13th Information Day - *Cedre*
Hazardous pollution by HNS

Aerial modelling

Dispersion mechanisms and simulation

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maîtriser le risque
pour un développement durable

Presentation plan

Introduction

- Dispersion of a hazardous material in the atmosphere

Atmospheric dispersion - Main mechanisms and impact parameters

- Characterisation of the release of pollutant
- Impact of cloud density
- Impact of meteorological and orographic parameters

Atmospheric dispersion - Models

- Gaussian
- Integral
- Complex (CFD)

Introduction (1/3)
Dispersion of a hazardous material in the atmosphere

EMISSION

(Accidental) release
or « source term »

- gas or liquid jet
- instantaneous release (liq/gaz)
- evaporating pool
- fire smokes...

Atmosphere (humid air)

- meteorological conditions
- sea surface (waves)
- coastal zone...

TRANSPORT
DIFFUSION
(Dispersion)

Toxic effects
(inhalation, ingestion)

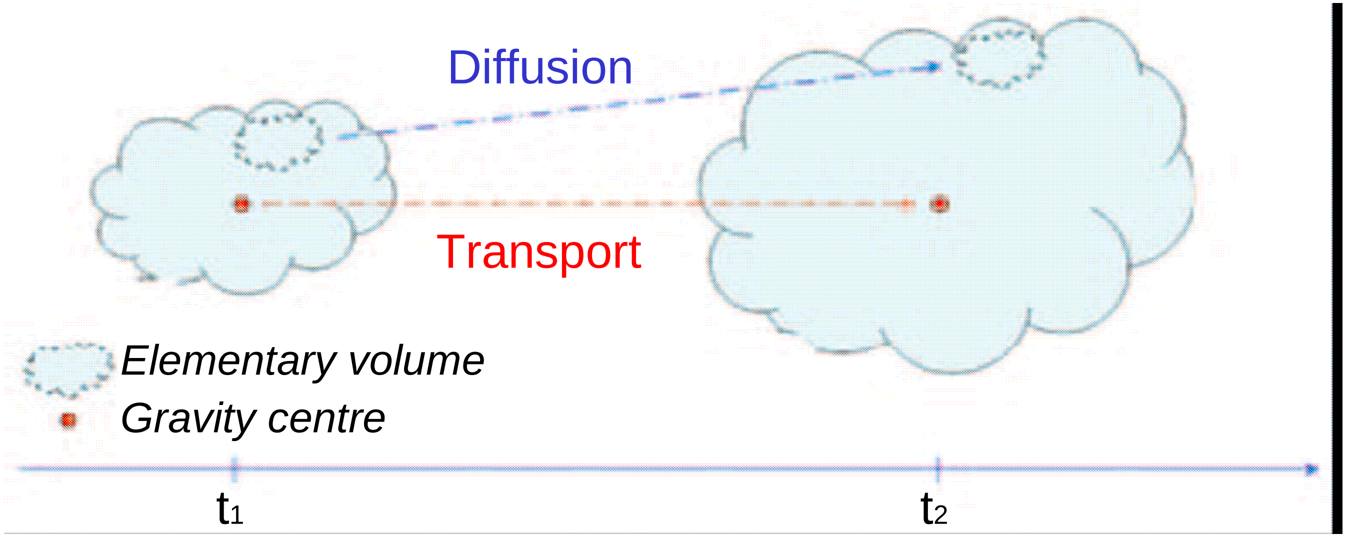
Thermal effects
(ignition)

Pressure effects
(explosion)

Targets/stakes

- Human (emergency services, coastal population...)
- Environnemental

Introduction (2/3)
Dispersion of a hazardous material in the atmosphere
Transport and diffusion



Representation of the atmospheric dispersion process

(from F. Jourdain, 2007 - Techniques de l'Ingénieur)?

