Validation of the Atmospheric Module of *Code_Saturne*

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Purpose

The objective of this work is to validate the atmospheric module of the *Code_Saturne 3.0* . To do this, some test cases are used as support for comparison and the validation of the code. In addition, these test cases cover different spatial and temporal scales. Moreover, the chosen test cases are of two kinds: (i) Analytical test cases described by the partial differential equations and Experimental test cases characterized by stored database.

Analytical test cases:

The sea breeze flow: this flow occurs due to the temperature gradients between the land and sea surfaces. Its behavior is described by Defant's solution **[1]**.

Gravity waves over mountain: gravity waves occur under stable atmospheric flow. When the air parcel meet an obstacle, it will be moved upward to higher altitude where the air density is lower. Due to buoyancy, the air parcel oscillates vertically with a frequency of Brunt-Vaissala *N,* given by the thermal stratification of the atmosphere, $N = \sqrt{\frac{g}{\theta_0}\frac{\partial \theta}{\partial z}}$. For the bell-shaped mountain, the solution of gravity waves is described in **[2].**

Experimental test cases :

Heavy gas dispersion: This test case consists of experiment performed in **Thorney-Island [3]** to validate the models of pollutant dispersion. The heavy gas is contained within a cylindrical plastic tent of height 14m which collapses abruptly, and the contained heavy gas is released. The dispersion is monitored by several concentration sensors located at different distance from the source. Moreover, the plume morphology and its spreading were measured using the integral properties of the cloud **[3]**.

Propane jet with flashing: Leakage from the vessel containing pressurized propane . In the vessel, the propane is in liquid state, but when it reaches the aperture, the liquid propane evaporates partially and form a mixture of droplet, propane vapour and air. Experiments in **Germany [4]**. The propane jet with flashing was simulated with a sudden valve opening. In the first stage of the experiment, a wall is placed downstream to investigate the effect of the obstacle. Afterward, the obstacle is removed. In each stage of experiment concentration sensors were placed at different location from the source and used for comparison **[4]**.

Plume dispersion from cooling towers: Experiments on plume dispersion from Natural Draft Wet Cooling Towers (NDWCT) of **Bugey** were performed by EDF from February 27 until 13 March 1980 **[5].** An airplane crosses the plume released from NDWCT at several altitudes to measure the vertical variation of the vertical velocity **w**, liquid water content **ql** and the temperature **T** of the plume. In addition the shape of the plume were stored using the photography. The ambient conditions of the atmosphere during each experiment were measured either by radio sounding or the airplane.

Conclusion

Code_Saturne ATMO module is tested with analytical and experimental test cases. It Appears that it is capable to simulate the multiple processes in the atmosphere Concerning turbulence, dispersion, microphysics. Globally, the *Code_Saturne* ATMO module is validated with a satisfactory accuracy. The best test case is that of sea breeze for which *Code_Saturne* solves exactly the same equations as those of the analytical sea breeze. For the other test cases, some discrepancies occur. They are due either to the RANS turbulence model, that deals with the mean of realizations rather than one realization as the case in different experiments, or to the experimental protocol and sensors accuracy.

