SARRIM
AN OPERATIONAL TOOL FOR ROCKET RELEASES IMPACT ASSESMENT

Marco Cencetti[1], Vince Veilleur[1], Armand Albergel[2] and Christophe Olry[2]

[1] CNES, Service Environnement et Sauvegarde Sol, BP 726 97387 Kourou cedex – France

[2] ARIA Technologies – 8-10, rue de la Ferme – 92 100 Boulogne-Billancourt – France

(aalbergel@aria.fr ; marco.cencetti@cnes.fr)

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Summary

- What releases for what uses ?
  - Launch vehicle propellant in Kourou CSG
  - Nominal launch and failure
- Pollutant dispersion modeling principle
  - Analytical solutions for
    - Stabilized Cloud
    - Short range – Large range
    - Microphysics of Al_2O_3 particles
- Validation
- Launcher explosion
- Batch mode ➔ Statistical approach
- Conclusion

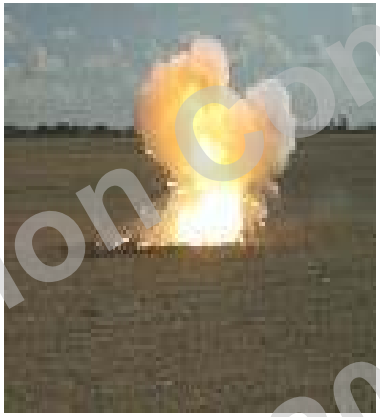
Solid or liquid propellant ?

ATMOSPHERIC POLLUTANTS	
Propergol	**Hypergol**
Solid propellant	**Liquid propellant**
HCl	MMH
CO	UDMH
CO2	HNO3
AL2O3	N2H4
NOx	…

For what use ?

Nominal launch

Launch failure (fire ball and scattered solid propellant)

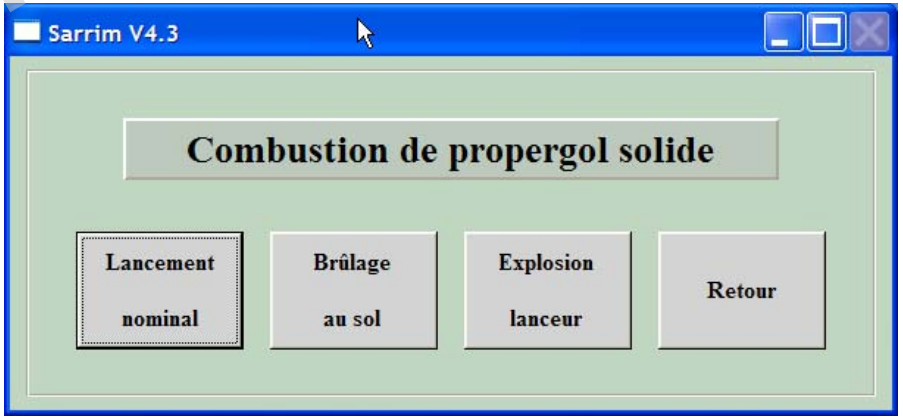


Solid propellant fires

Booster test bench (BEAP)

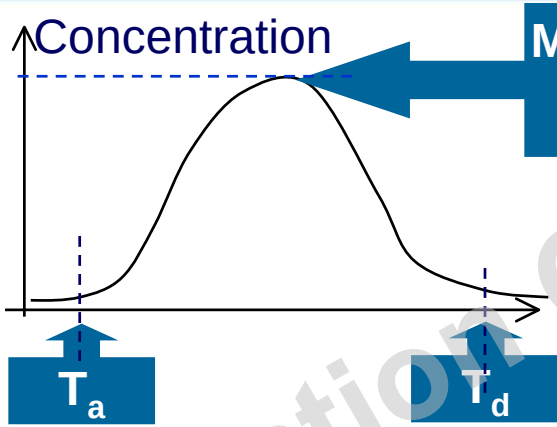
Ariane 5 ➔

240t x2 of solid propellant burnt in 120s



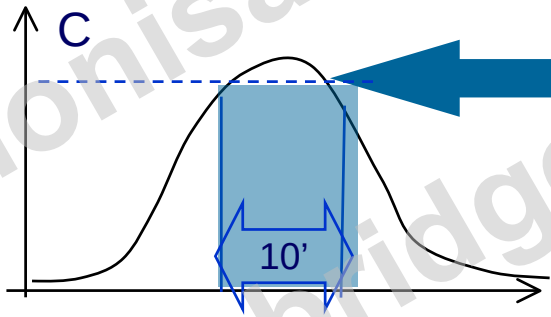
Computed parameters

- 5 values per receptor
- Ta, Td
- Peak, 10mnMax, 'Dose'



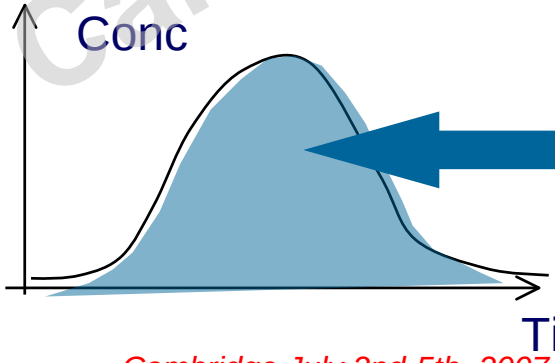
Max « peak » value

ppm



Max «10mn average»

