Comparison of 3D and 1D methods for automotive optical sensor simulation in foggy conditions

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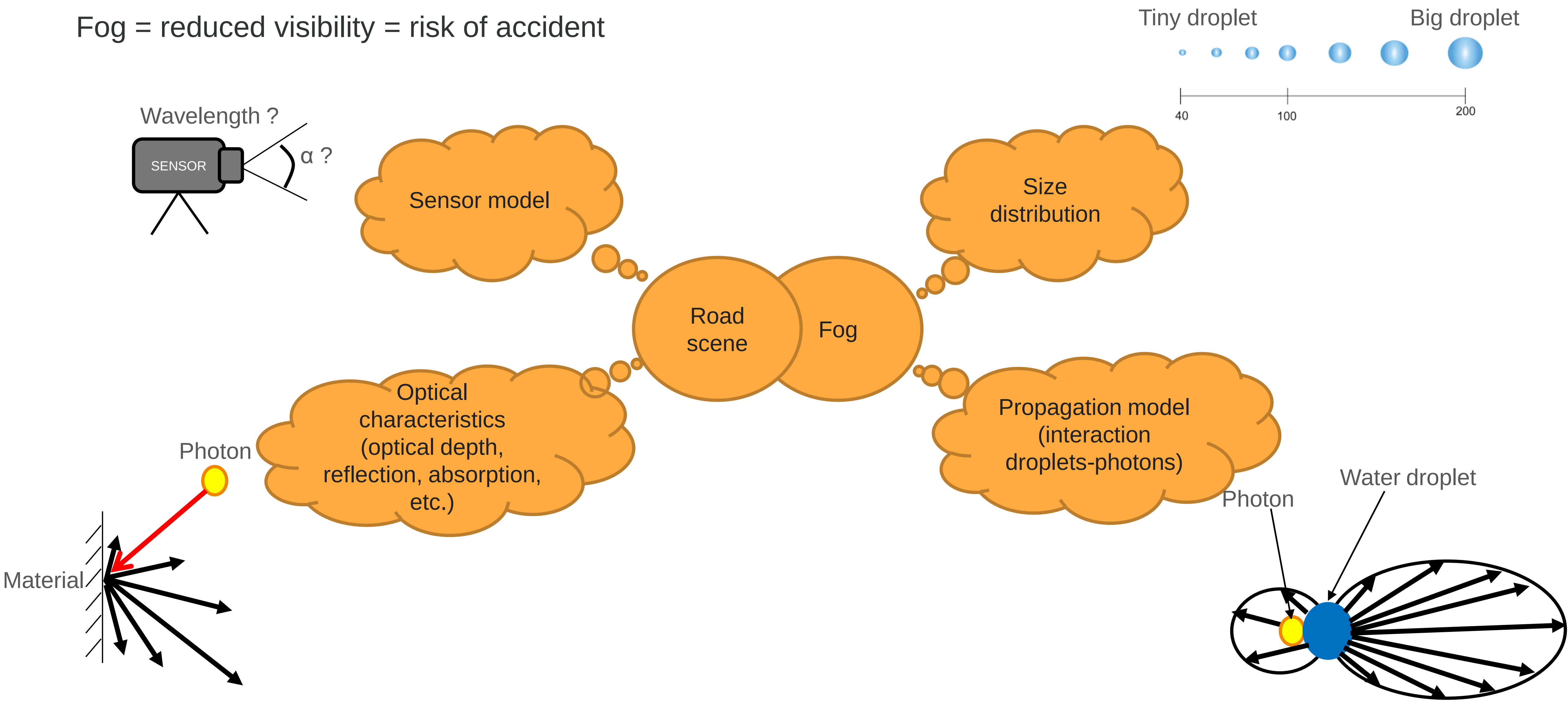
22

- **Introduction**
- **Methodology**
- **Results**
- **Application**
- **Conclusion**

Introduction

How can we see better in the fog?

