Effect of point source emission height on the error of the flux estimation through eddy covariance

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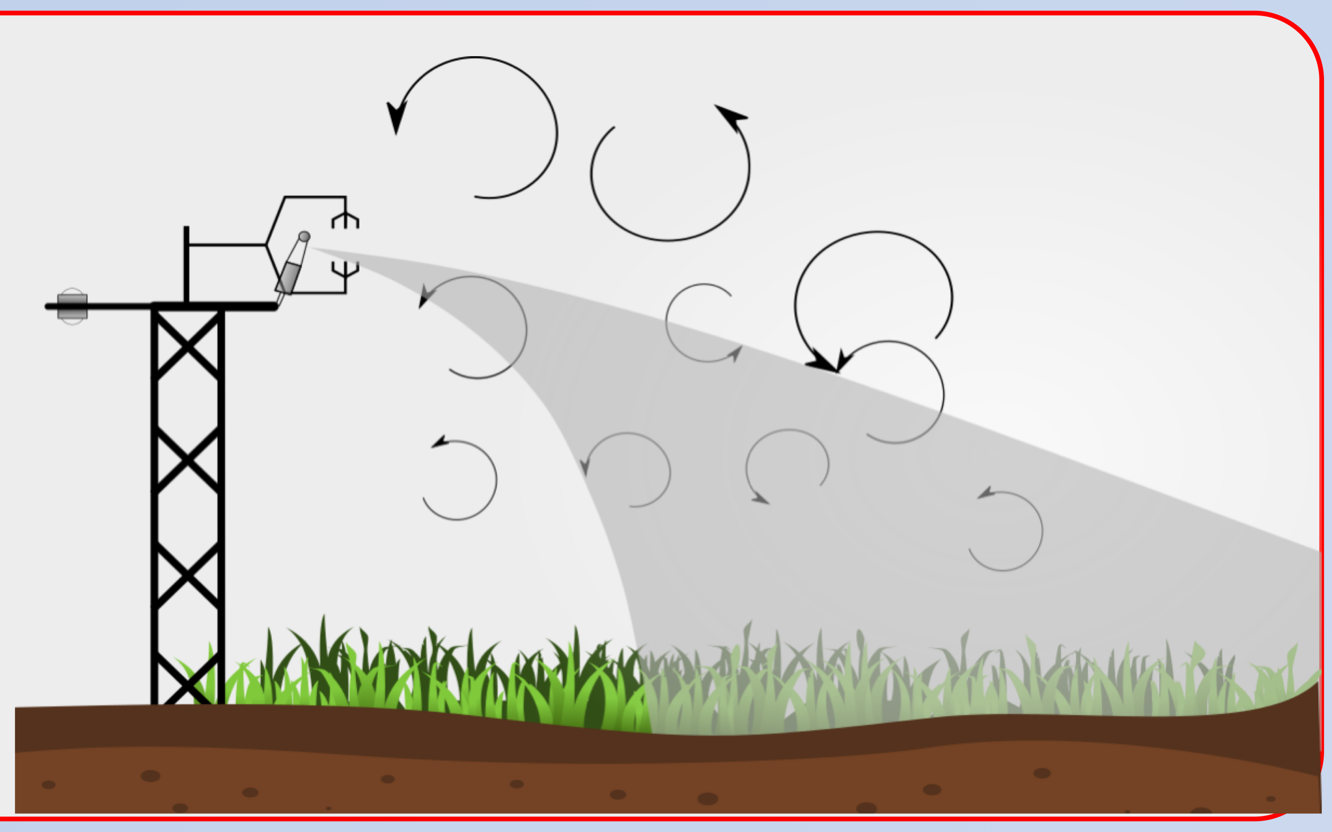
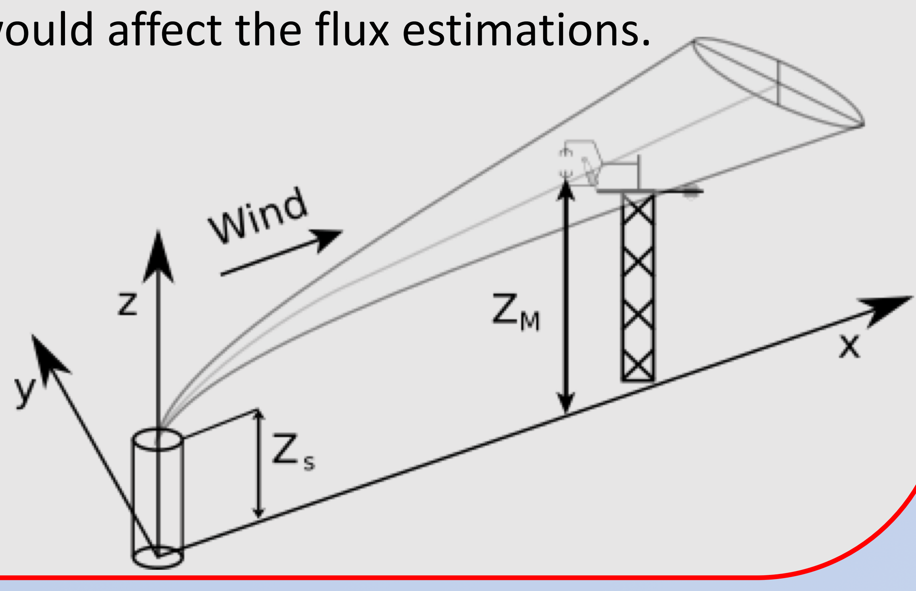
Context