ppm



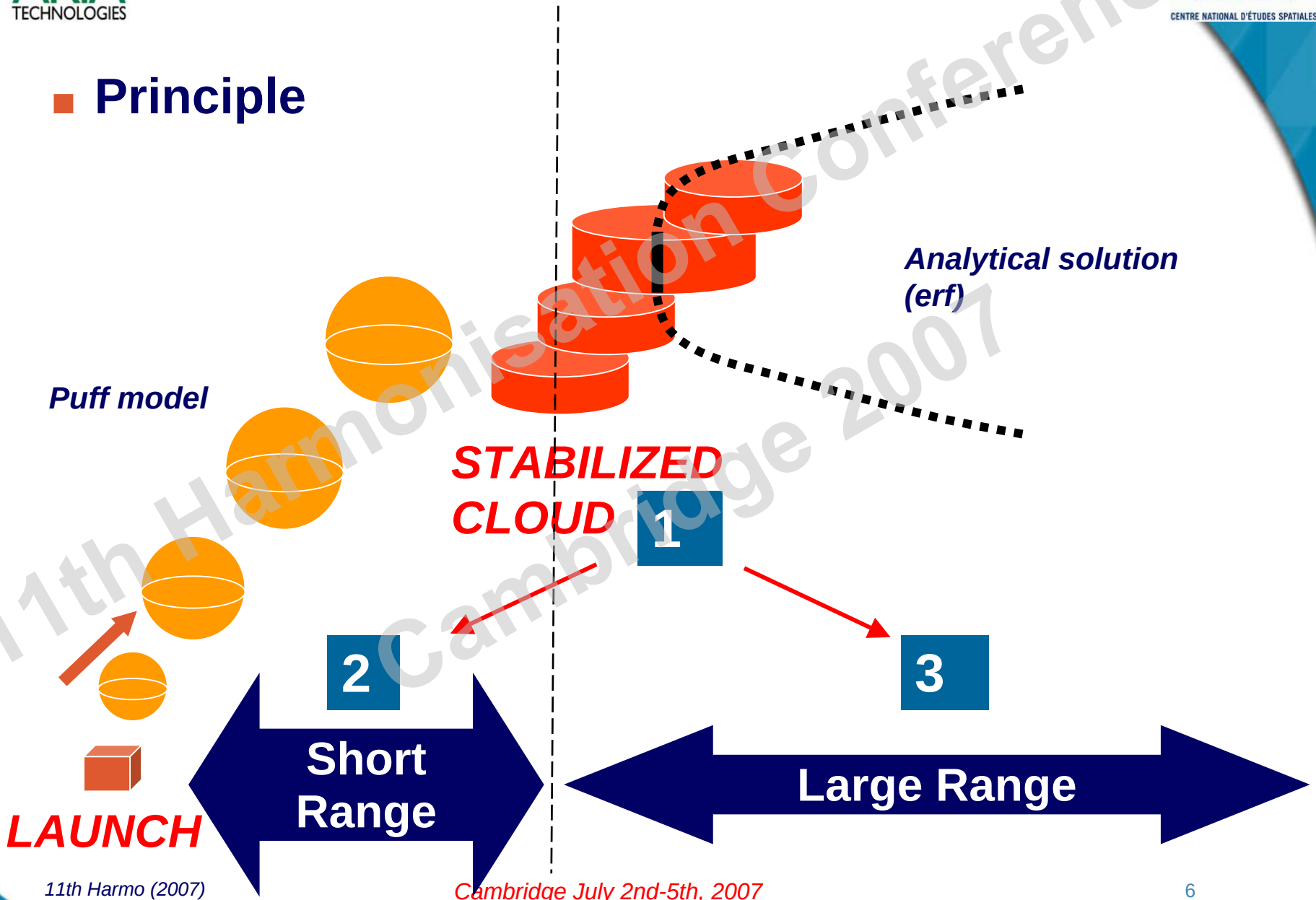
Dose =

ppm*s

$$\int_0^{+\infty} C(t)dt$$

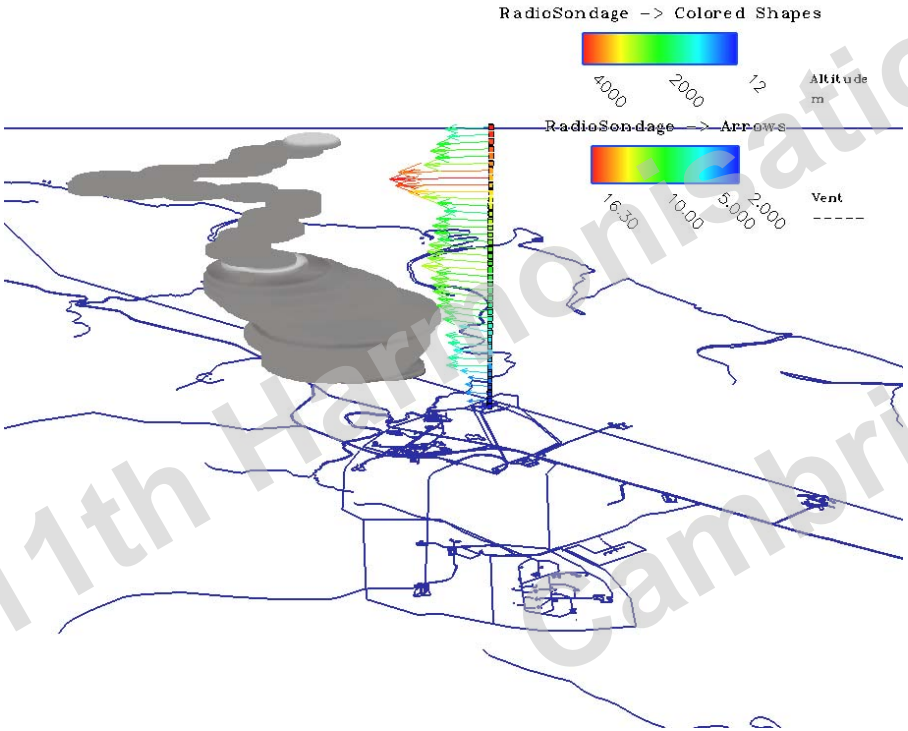
Dispersion : a 3 steps algorithm

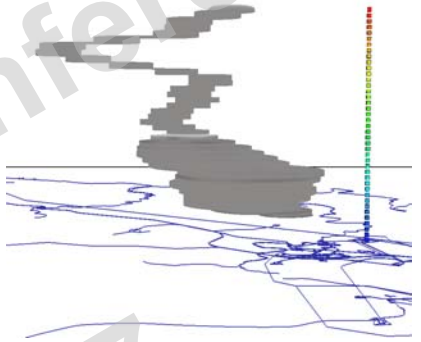
- **Principle**



Dispersion : a 3 steps algorithm

STEP 1 : The « stabilized » Cloud





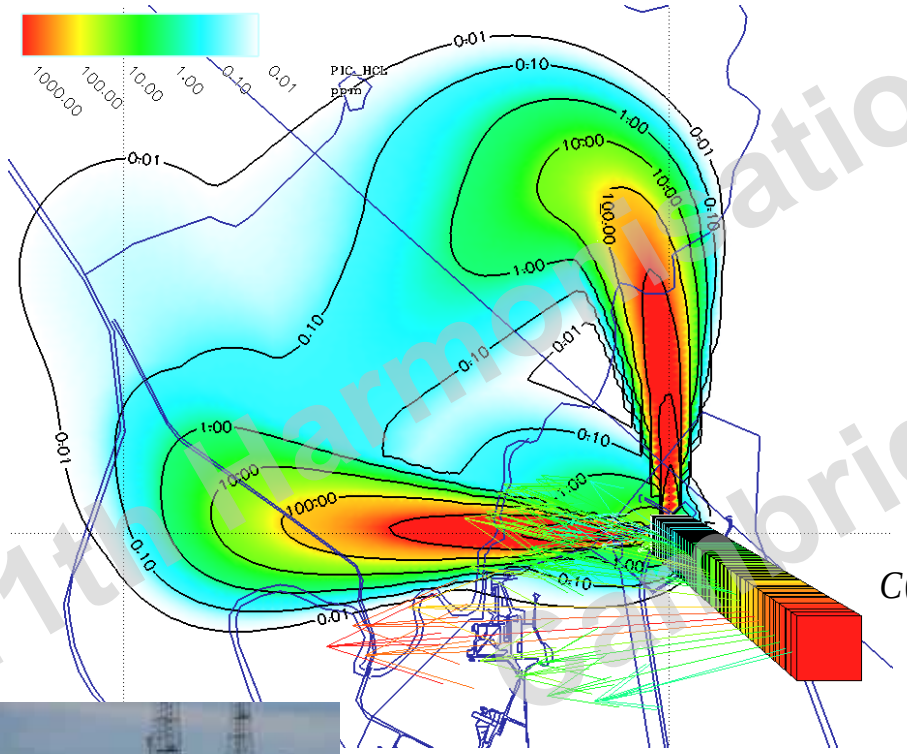
Analytical iterative BRIGGS formulation where the virtual potential temperature gradient is computed from ground to the kth layer :

$$\frac{\Delta\Phi}{\Delta z} = \frac{\sum_{i=1}^{k} \left\{ \left[z_i - \left(\sum_{j=1}^{k} z_j / k \right) \right] \left[\Phi_i - \left(\sum_{\varphi=1}^{\kappa} \Phi j / k \right) \right] \right\}}{\sum_{i=1}^{k} \left[z_i - \left(\sum_{j=1}^{k} zj / k \right) \right]^2}$$