Transport : by wind, depending on cloud density, initial velocity of release
Diffusion : by atmospheric turbulence (surface friction, thermal gradient)

Introduction (3/3)
Dispersion of a hazardous material in the atmosphere
Main impact parameters

- Wind profile and surface roughness
- Thermal gradient (atmospheric stability)
- Obstacles & topography (ships, coastal zone...)
- Characterisation of material and release

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Characterisation of source term (1/2)
Types of emissions

- Storages at ambiant pressure

  - liquide material at ambiant temperature

  (saturated vapour pressure < 1 atm, at T_{amb} - ex. : styrene, xylene, benzene)

  - refrigerated liquefied gas (ex. : NH_3 at -43°C, LNG at -162°C)

  ⇒ LIQUID RELEASES

Navire transporteur de gaz équipé de citernes pressurisées

surised storage

  - pressurized liquefied gas (ex : LPG) ⇒ TWO-PHASE
  - gas under pressure ⇒ GASEOUS

- Fire emitting smokes

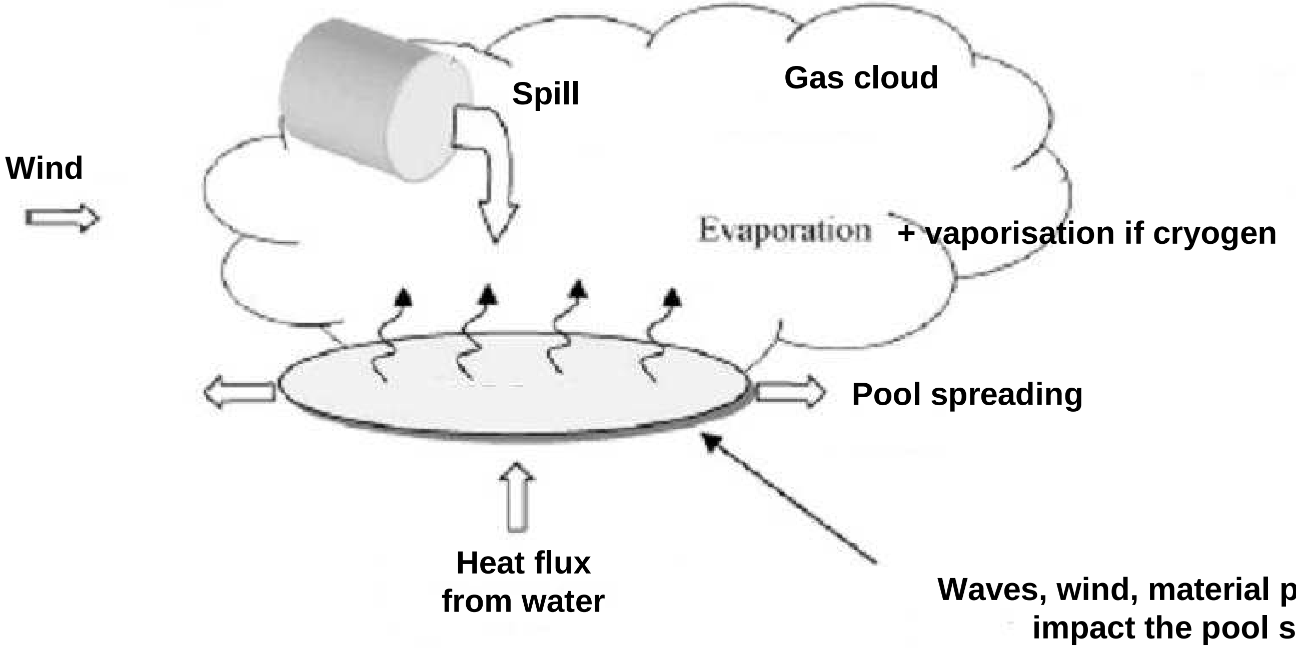
  ⇒ GASEOUS RELEASE + soot

LNG pool fire over water
(Gaz de France)

Oil-tanker Limburg (10/2002)
Cargo fire

Characterisation of source term (2/2)

