NEW LAGRANGIAN APPROACH FOR WET PLUME MODELLING

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CONTENT

- Context and objectives
- Development of a new wet plume model in the MSS (Micro-Swift-Spray) lagrangian model :
  - Microphysic of the droplet
  - Validation with wind tunnel data
- Dispersion modelling of experimental biological releases
- Conclusion and future work

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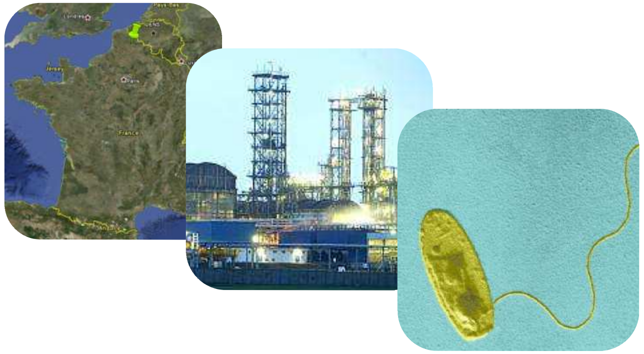
Context

2003 – Lens (France)

Outbreak of legionnaires' desease

83 victims including 14 death.



➡ Question to modellers:
« A suspected source of legionella exists but infected people are located up to 15km from source. Is it possible? »

➡ Observation : *Legionella* is present in aquatic systems, it survives in water droplets and is affected by temperature, humidity and radiation when isolated.

➡ Need to develop an accurate model able to take into account:
Urban area, microphysical process coupled with a biological model

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Requirements for the new wet plume model

Physical specifications:

- Need to investigate urban area (buildings)
- to take into account complex terrain
- to model periods of several days/week,

Lagrangian approach more relevant

Microphysical specifications:

- The evolution of a spectrum of water droplet (evaporation/condensation),
- Temperature evolution inside the plume,
- Diagnostic the moment when a water droplet is totally evaporated for then apply the biological model on the microorganisms (decay model).

Biological specifications:

- Concentration in Microorganisms has to be calculated for the water liquid phase and vapour.
- Biological model based on the work of CSTB (Ti Lan Ha, 2005)

Microphysic of the droplet : Mass and Temperature evolution

$$\left.\frac{dm}{dt}\right|_{droplet} = \pi \times D_{diff\_vapour} \times D_{droplet} \times S_h \times \left(C_s - C_\infty\right)$$

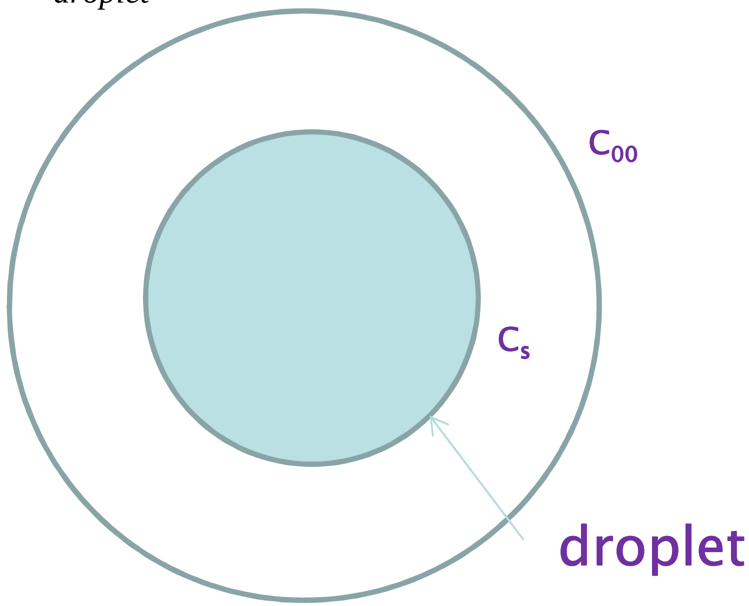
C_s saturated water vapor concentration [kg/m³] $C_s = P_{sat} \cdot \dfrac{M_{water}}{R.T_{droplet}}$

C_∞ water vapor concentration [kg/m³]

$$C_\infty = C_{vapour\_atm} + C_{vapour\_plume}$$

$D_{droplet}$: droplet diameter [m]