Thermal Launch pad's deluge system effects are also considered

Dispersion : a 3 steps algorithm

STEP 2 : Short range impact

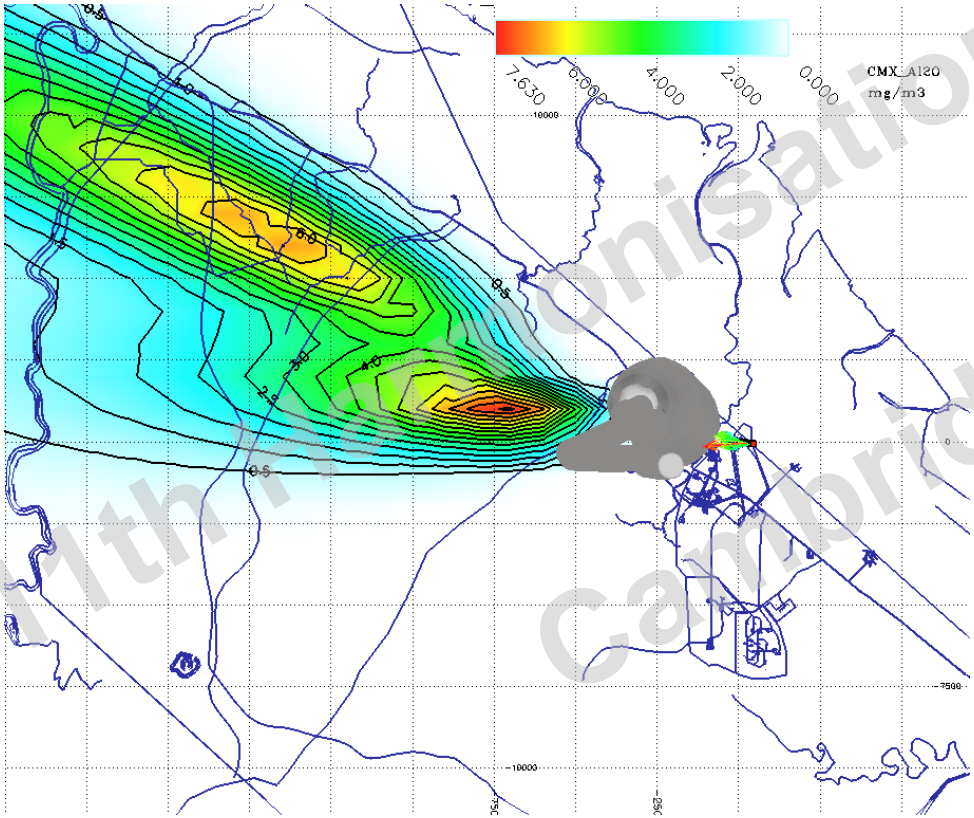


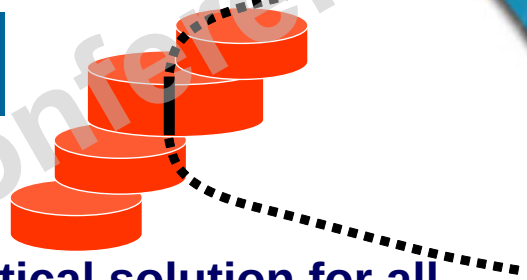
Analytical puff model : puffs follow 3D trajectories computed from initial condition (flame trenches including) and final stabilized cloud

$$C(x,y,z,t) = \sum_{i=1,N} \left[\frac{M_i}{(2\pi)^{3/2}\sigma_{ih}(t)^2\sigma_{iv}(t)} \times \exp\left(-\frac{(x-x_{ci}(t))^2}{2\sigma_{ih}(t)^2}\right) \times \exp\left(-\frac{(y-y_{ci}(t))^2}{2\sigma_{ih}(t)^2}\right) \times \left(\exp\left(-\frac{(z-z_{ci}(t))^2}{2\sigma_{iv}(t)^2}\right) + \exp\left(-\frac{(z+z_{ci}(t))^2}{2\sigma_{iv}(t)^2}\right)\right) \right]$$

Dispersion : a 3 steps algorithm

STEP 3 : Long range impact





Analytical solution for all vertical segment sources :

$$D_{L,K}=\frac{F\{K\}}{2\sqrt{2\pi}\sigma_{yL,K}(z_k - z_{k-1})u_L}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_{yL,K}}\right)^2\right]$$

$$\left\{\sum_{j=1}^{N} fj\left\{\sum_{i=0}^{\alpha}\left[\gamma_j\left[\operatorname{erf}\left(\frac{-2i(z_{tl}-z_{bl})-z_{i-1}+z+V_j x/u_L}{\sqrt{2}\sigma_{zL,K}}\right)\right.\right.\right.$$

$$\left.+\operatorname{erf}\left(\frac{2i(z_{tl}-z_{bl})+z_i-z-V_j x/u_L}{\sqrt{2}\sigma_{zL,K}}\right)\right]+\gamma_j{}^{i+1}$$

$$\left[\operatorname{erf}\left(\frac{2i(z_{tl}-z_{bl})-2z_{bl}+z_i+z-V_j x/u_L}{\sqrt{2}\sigma_{zL,K}}\right)\right.$$

$$\left.\left.+\operatorname{erf}\left(\frac{-2i(z_{tl}-z_{bl})+2z_{bl}-z_{i-1}-z+V_j x/u_L}{\sqrt{2}\,\sigma_{zL,K}}\right)\right]\right]$$

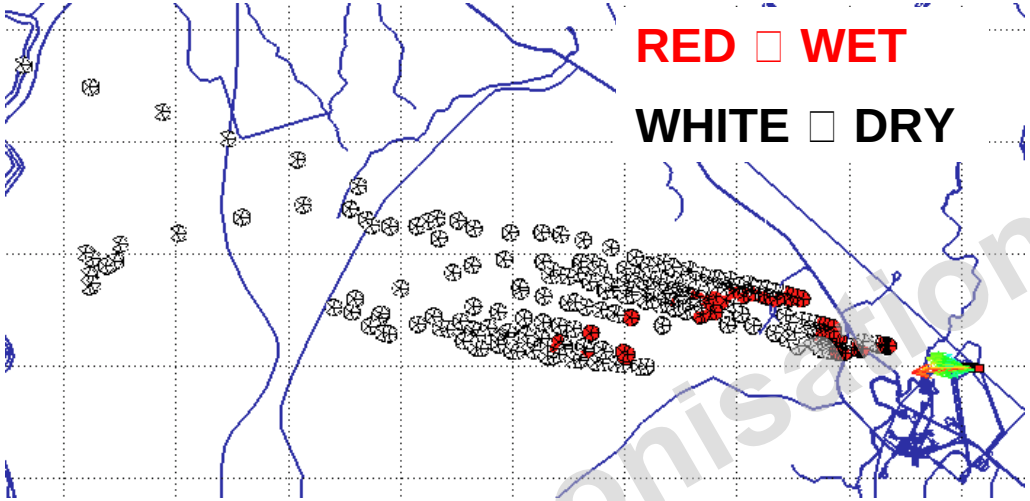
$$+\sum_{i=1}^{\alpha}\left[\gamma_j{}^{i}\left[\operatorname{erf}\left(\frac{-2i(z_{tl}-z_{bl})+z_i-z-V_j x/u_L}{\sqrt{2}\sigma_{zL,K}}\right)\right.\right.$$