Fog = reduced visibility = risk of accident



Radiatif transfer equation

$$u.\nabla_r L_\lambda(r,u) \;=\; -\beta_\lambda L_\lambda(r,u) + \frac{\sigma_\lambda}{4\pi}\int_{S^2} L_\lambda(r,v)\;\Phi_\lambda(v.u)\,dv$$

r : position in 3D space
u, v : directions in 3D space
β_λ : extinction coef. ($\beta_\lambda = \sigma_\lambda + \kappa_\lambda$)
σ_λ: scattering coef.
κ_λ : absorption coef.
S^2 : unit sphere in 3D space
Φ_λ : phase function
L_λ : radiance
λ : wavelength

Assumptions

- Homogeneous medium (σ_λ, κ_λ, Φ_λ do not depend on r)
- Stationarity
- Lambertian light sources

Irradiance equation

$$E_\lambda(r) = \int_{\theta=0}^{\frac{\pi}{2}}\int_{\varphi=0}^{2\pi} L_\lambda(r,\theta,\varphi)\sin(\theta)\,d\varphi\,d\theta$$

θ,φ : latitude and longitude in 3D space

Radiatif transfer equation

3D CASE

$$u.\nabla_r L_\lambda(r,u) = -\beta_\lambda L_\lambda(r,u) + \frac{\sigma_\lambda}{4\pi}\int_{S^2} L_\lambda(r,v)\ \Phi_\lambda(v.u)\,dv$$

1D CASE (slab modelling)

$$u.\frac{\partial L_\lambda(\mathrm{x},u)}{\partial x} = -\beta_\lambda L_\lambda(\mathrm{x},u) + \frac{\sigma_\lambda}{4\pi}\int_{S^2} L_\lambda(\mathrm{x},v)\ \Phi_\lambda(v.u)\,dv$$