D_{diff_vapour} : molecular diffusivity of water vapor in air [m²/s]



$$\frac{dT_{droplet}}{dt} = \frac{Nu}{3\Pr}\left(\frac{\theta_1}{\tau_d}\right)\left(T_{air} - T_{droplet}\right) + \frac{L_v}{C_L}\,\frac{dm_{droplet}/dt}{m_{droplet}}$$

T_{air} (K) local carrier plume temperature

$T_{droplet}$ (K) droplet temperature

Validation test (0D) : Evaporation rate, temperature evolution

Small wind tunnel experiments : *Kincaid, D.C., Longley, T.S. (1989)*

Controlled and tested parameters

- air velocities : up to 10 m/s
- Temperature of the flow
- humidity : up to 81% for T = 22°C
- droplet diameter : 0,3 to 1,5 mm

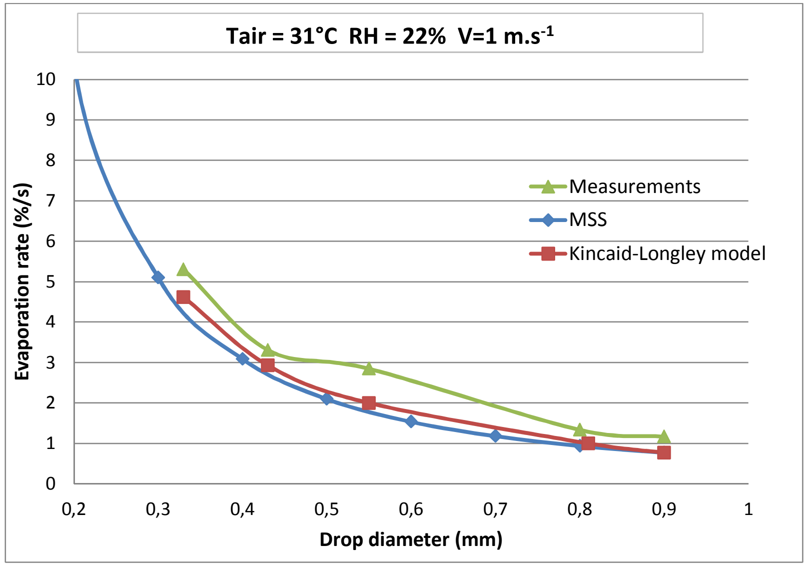
Measurements

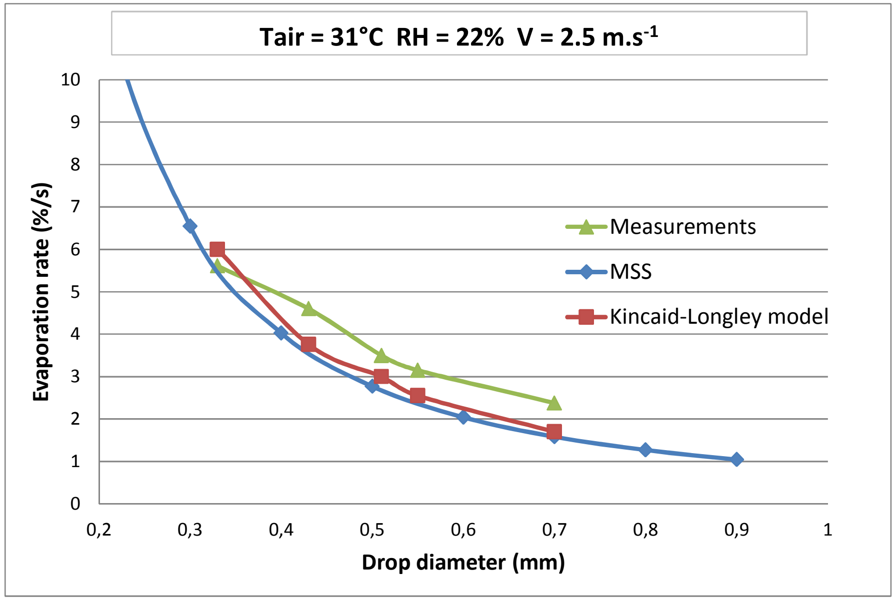
- wet bulb temperature in the flow : electric psychrometers
- droplet temperature
- diameter → evaporation rate (steady state case)