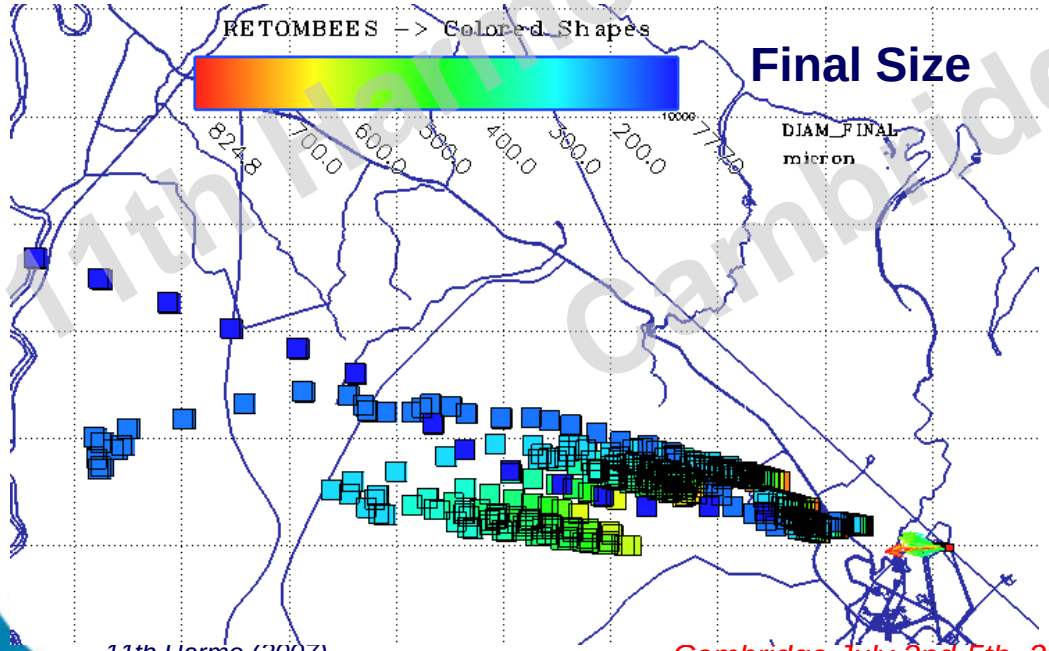
$$\left.+\operatorname{erf}\left(\frac{2i(z_{tl}-z_{bl})-z_{i-1}+z+V_j x/u_L}{\sqrt{2}\sigma_{zL,K}}\right)\right]$$

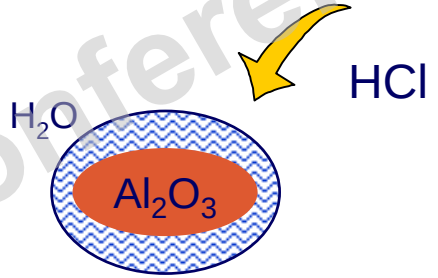
$$+\gamma_j{}^{i-1}\left[\operatorname{erf}\left(\frac{2i(z_{tl}-z_{bl})+2z_{bl}-z_{i-1}-z+V_j x/u_L}{\sqrt{2}\,\sigma_{zL,K}}\right)\right.$$

$$\left.\left.\left.\left.+\operatorname{erf}\left(\frac{-2i(z_{tl}-z_{bl})-2z_{bl}+z_i+z-V_j x/u_L}{\sqrt{2}\,\sigma_{zL,K}}\right)\right]\right]\right]\right\}\right\}$$

Aluminium Oxide (Al_2O_3) case







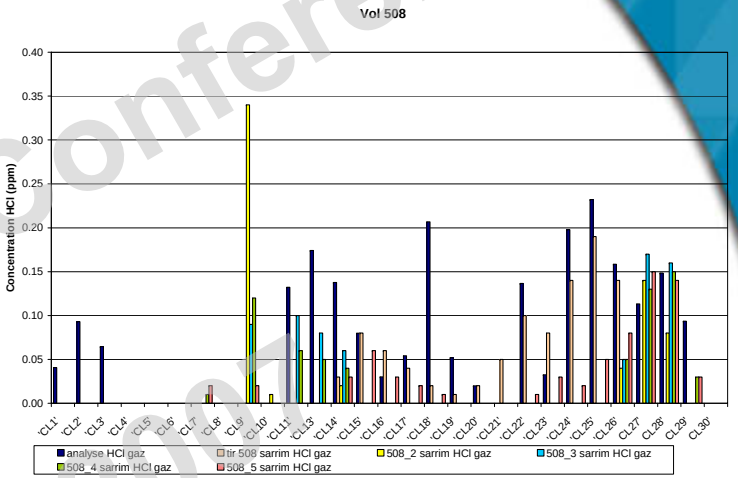
(1) Direct Condensation/ Evaporation process
- F(RH)
- No evaporation from particle ventilation $F(V_g)$