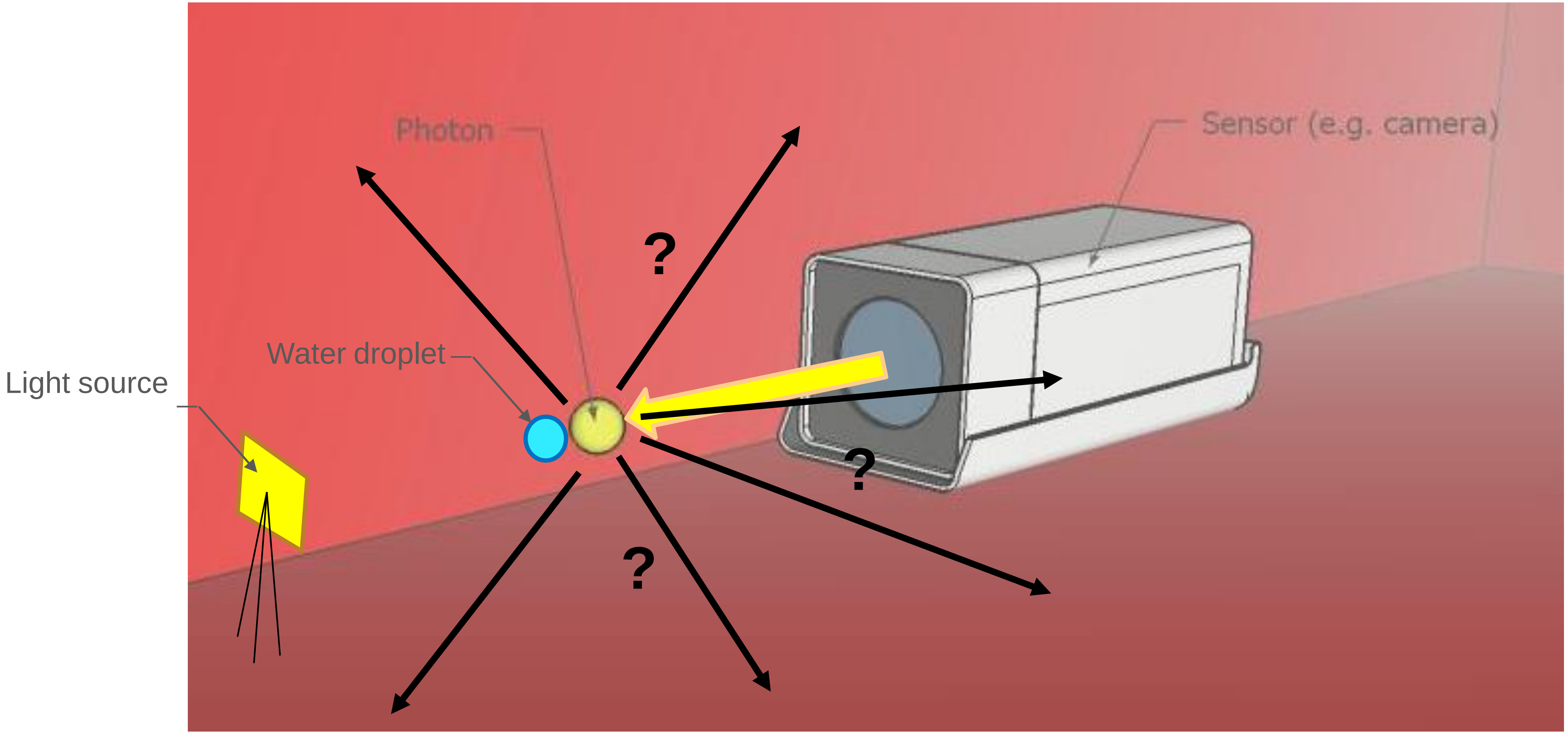
L_λ **does not depend on y and z**

Beer-Lambert Case :

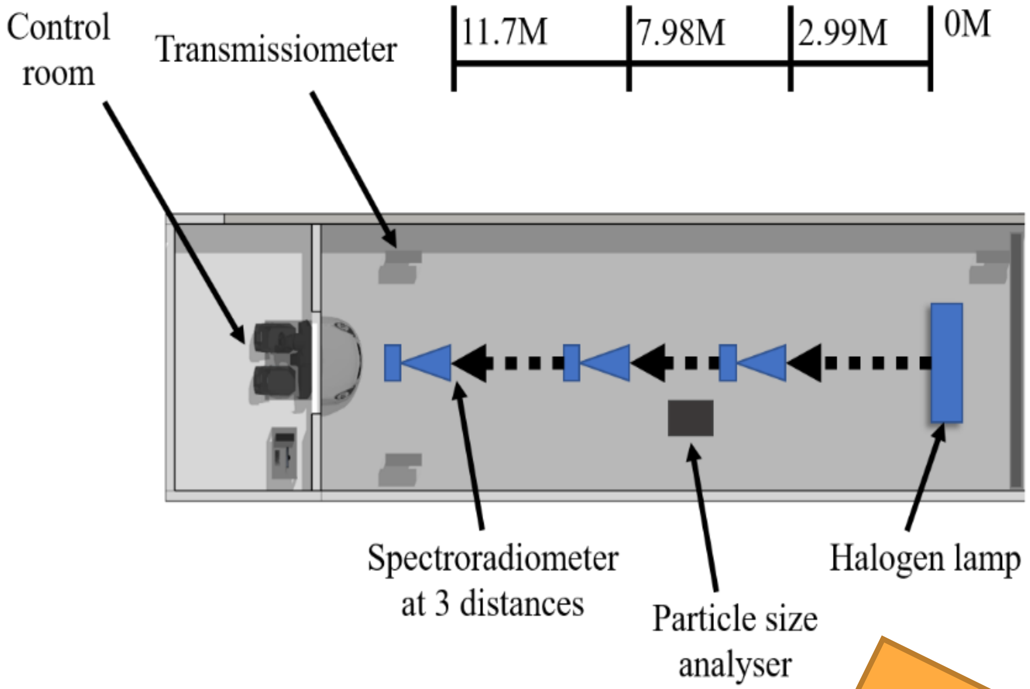
$$u.\nabla_r L_\lambda(r,u) = -\beta_\lambda L_\lambda(\mathrm{r},u)$$