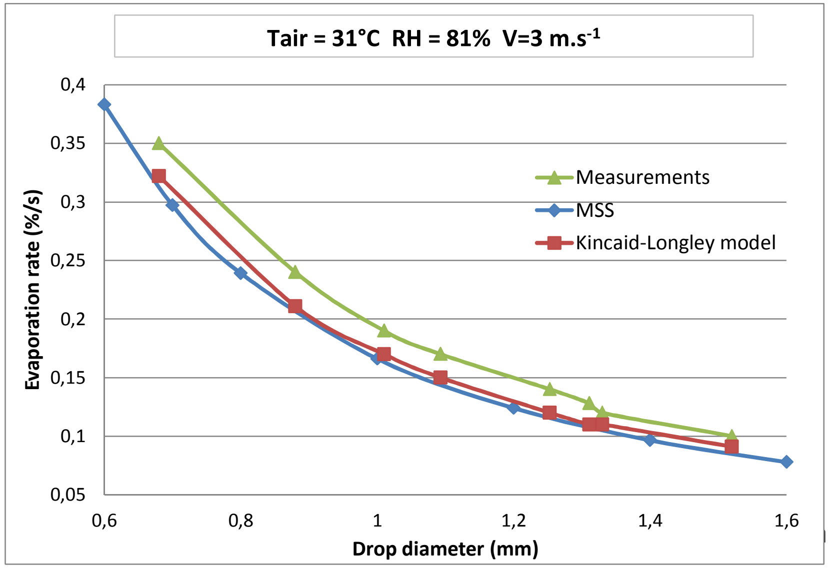
Kincaid et al. : model for T (lagrangian equation) and evaporation rate (energy balance)