Bibliography

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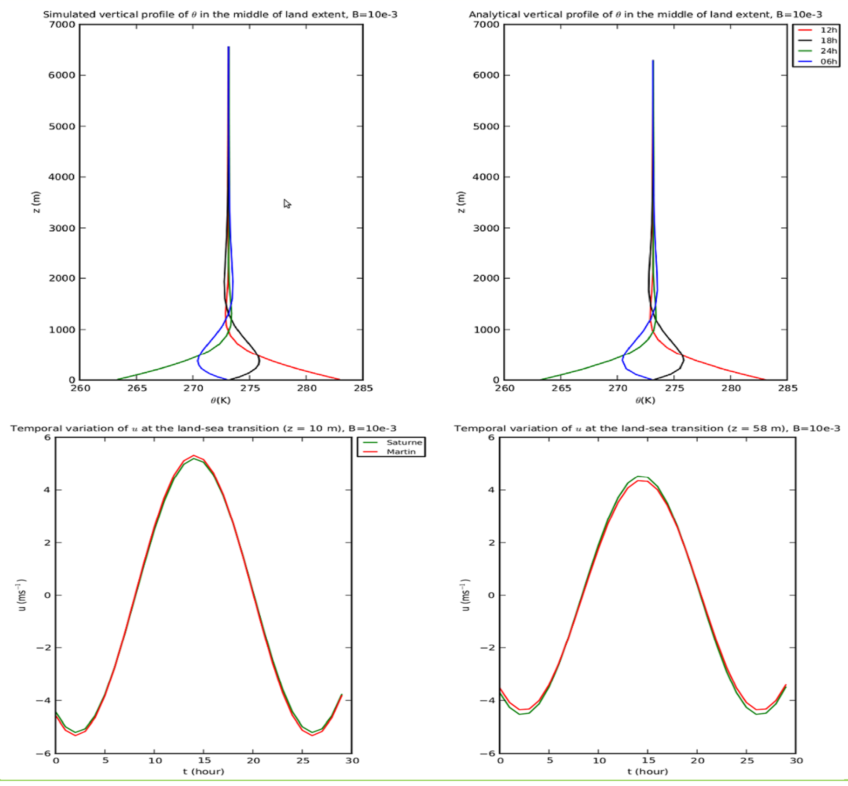
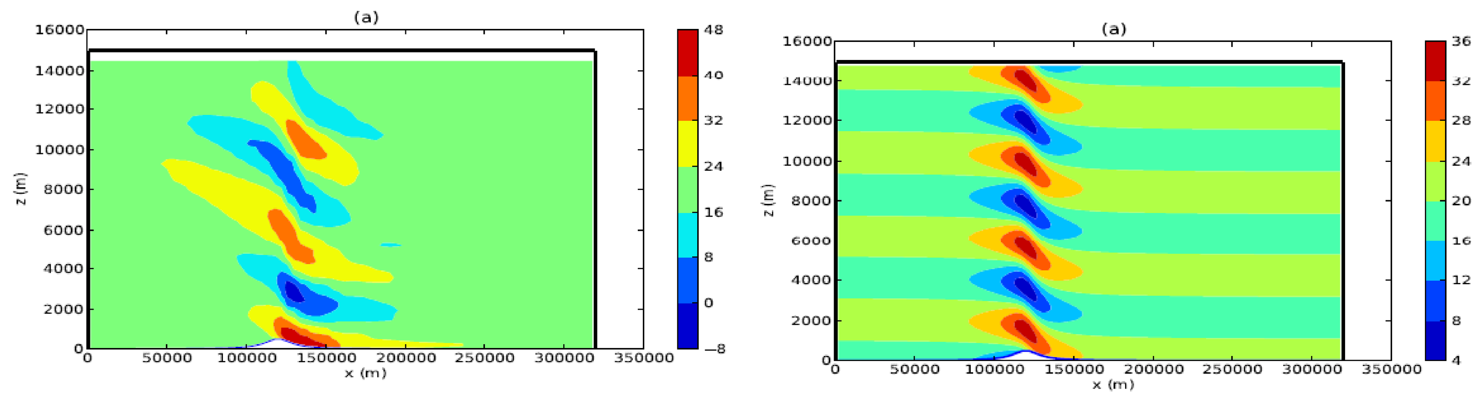
[5] Hodin A., Etude expérimentale des panaches des réfrigérants atmosphériques du Bugey, premier bilan des mesures physiques effectuées entre le 25 février et le 13 mars 1980', *Rapport EDF HE/32-80.33* , Octobre 1980

Code_Saturne parameters and validation results

- Laminar, constant density
- Buoyancy as source term in N.S. equations
- The land-sea surface is forced with a sinusoidal spatio-temporal profile, with temporal period of 24h
- Absence of advection and diffusion in u, w and θ equations



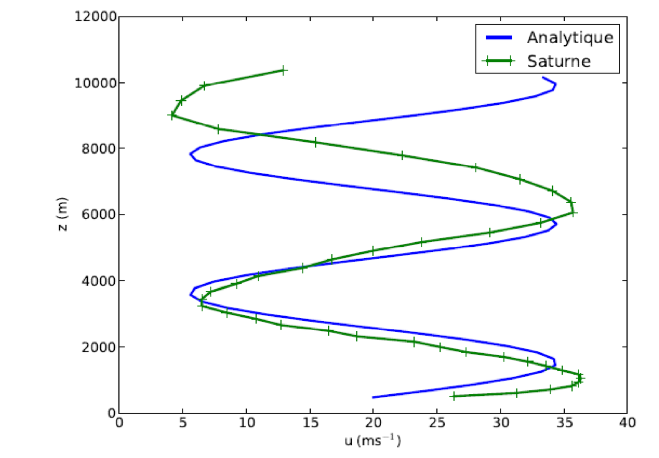
- ✓ 1. The vertical profiles of sea breeze variables agree well with those of analytical model (Martin),
- ✓ 2. The hourly variation of the velocity *u* is in time phase with the analytical one, negligible amplitude and phase errors.