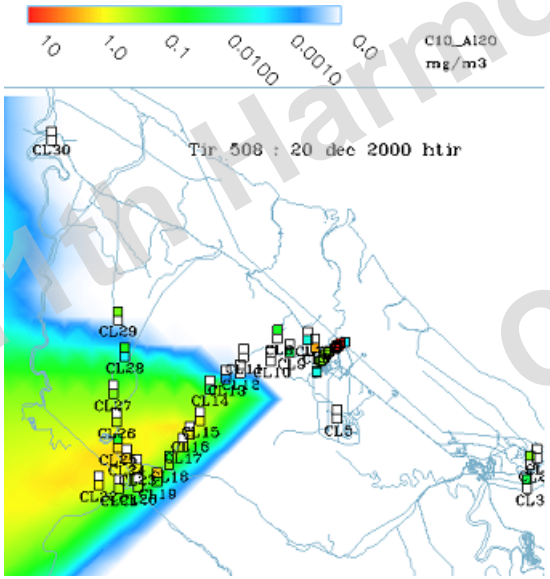
(2) Coalescence process
- When falling collision of big particles on smaller
- No fragmentation of the biggest droplets

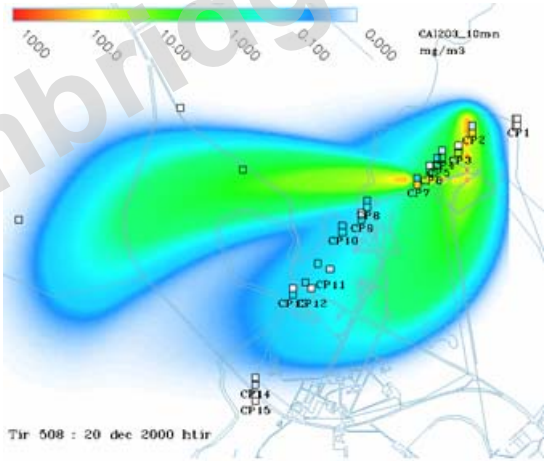
(3) pH Acid from solving HCl
 "Acid rain"

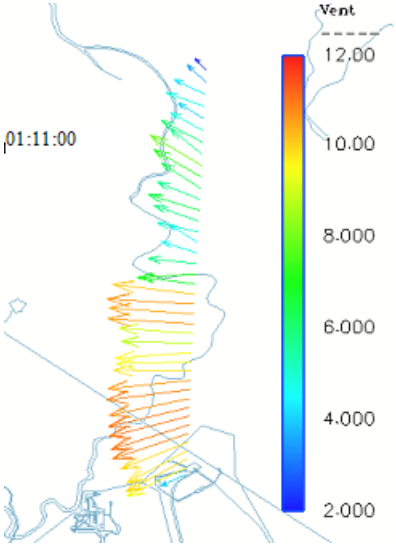
Validation (nominal launch)

- **Cloud rise : Visual evaluation**
  - **helicopter tracking (GPS)**
  - **Photo interpretation**
- **Concentration and deposition**
  - **Environmental Survey plan**