Validation test (0D) : Evaporation rate

Comparison : MSS, Kincaid et al. : measurements and model

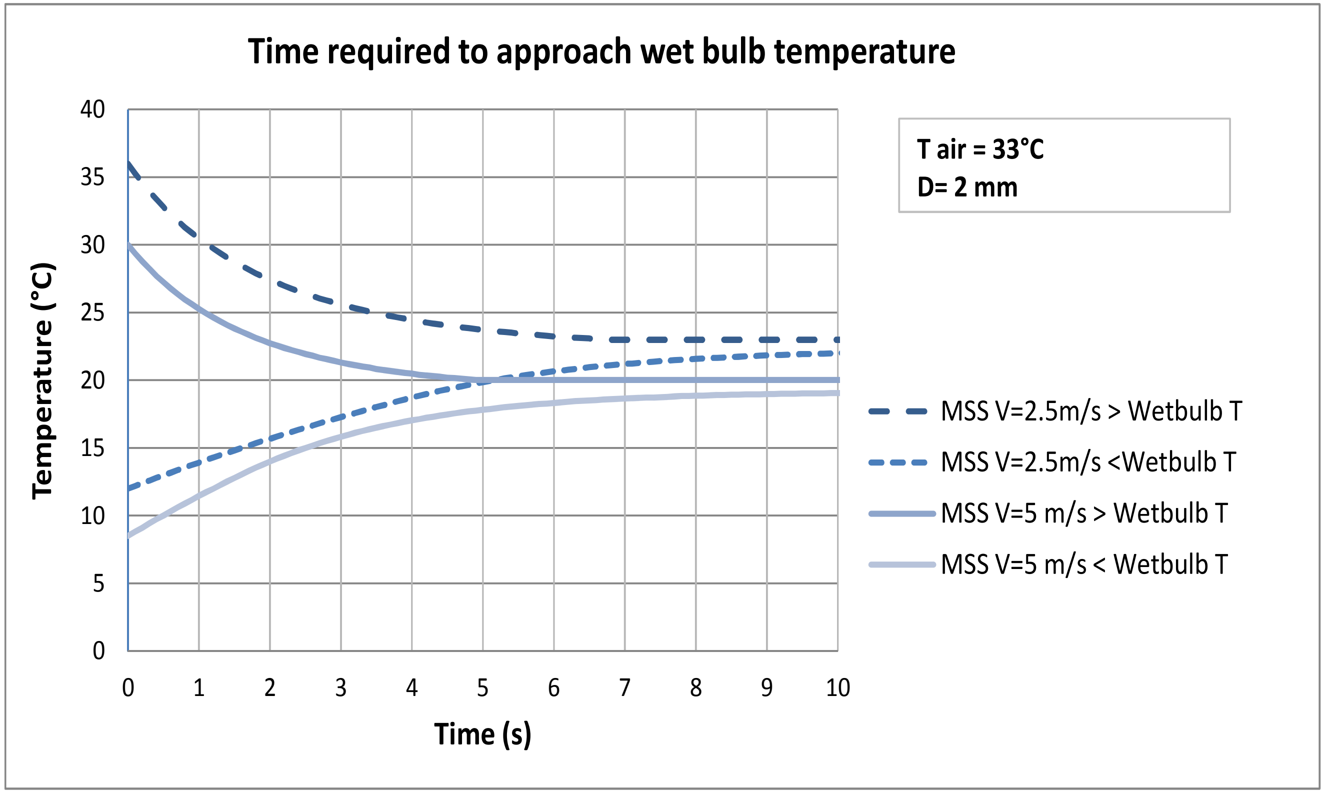


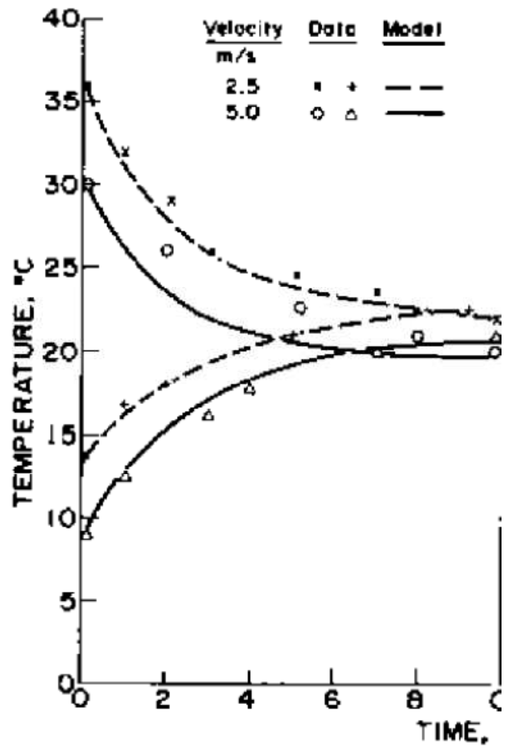




Validation test (0D) : temperature evolution

→Air velocity condition and temperature influence





MSS calculations

Kincaid et al.: measurements and model

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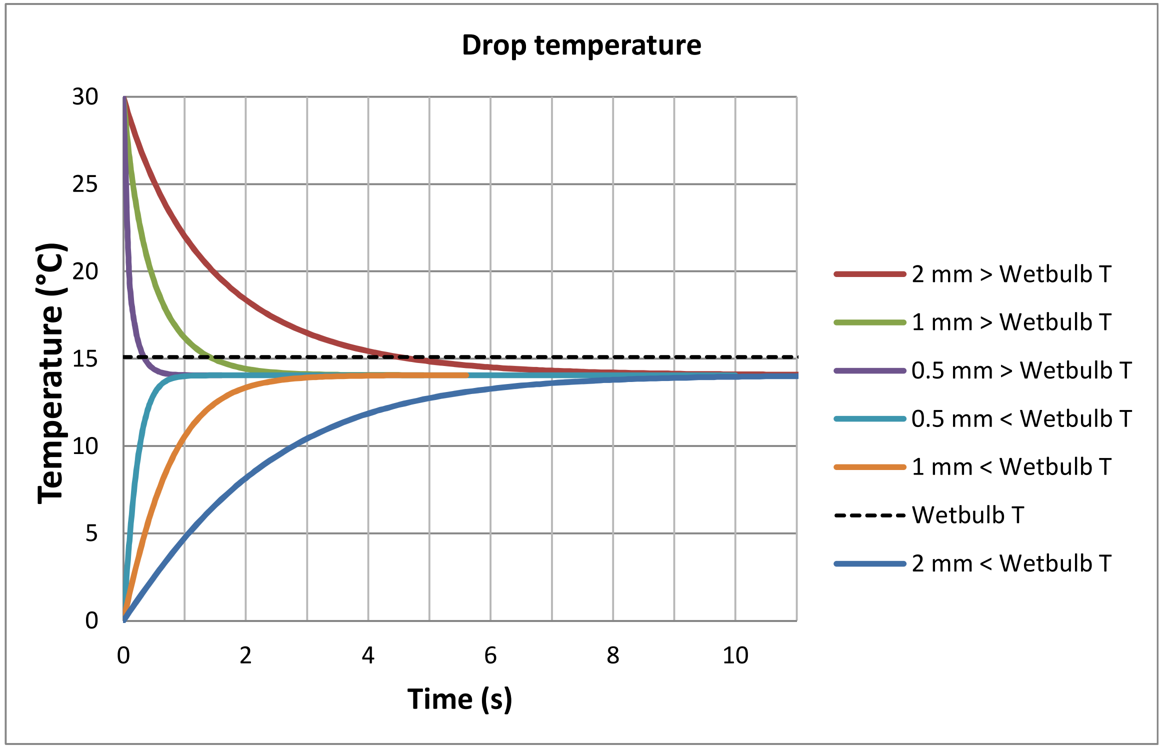
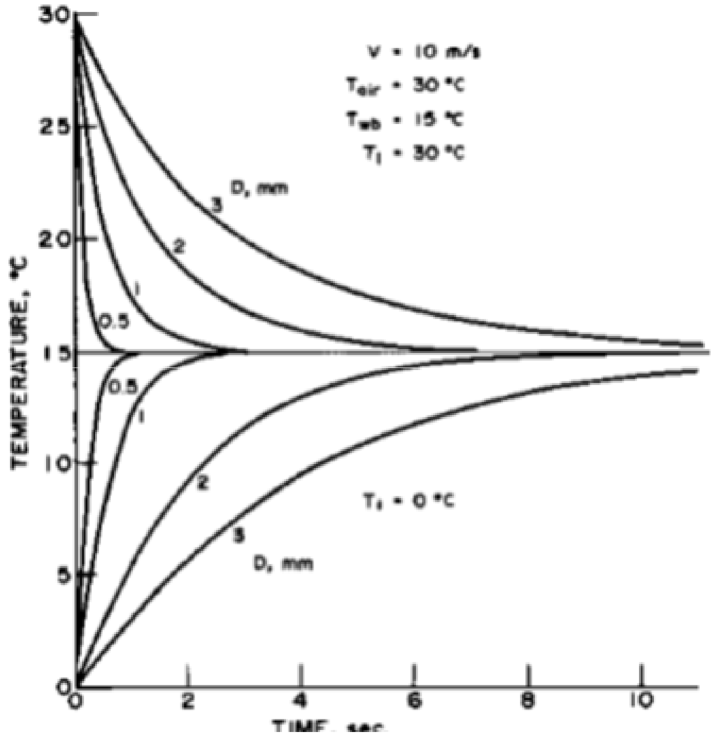
Validation test (0D) : temperature evolution

→ Drop size influence



MSS calculations



Kincaid et al. model

Synthesis

Inside the virtual particles of the lagrangian models:

- Liquid water droplets
- Vapour
- Microorganisms included inside the water droplets
- After total evaporation the isolated microorganisms are transported as free airborne

Evaporation:
Laws for evaporation rate and temperature droplet evolution.

Condensation :
When the saturation level is reached, all the exceeding vapour mass is distributed into new droplet.

Comparisons with other dispersion models

- *Code_Saturne*

Open sources CFD model developed by EDF, with atmospheric module

Version 3.0 was released in march 2013, with humid atmosphere model based on E. BOUZEREAU PhD (2004) : 3 equations (number of droplets, total water, virtual potential temperature)

Comparison not available yet because of late availability

- *GEDEON*

Model developed at EDF in the 80s, based on KESSLER scheme:

3 equations : cloud water, rain water, vapour water.

Instantaneous mass transfer between the different phases

Validated on METEOTRON experiment (1000 MW cooling tower)

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Biological model

When water droplets are totally evaporated, microorganisms are released and transported as free airborne tracers.

Assumption : microorganisms are safe inside the water droplets and impacted by solar radiations, temperature and humidity when isolated (not contained in a water droplet).