Code_Saturne — Analytical model

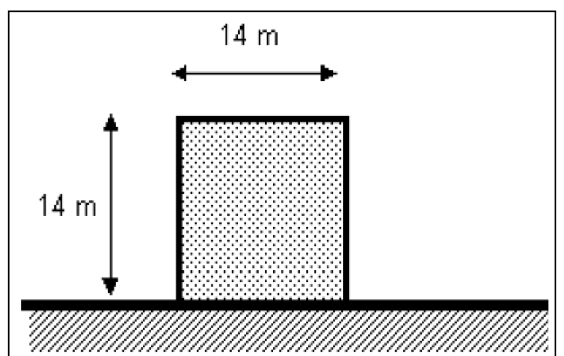
Flow structure over the bell-shaped mountain

- Laminar, dry atmosphere
- Thermodynamic gas perfect law
- Absence of dynamic and thermal diffusion IDIFF(u, w, θ)=0
- Uniform horizontal mean wind (U=20m/s)

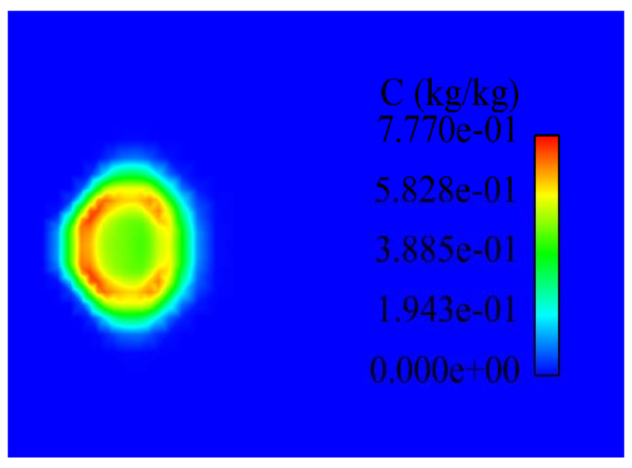


Vertical profiles of the horizontal velocity u at the mountain peak horizontal location

- ✓ The simulated flow structure agree well with the analytical solution
- ✓ The wave length of the structures is almost the same, λ= 4.18 Km
- ✓ The vertical profiles of u are similar, with the vertical shift of the position of the max and min of u.



Cylindrical tent filled with heavy gas before collapse

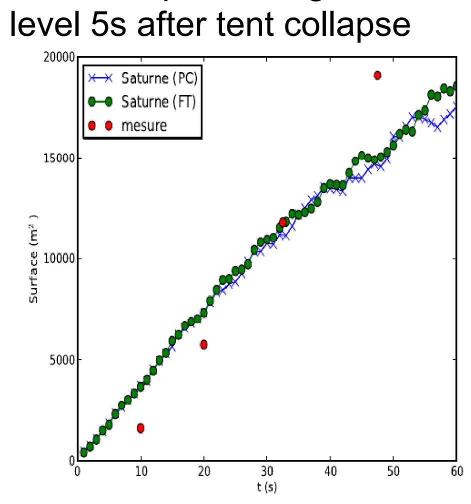


Cloud shape at the ground level 5s after tent collapse

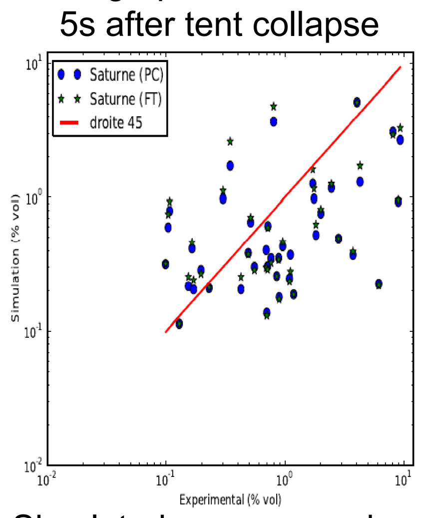
Photograph of the cloud at 5s after tent collapse

- k-ε model for turbulence
- Momentum sink in the volume of tent before collapse.

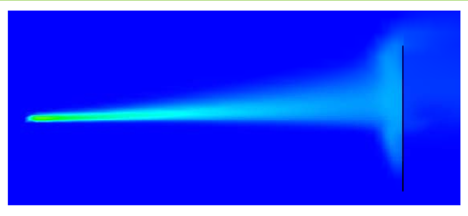
- ✓ The simulated and observed shape of the cloud at t=5s after tent collapse are the same: formation of the toroidal vortex
- ✓ The time variation of the top view area of the dispersed heavy gas cloud is well reproduced with *Code_Saturne*
- ✓ The simulated dose in different sensors location are around the red symmetry line: satisfactory agreement.