no collision term

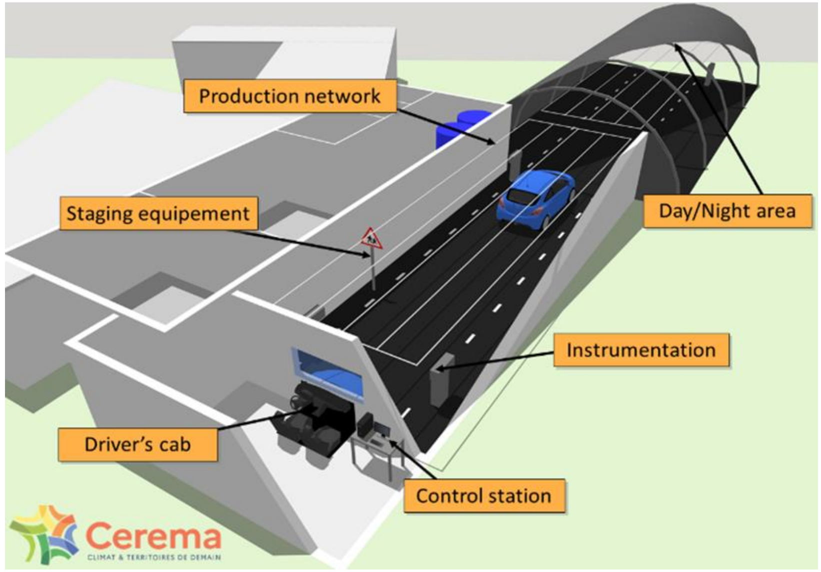
Monte Carlo algorithm (Backward ray-tracing)