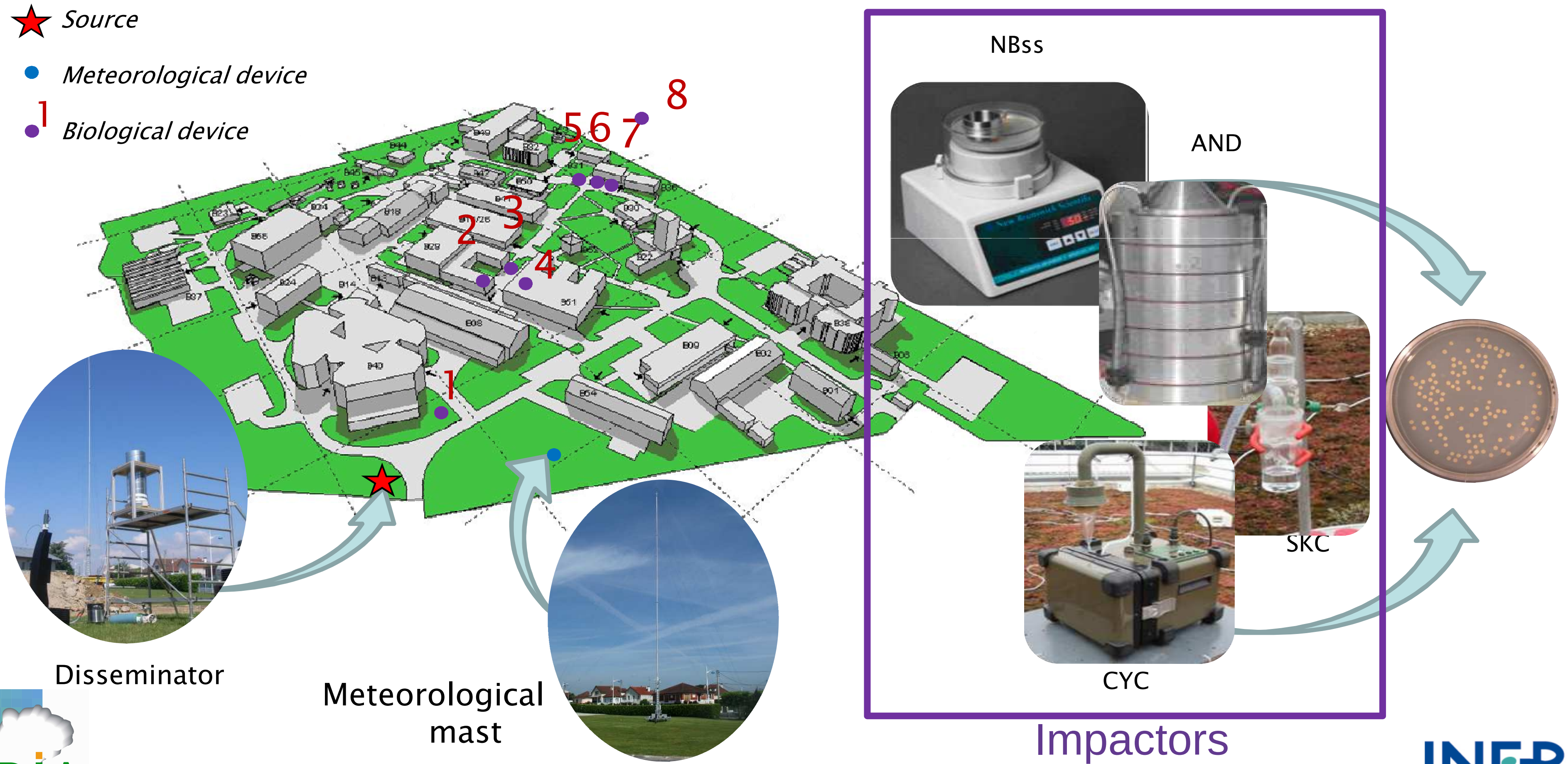
Following the law:

$$N_{spores}(t+\Delta t) = N_{spores}(t).e^{-\alpha_i.\Delta t}$$

Where α (T,Rad,HR) is the decay parameter.
For legionella we used the values issued from (Ti Lan Ha,2005)

Local scale experiments: release in suburban area
(Tognet et al., Harmo 14)

3 releases of Inoffensive spores ***Bacillus Globigii*** *(known as BG spores)*.
were carried out in suburban areas by CSTB, DGA (NRBC) and INERIS in June 2009.