- Instantaeous release (sudden aperture of a tank)
- Continuous release (long-lasting leak on a tank)



Release conditions
(pressure, temperature, location/water)

+ vaporisation if cryogen

Pool spreading

Heat flux
from water

Waves, wind, material properties, obstacles
impact the pool size and shape

(From Luketa-Hanlin, 2006)

Illustration - Release of liquefied gas over water

Impact of the density of released materials

	> Passive gas	> Dense gas	> Buoyant gas
Origin?	• Same density as air • Very diluted with air • no inertial jet	• High density at T_{amb} (Cl_2, $COCl_2$…) • Two-phase release (pressurized LPG) • Cooled gas	• Low density at T_{amb} (H_2, CH_4, NH3 gas...) • hot gases (fire smokes…)
Consequences?	• Transport at wind velocity • Dilution by atmospheric turbulence	• Gravity effects ⇒ collapse ⇒ increased dilution at cloud lateral faces • Higher surface friction • High concentrations at surface level	• Elevation • Increased dilution by wind shear • Lower concentrations at surface level

Illustration - Release of liquefied ammonia

- Movie : Release of ammonia in free field (over flat terrain)

  INERIS Trials, 1997 (movie Trial 2)

TRIAL N°2

Horizontal free jet Ø 20 mm

ESSAI N°2

Jet libre horizontal Ø 20 mm

Dispersion of a hazardous material in the atmosphere
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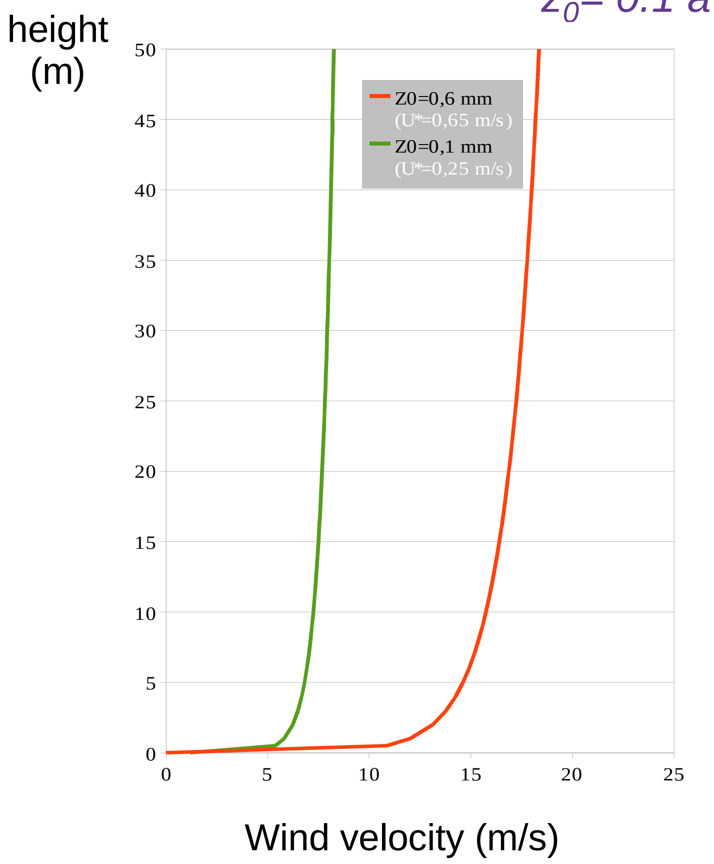
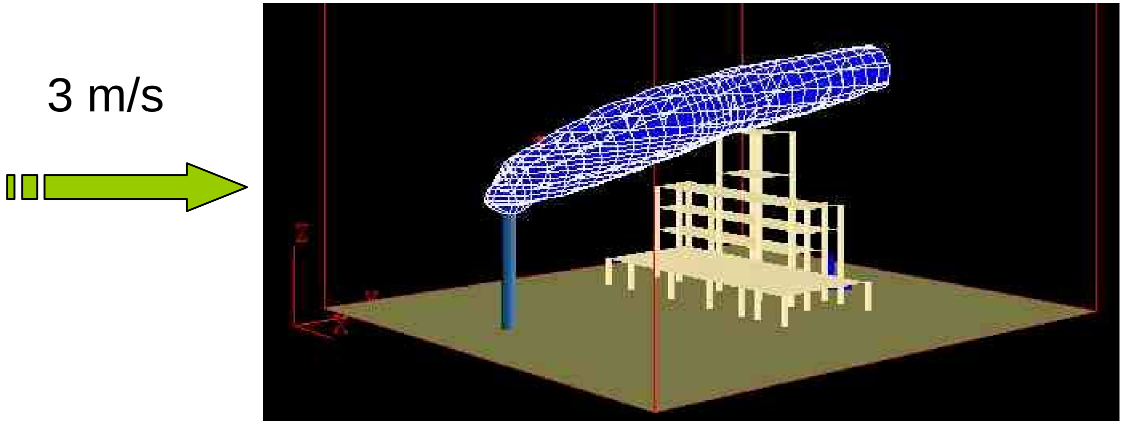
Wind velocity and surface roughness length (sea)