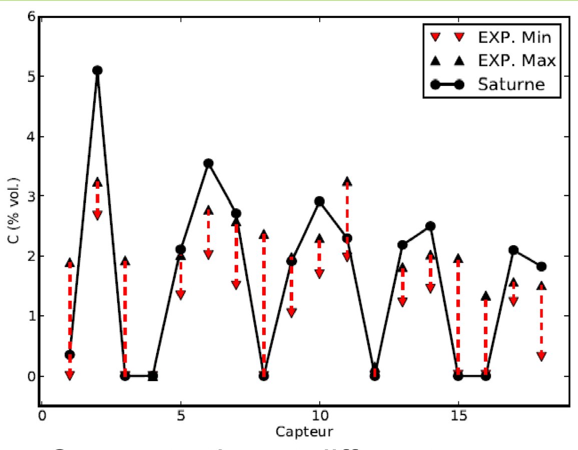
Top view area of the heavy gas cloud



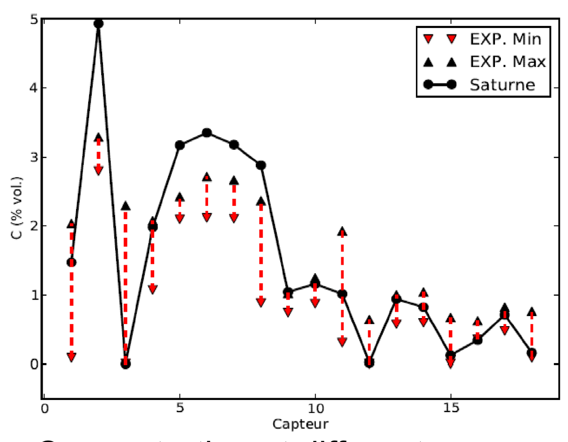
Simulated vs measured concentration doses



Top view of the gaseous propane cloud with wall



Concentration at different sensor locations without wall

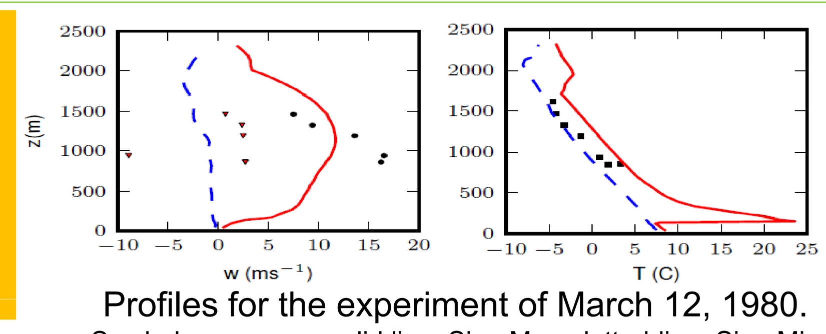


Concentration at different sensor locations with wall

- k-ε model for turbulence, dry atmosphere
- Thermodynamic of the propane mixture
- Thermodynamic isenthalpic equilibrium model for propane phase change.

- ✓ The simulated concentration are within the variation of the measured one
- ✓ The effect of the obstacle on propane dispersion is well detected by Code_Saturne: concentrations in the sensors located downward the obstacle are lower than in the absence of obstacle.

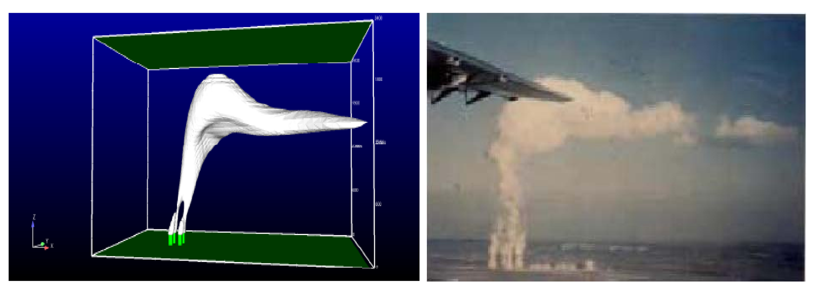
- k-ε model for turbulence, humid atmosphere
- Microphysics law for water and cloud
- Each tower is modeled as hexahedral volume, with dirichlet conditions at their top for plume release conditions.



Profiles for the experiment of March 12, 1980.

Symbols: measure, solid line: Sim. Max, dotted-line: Sim. Min

- ✓ The vertical profiles of w and T are well reproduced by *Code_Saturne*.
- ✓ The shape of the simulated and observed plumes are similar.



Simulated (ql=5e-5 kg/kg) and observed shape of the plume