A challenge commonly associated with eddy covariance is that real measurement sites are rarely homogeneous. Therefore, scientists had to identify a footprint area or "effective upwind source area sensed by the observation" in order to make sense of the measurements. This led to the development of footprint functions weighting the respective contribution of each element of the surface to the measured vertical flux. A promising use of footprint models would be to extend the use of eddy covariance to quantify point source emissions, such as methane emissions from livestock or emissions from vents in geothermal areas. However, most footprint models consider the source at ground level which may not be a valid hypothesis for all point sources as for example livestock.



Objective

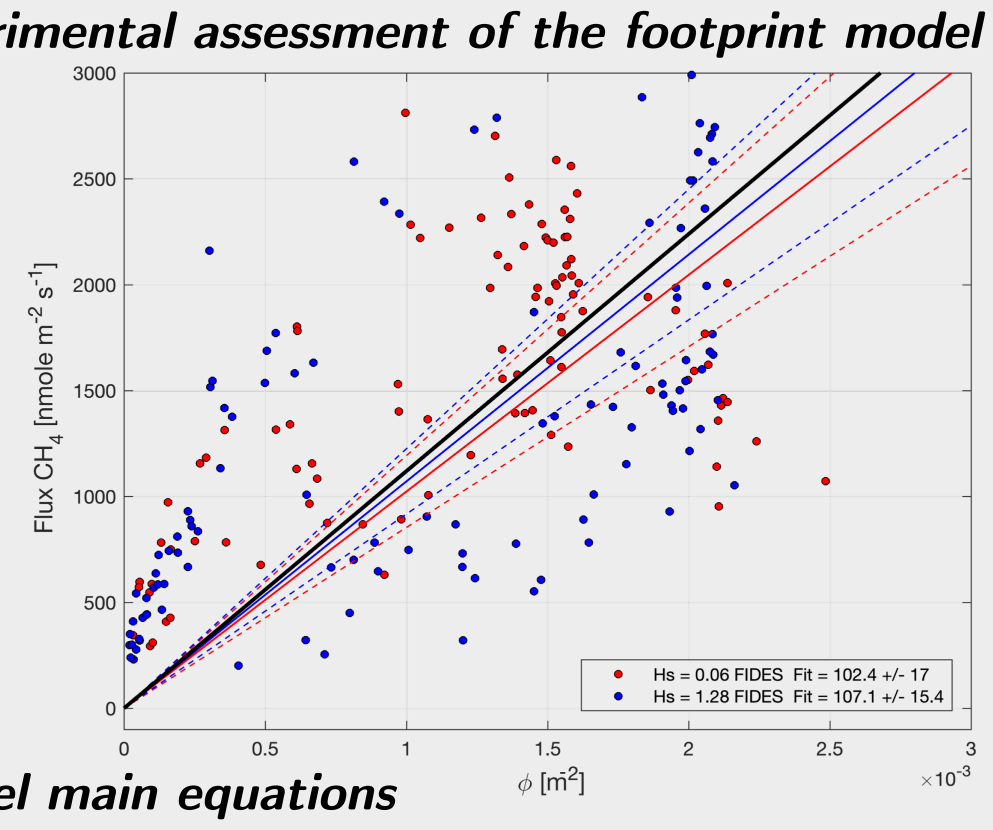
The footprint function is affected by the source height, therefore considering the source height as ground level may lead to large errors on flux estimation. The goal of the present work is to perform a sensitivity analysis of source height on the footprint function in order to understand how an error on the source height would affect the flux estimations.