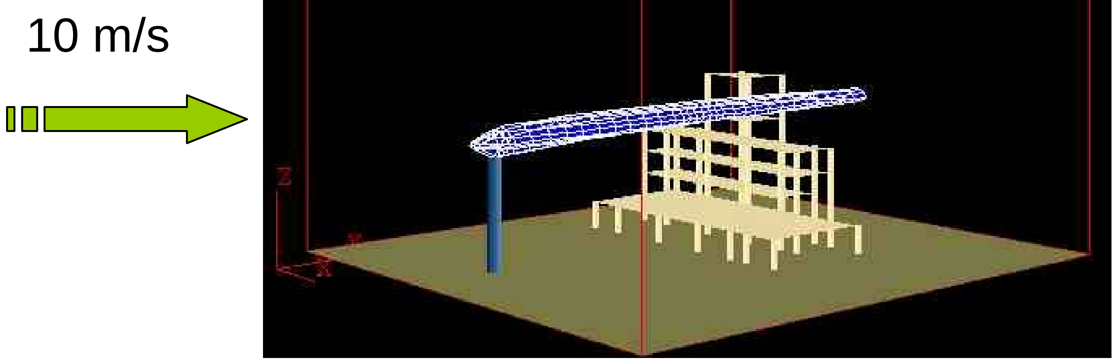
Vertical wind profile typically logarithmic / depending on surface roughness

Open water surface roughness depend on waves, thus on wind shear

z_0= 0.1 à 0.6 mm according to Brutsaert (1982)







The more wind, the more dilution (impact of shear)

Dispersion of a hazardous material in the atmosphere
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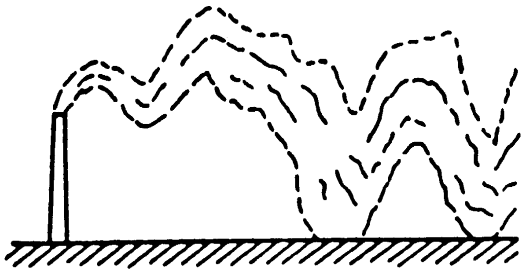
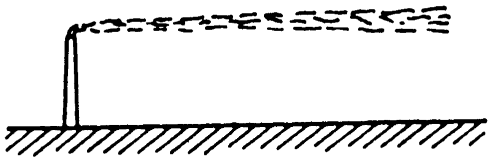
Atmospheric stability ⇔ vertical temperature gradient