Numerical simulation

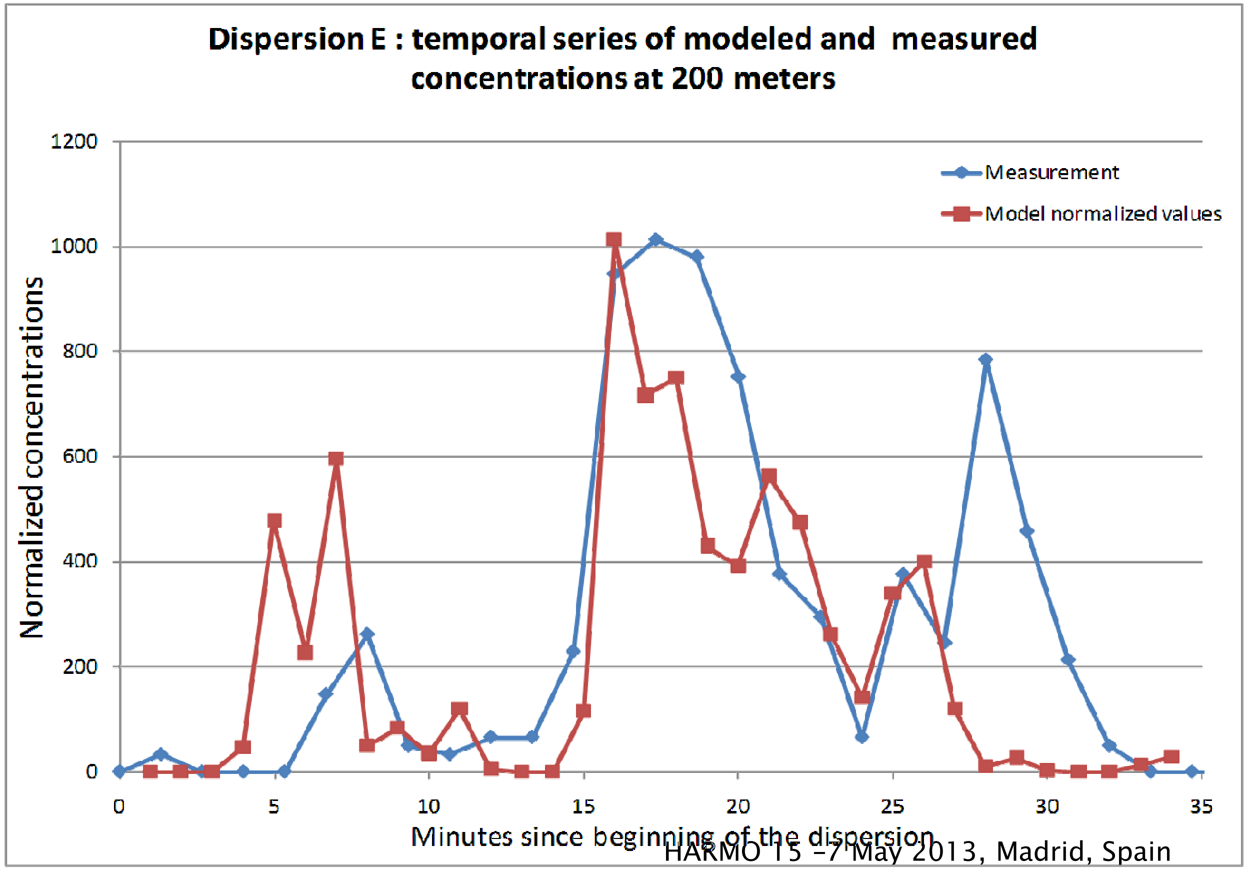
Wind flow: 1 minute meteorological time step using the micro swift meteo processor.