Footprint model

- The footprint is computed using FIDES a pseudo gaussian model (Loubet et al., 2011). The advantage of this model is that the height of the source is an input variable/parameter.
- The model quality has been assessed by an experimental campaign using an artificial CH_4 source with a known emission rate at different heights.

Experimental assessment of the footprint model

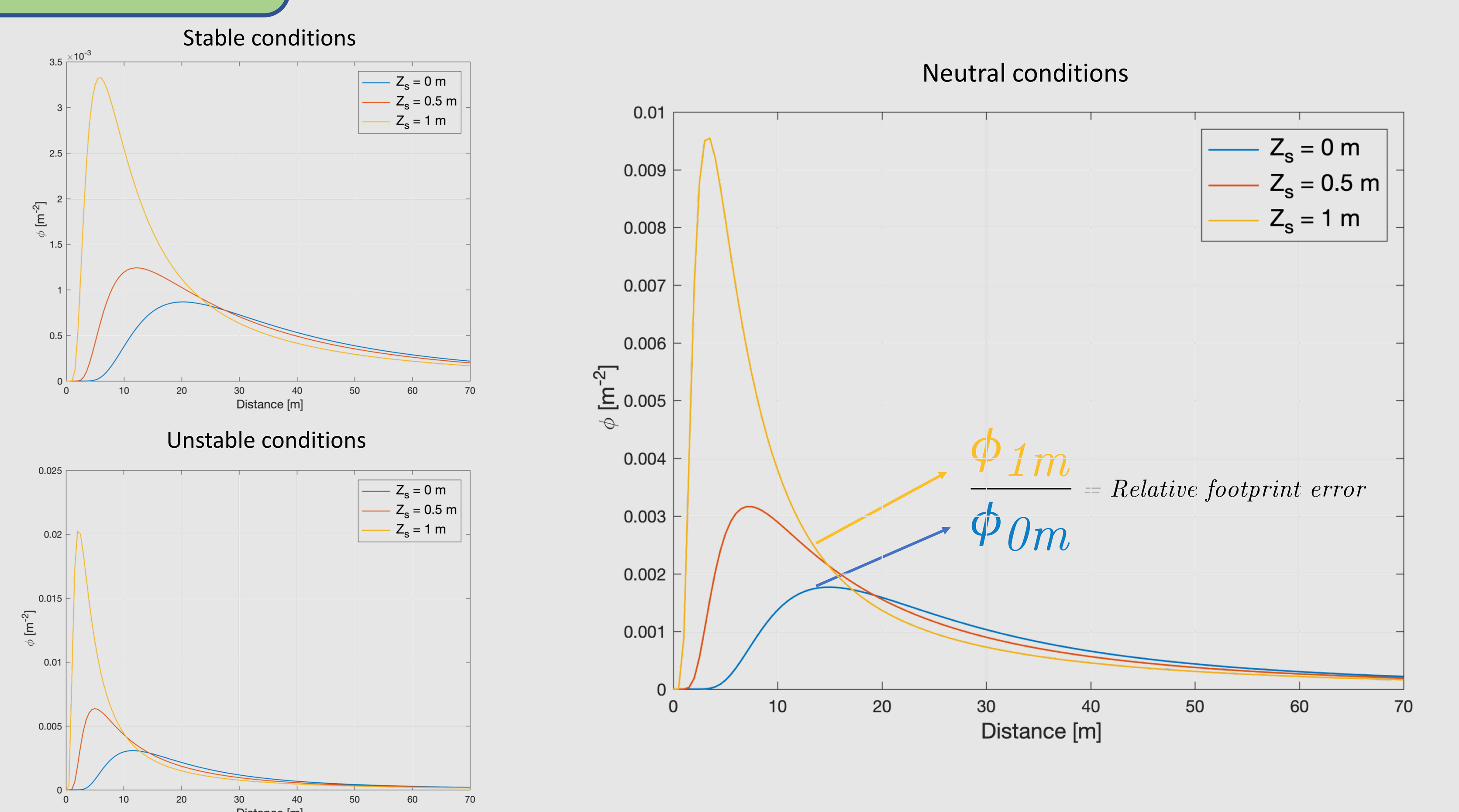


Model main equations

$$\begin{cases} U(z) = az^p, \quad K_z(z) = bz^n, \quad \phi(x,y) = K_z(z)\dfrac{\partial D}{\partial z} \\ D(X,Y,z) = \dfrac{1}{\sigma_y\sqrt{2\pi}}\exp\left(-\dfrac{(Y)^2}{2\sigma_y^2}\right) \times \dfrac{(zz_s)^{(1-n)/2}}{b\alpha X} \times \exp\left(-\dfrac{a(z^\alpha + z_s^\alpha)}{b\alpha^2 X}\right) \times I_{-\upsilon}\left(\dfrac{2a(zz_s)^{\alpha/2}}{b\alpha^2 X}\right) \end{cases}$$