- P_{atm} decreases with height : cooling of the air

	Neutral atmosphere	**Unstable atmosphere** (or “convective”)	**Stable atmosphere**
When?	Day/night transition High cloud cover Strong wind	Sunny day, low wind (surface heated by solar radiation)	Clear night, low wind (surface cooling faster than the air above)
Consequence?	*Rising air mass “__stays at its new location__”* *Mean turbulence intensity* ⇒ *“normal” dilution* *(Class of Pasquill D)*	*Rising air mass warmer than the air around* ⇒ *__goes on rising__* *High turbulence intensity* ⇒ *high dilution* *(Classes of Pasquill A to C)*	*Rising air mass cooler than the air around* ⇒ *__back to initial position__* *Low turbulence intensity* ⇒ *Low dilution* *(Classes of Pasquill E and F)*
			

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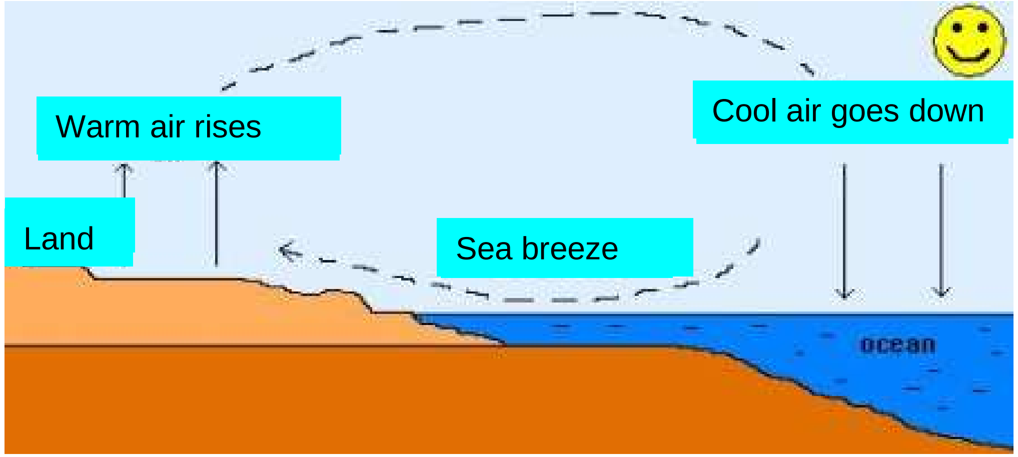
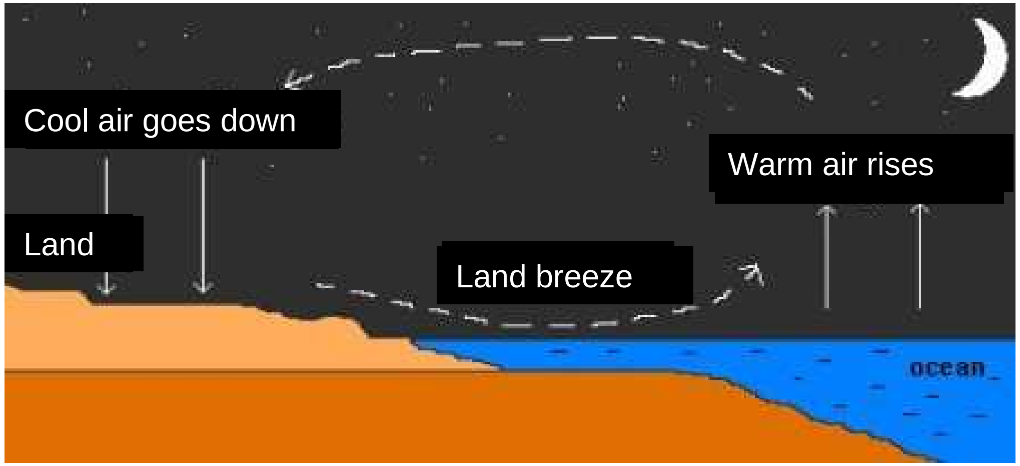
Coastal zone : littoral breezes