Source term: liquid mass flow rate, water droplet spectrum, vapour flux

Wet plume behavior modelled:

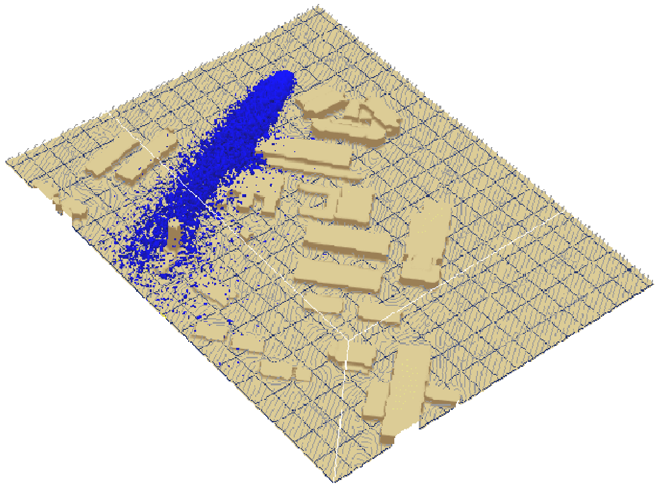
quick evaporation of the water droplet, (input : dry atmosphere and hot temperature)

Then, the dispersion of the spores are modelled as free airborn.



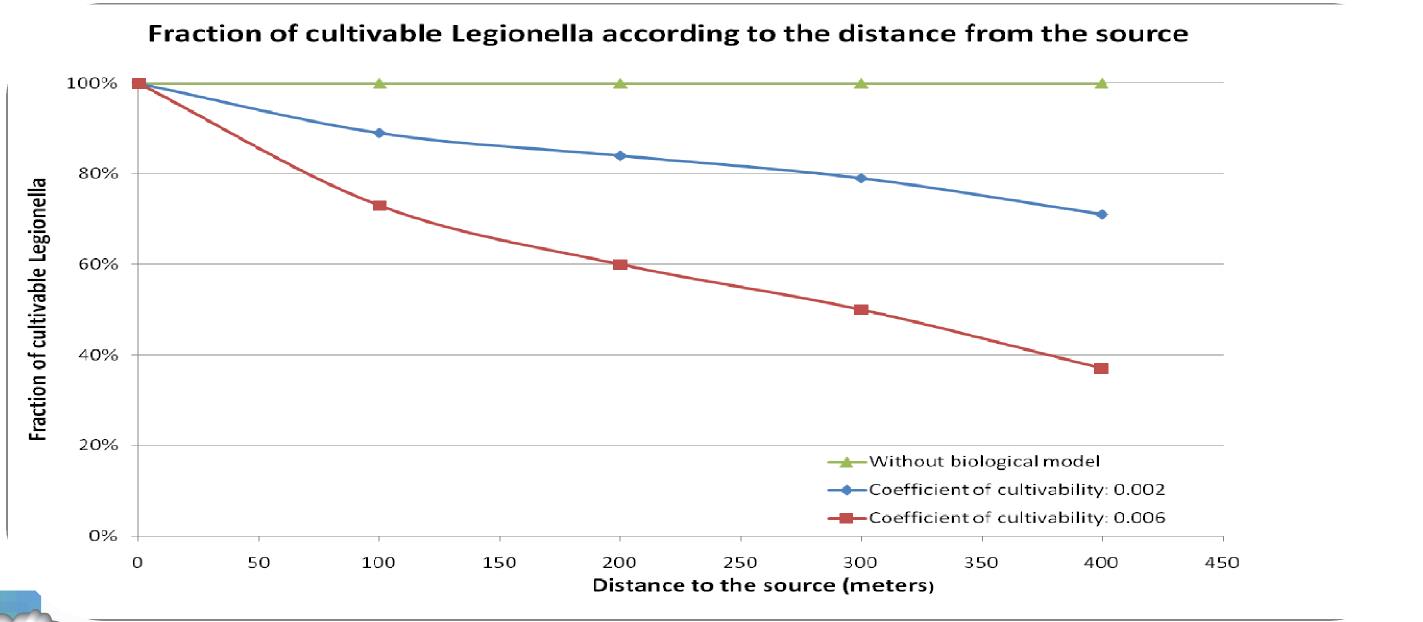
The biological model was not apply for these simulations, because of this kind of spores which are really resistant,

Test of the biological model



CSTB performed an experimental caracterisation of a small cooling tower.

Simulation of fictive dispersion of *legionella pneumophila.*



α1: stress since emission.

α2 (T,Rad,HR).

Concluding comments

- A good behaviour of the thermodynamic equilibrium model is obtained
- Promising comparisons with experimental tests
- Perspectives : comparisons with other dispersion models :
  - open source Code_Saturne
  - Spray version (L. Mortarini et al., Harmo 14)