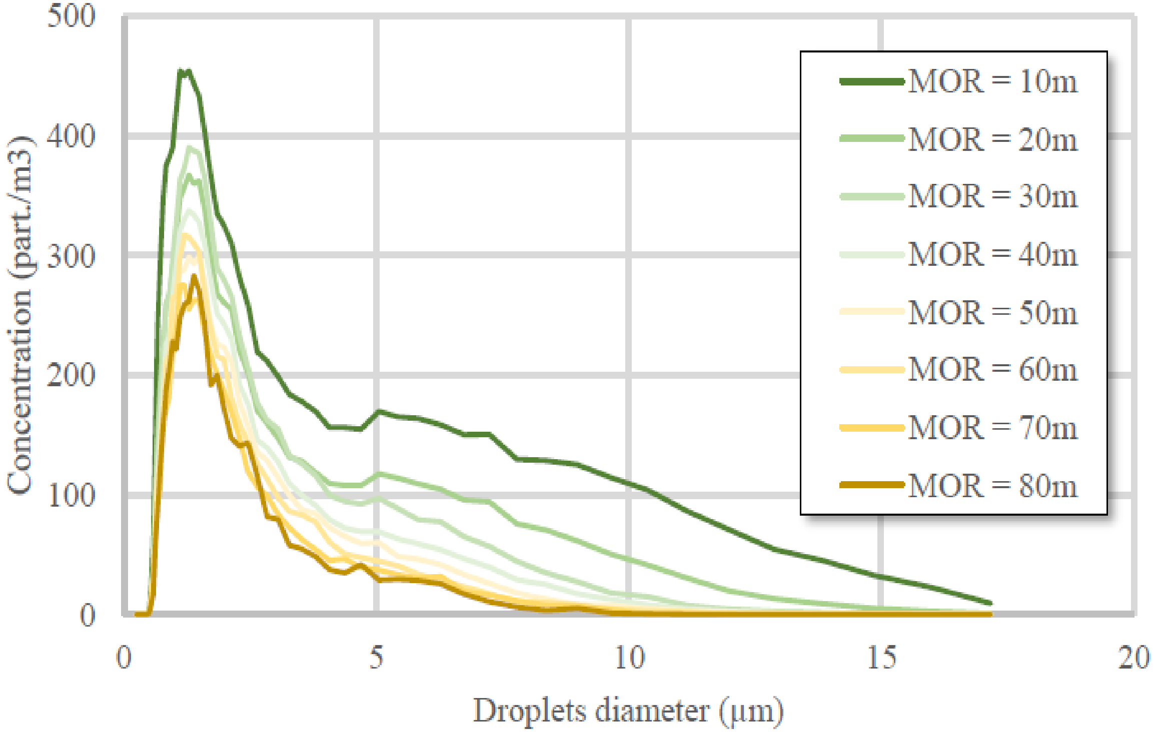


Experiement map and granulometry



Cerema PAVIN plateform

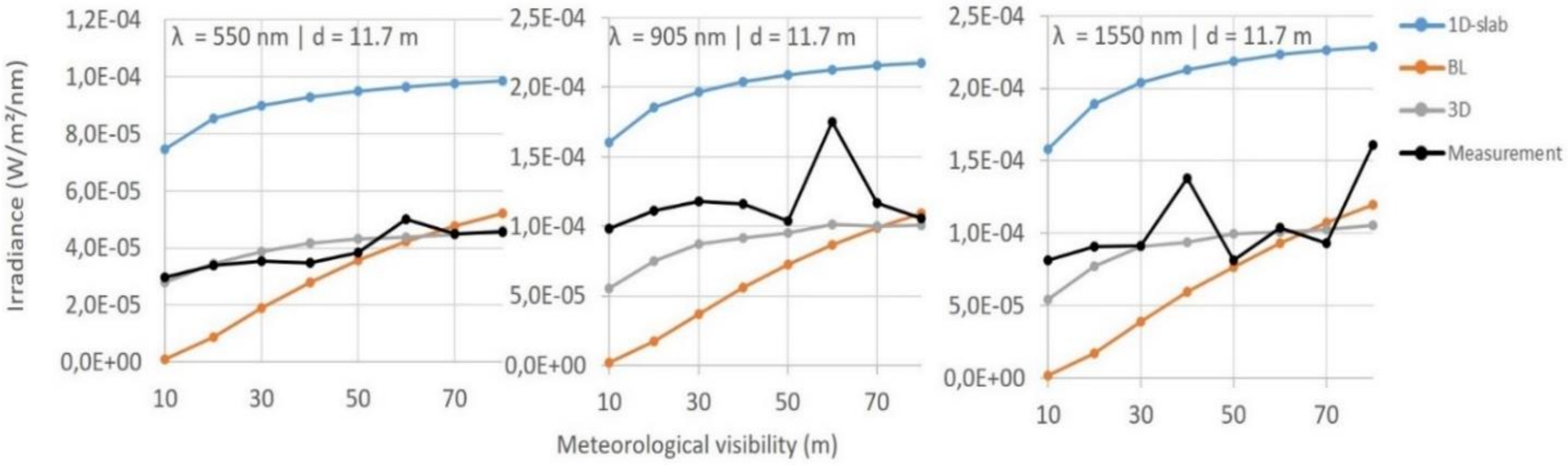




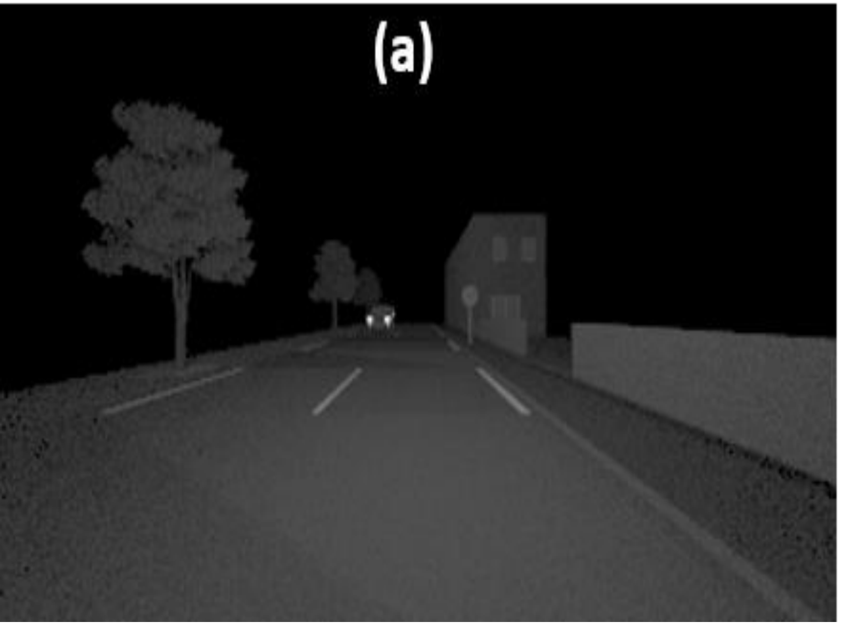
$$Mie\ theory\ domain : 0.1 < \frac{r}{\lambda} < 1.6$$

$*\ MOR: Meteorological\ Optical\ Range$

Comparison of methods

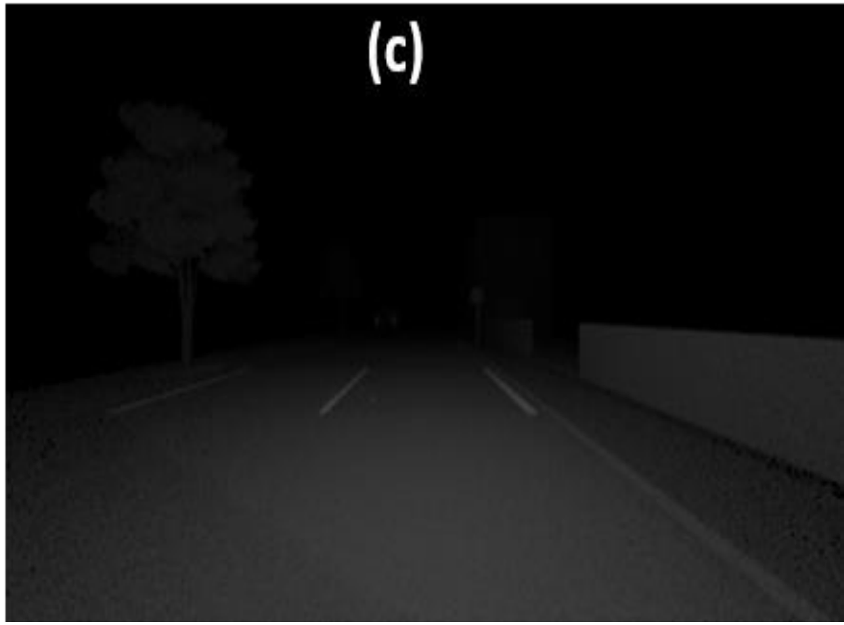


Application in the visible (550 nm)



Without fog

With fog (MOR 21m), 3D model



With fog (MOR 21m), Beer-Lambert model

Conclusions

- Robustness of the 3D model and ability to stick to the measurements, despite the uncertainties
- Ability to simulate various scenes in the visible and in the thermal infrared

Ongoing work

- Uncertainties quantification
- Developing a digital twin to complete the PAVIN plateform of Cerema (based on digital simulation and artificial intelligence)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Thank you!