Thermally induced turbulence



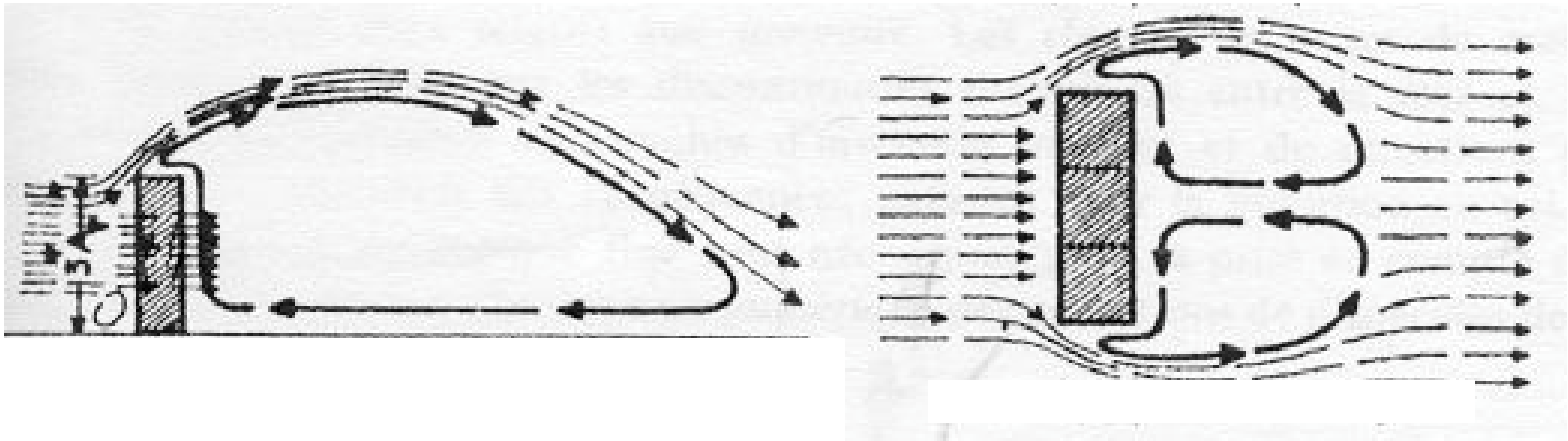
Sea breeze

Land breeze



Presence of an obstacle (ex. : ships nearby)

Mechanically induced turbulence - Wake effects



INERIS Trials, 1997 (movie Trial 5)

Accidental aerial dispersion models (near field / short term)

GAUSSIAN

Dispersion driven
only by meteo
conditions !

Validity
100 m < d < 10 km

INTEGRAL

« Over » simplified
equations of
fluid mechanics !

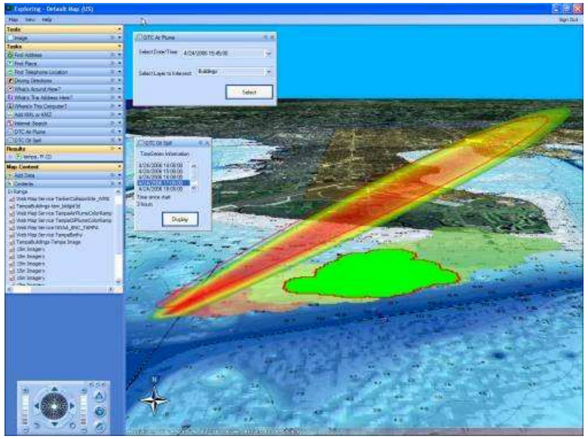
Validity
20 m < d < 10 km

« 3D » ou CFD

Less simplified
equations of
fluid mechanics...