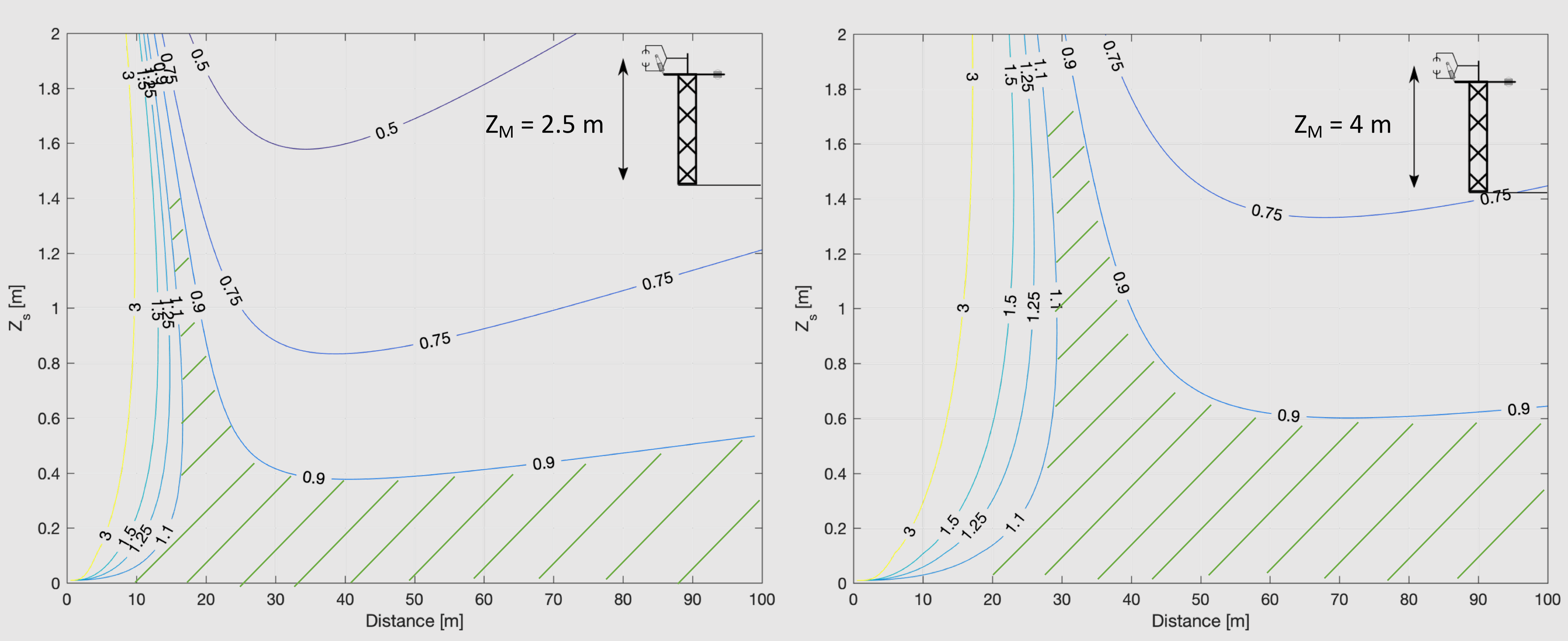
Results

Effect of source height on the footprint function



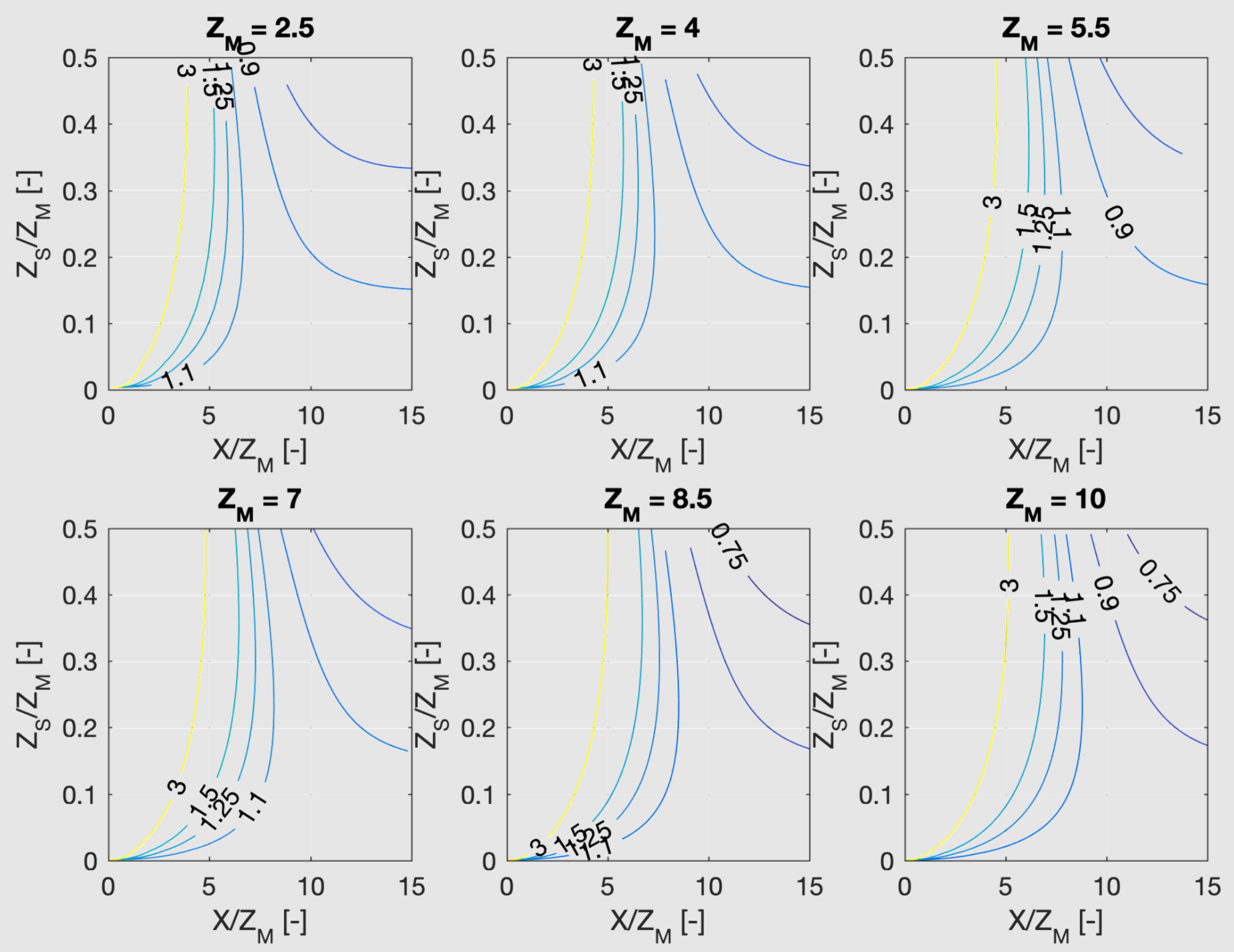
When the source height increases, the footprint peak shifts toward the mast and the peak magnitude increases. This behavior is observed for each atmospheric conditions.

Relative footprint error in function of distance, source and mast heights



It exists a domain depending on the source height and the distance from the mast for which neglecting the source height induce a small error on the footprint (<10%). This domain is affected by the mast height.

Dimensionless representation of the relative footprint error



The distance from the mast and the source height can be normalized by the mast height leading to a dimensionless plot showing at which distance an error on the source height would induce an important flux estimation error.

Conclusions

Flux footprint shows a high sensitivity of source height close to the footprint peak. However, the source height can be neglected if the source is located far enough from the mast.

These results can be used to design future experiments in order to minimize the flux measurements error when the height of the source may not be exactly known by sampling within a defined domain in which the measurement errors remains low.