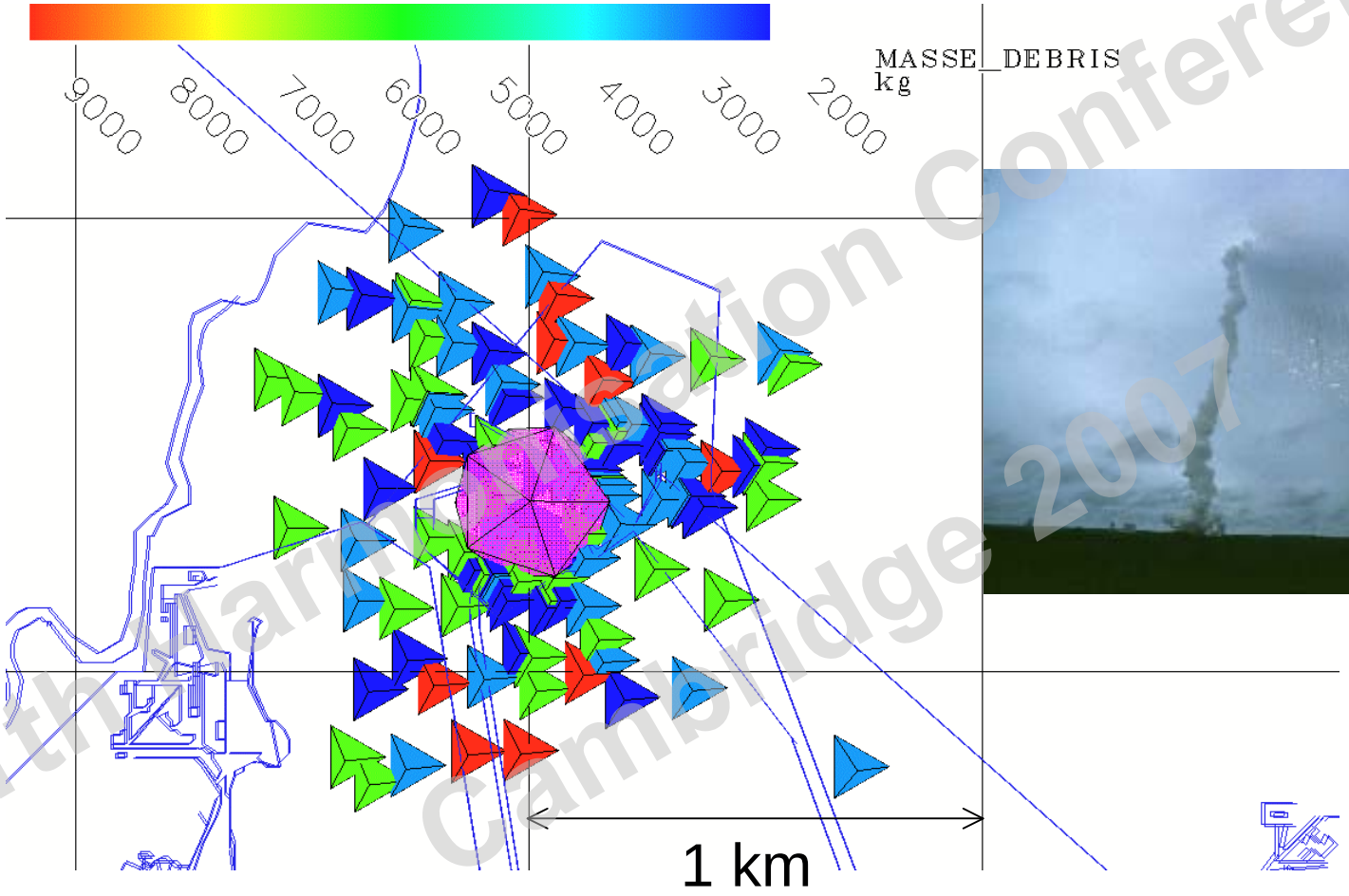








Explosion case



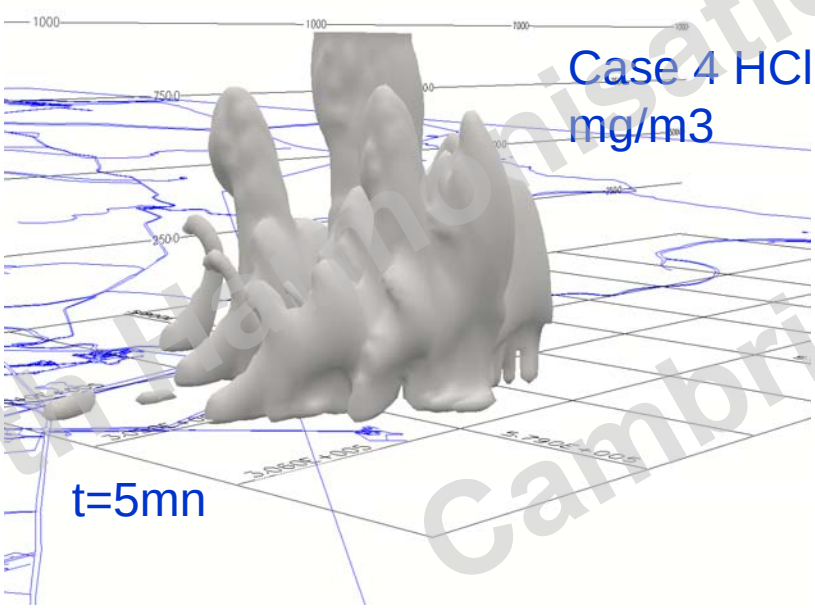
Independant plume from each piece of solid propellant ➔ very high overestimation of ground concentration

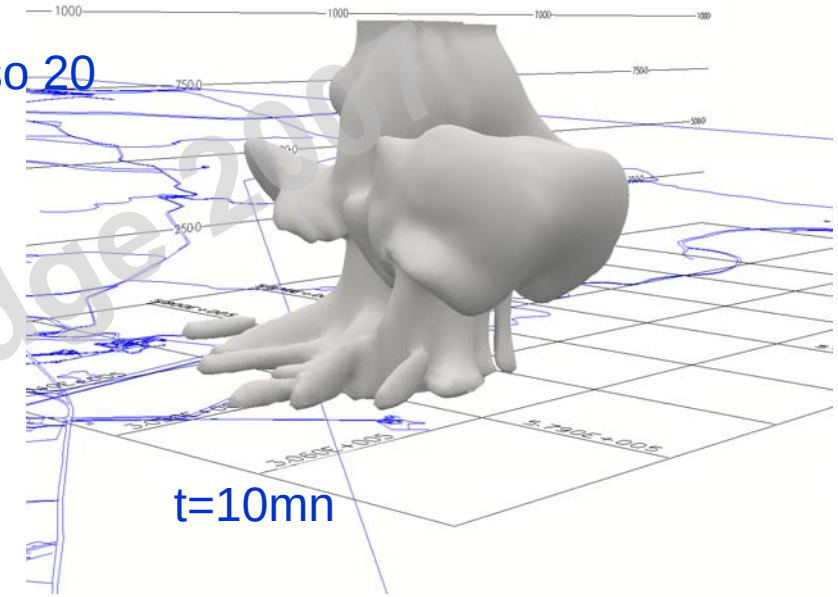
Explosion case

Combination of clouds from pieces

- Two pieces ➔1 cloud if enough overlapping
- Iterative process ➔ “new” clouds may also overlap
- Calibration using CFD (GEDEON/MERCURE Software)