Validity
1 cm < d < 10 km

Gaussian-type models



Principle

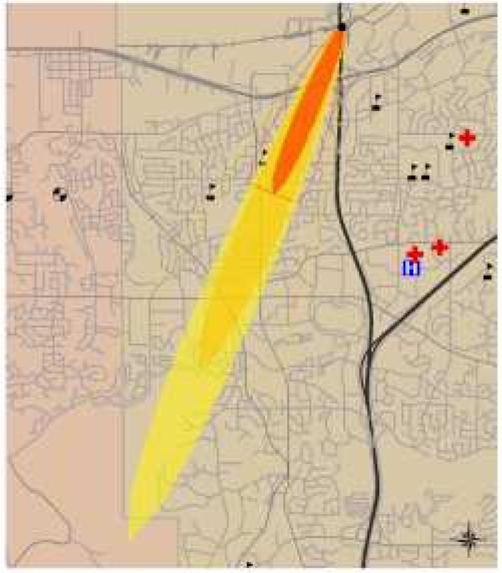
- Solution of dispersion equation = gaussian distribution law

Applications

- Passive gas
- Emergency situations

Simplified hypotheses and limits

- Neglect molecular diffusion
- Uniform wind field (speed and direction) in time and space
- No obstacle / no relief...
- Not adapted for heavy gas dispersion



Examples

ALOHA (EPA/NOAA) *(+ integral model for dense gas (DEGADIS)*)

EPIcode (Homann Associates, Inc.)

INPUFF (EPA) (*multisource + adaptation for light gases*)

...

Integral-type dispersion models

Principle

- Simplified resolution of fluid mechanics equations
- Setting of parameters in order to obtain conservative hazardous distances

Applications

- Passive gas, heavy/dense gas, and sometimes buoyant gas

Hypotheses

- Several successive models (jet model, heavy gas model, buoyant gzs model...)
- Gaussian model used for the final (passive) dispersion phase

Limitations

- Conservative parametric approach
- Gaussian model limits (constant meteo conditions, neither relief nor obstacles)
- Nt adapted to low wind/laminar release (no molecular diffusion considered)

Examples

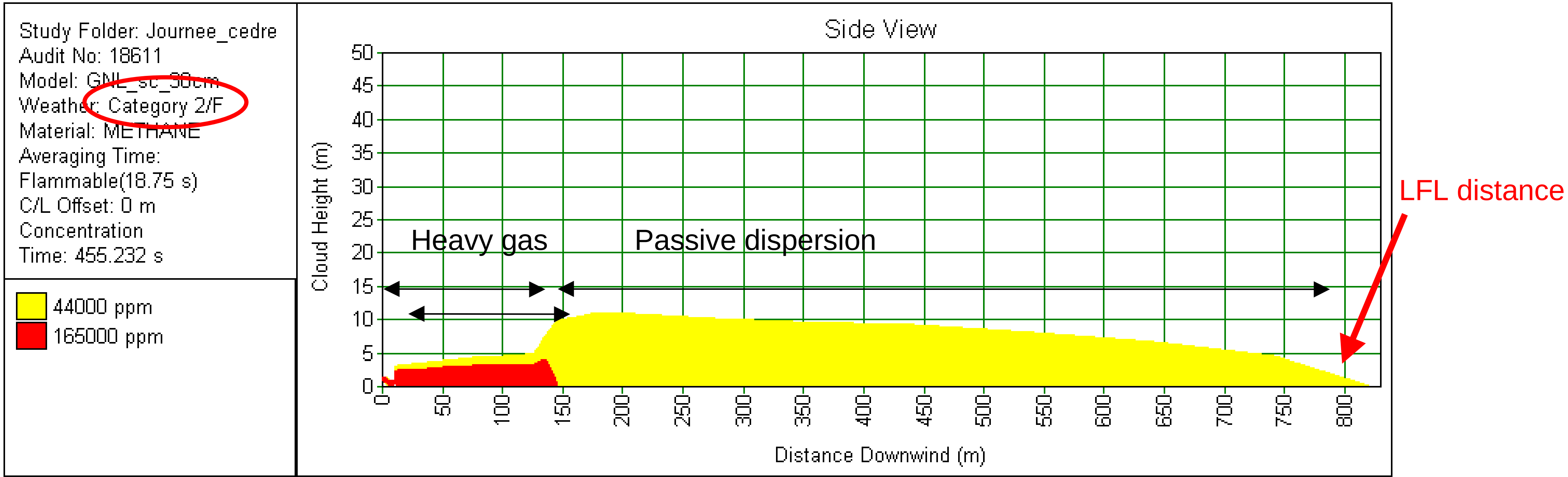
EFFECTS (TNO, Pays-Bas)

