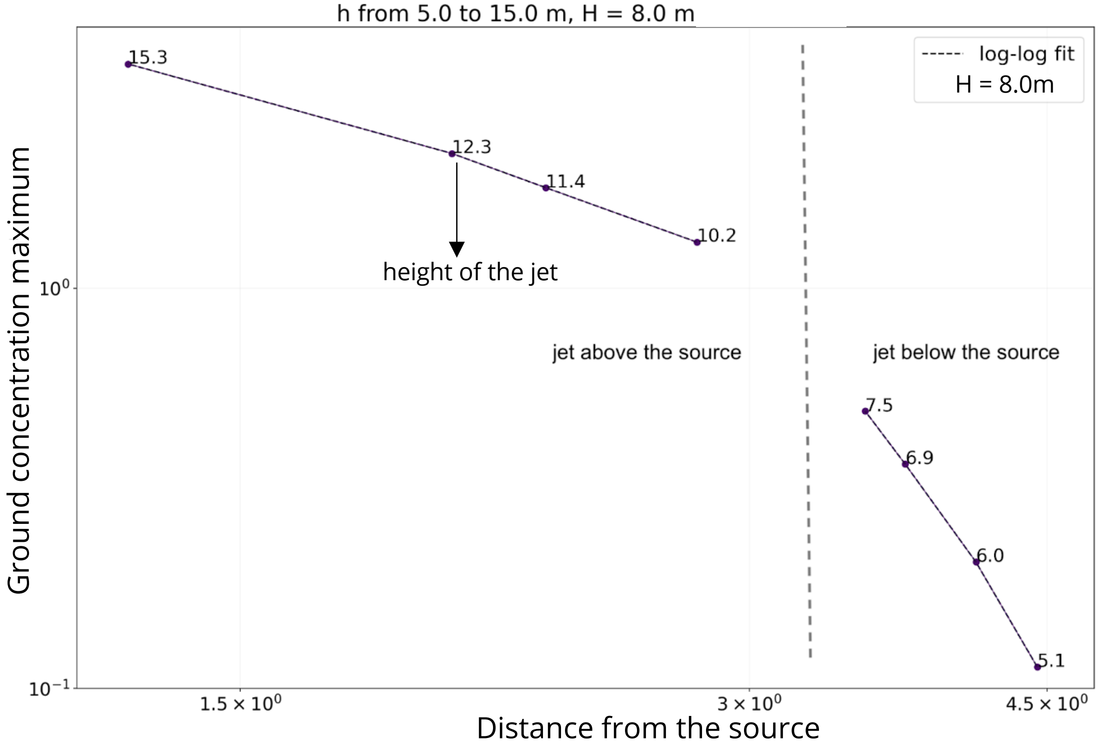


(a) Strong shear.



(b) Weak shear.

Study on the relation between position and intensity of ground concentration for different combinations of H and h and fit of the results with a logarithmic profile.



Regime H<h **Regime H>h**

The crucial factor is **H-h**.

CONCLUSIONS AND FURTHER DEVELOPMENTS

Conclusions

- The final concentration field is determined by the **position and intensity of the wind jet**, determined by environmental conditions and topographical configuration, and **the height of the source**, and its **relative position** with respect to the maximum of velocity.
- The **errors** induced by the use of a Gaussian model are stronger **closer to the ground**.
- The concentration fields of a substance emitted by a source located **above or below the jet** are sharply different, with stronger deviations from the analytical solution for a constant u in the case of $H < h$.

Further developments

- Validation of the **parameterization for K** using experimental data (<u>work in progress</u>)
- Implementation of a **Lagrangian model** for tracer dispersion (<u>work in progress</u>)
- Test of the model for different source configurations and for the entire **daily cycle of slope winds.**
- Validation with experimental data from tracer release experiments.

Thank you for your kind attention!

For further information and discussion do not hesitate to contact me at s.farina@unitn.it.