Case 4 HCl iso 20 mg/m3

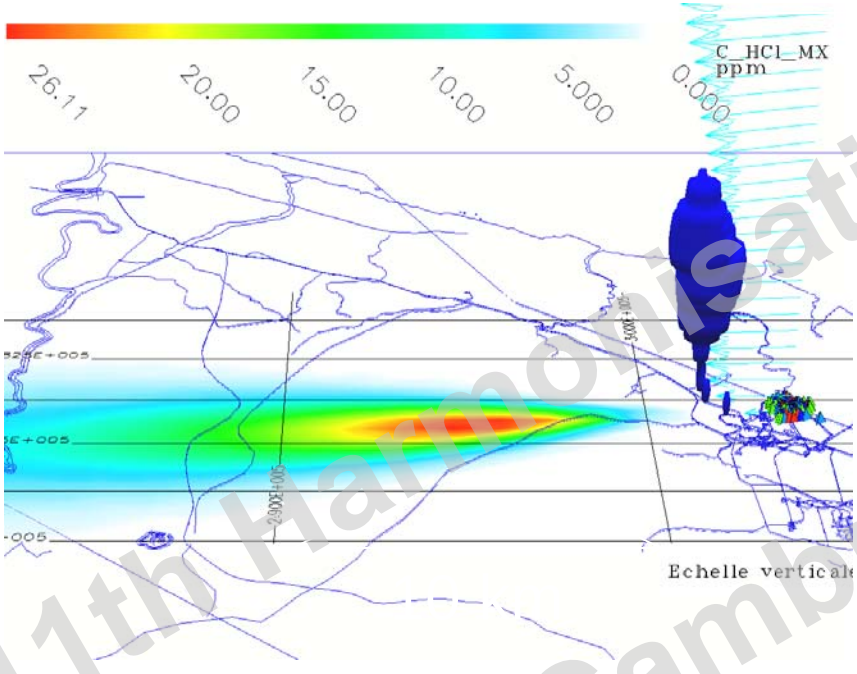


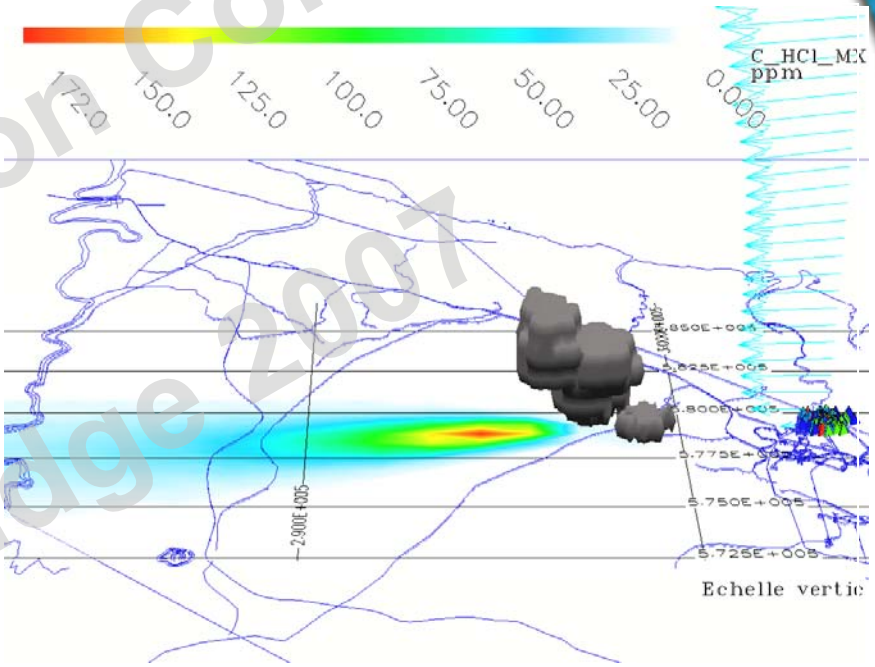


Validation using CFD code GEDEON

Explosion case

Large range





With « fusion »

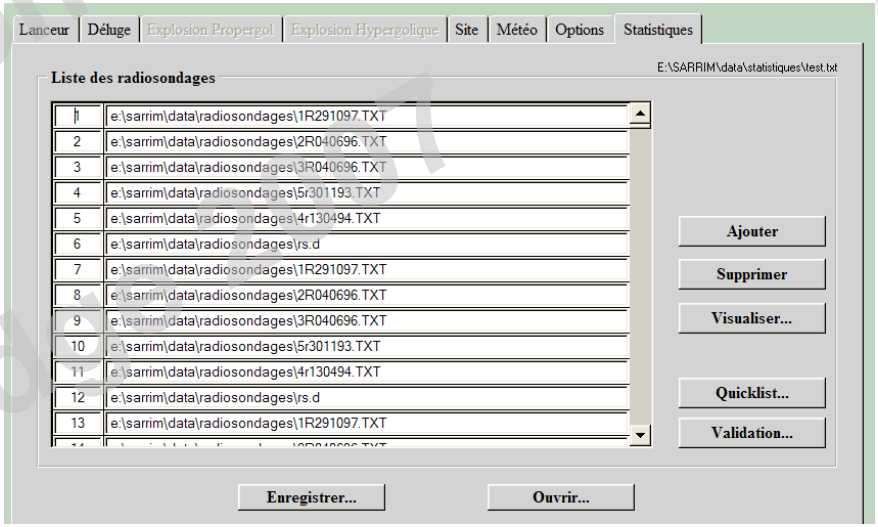
Max 26 ppm

Without fusion

Max 172 ppm

« Batch » mode : Statistical assessment

- Using a 18 years radiosounding (RS) database over Kourou CSG site
  - Routine and Launch radiosoundings
  - « Quick list » button ➔ extraction of profiles
    - Per day / month / hour
- Output
  - Sorted list of RS of maximal impact
  - Map of the localisation of all maximum
- A reduced data set of « worst cases »



Conclusion

- **SARRIM as an operational tool**
  - **CPU Time : OK for use one hour before the launch**
  - **Compatible with regulatory documents in regard of local authorities**
  - **Helpful for safety planning and management**
- **Improvements**
  - **Short range**
    - Not in the initial purpose (large range impact)
    - Present solution too conservative (overestimation)
    - New improvement in comparison with CFD in progress
  - **Forecast mode**
    - Using Forecast profiles
    - Improvement of the Steady-state assumption