SAFER (Safer Systems, USA)

PHAST (DNV Software, UK)

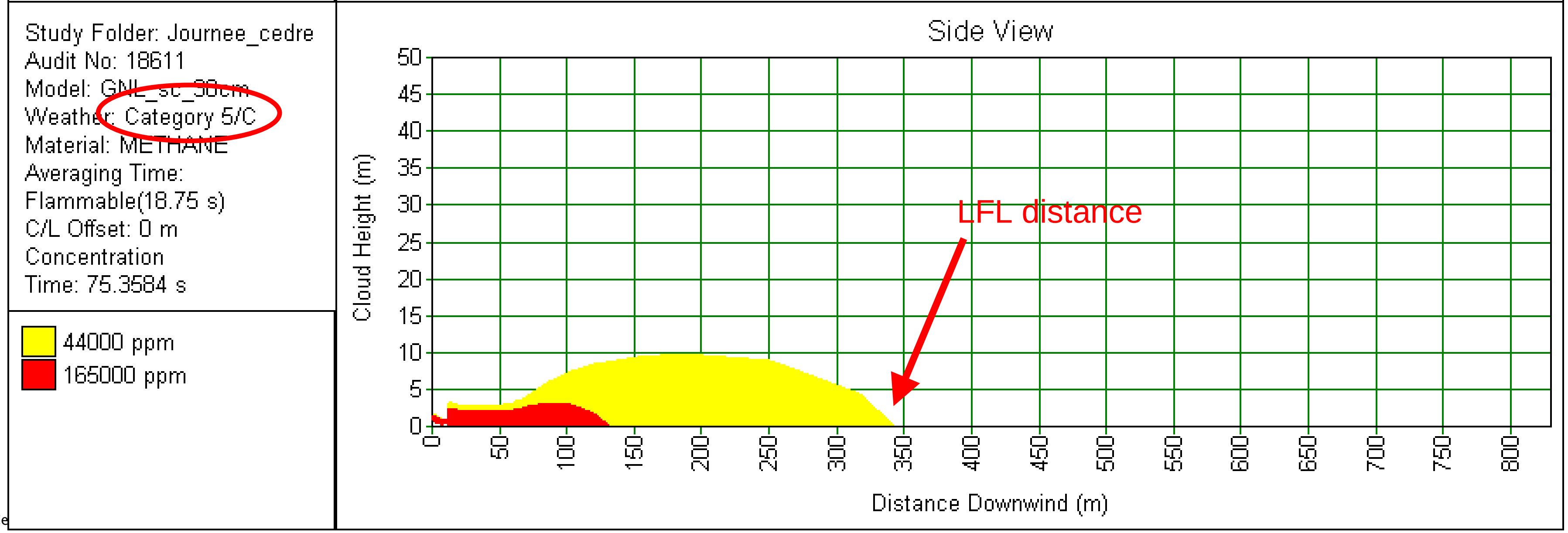
SEVEX (Atm-Pro / Faculté Polytechnique de Mons, Belgique)...

Example : simulation of aerial dispersion of LNG over water with Phast



Study Folder: Journee_cedre
Audit No: 18611
Model: GNL_sc_30cm
Weather: Category 2/F
Material: METHANE
Averaging Time:
Flammable(18.75 s)
C/L Offset: 0 m
Concentration
Time: 455.232 s

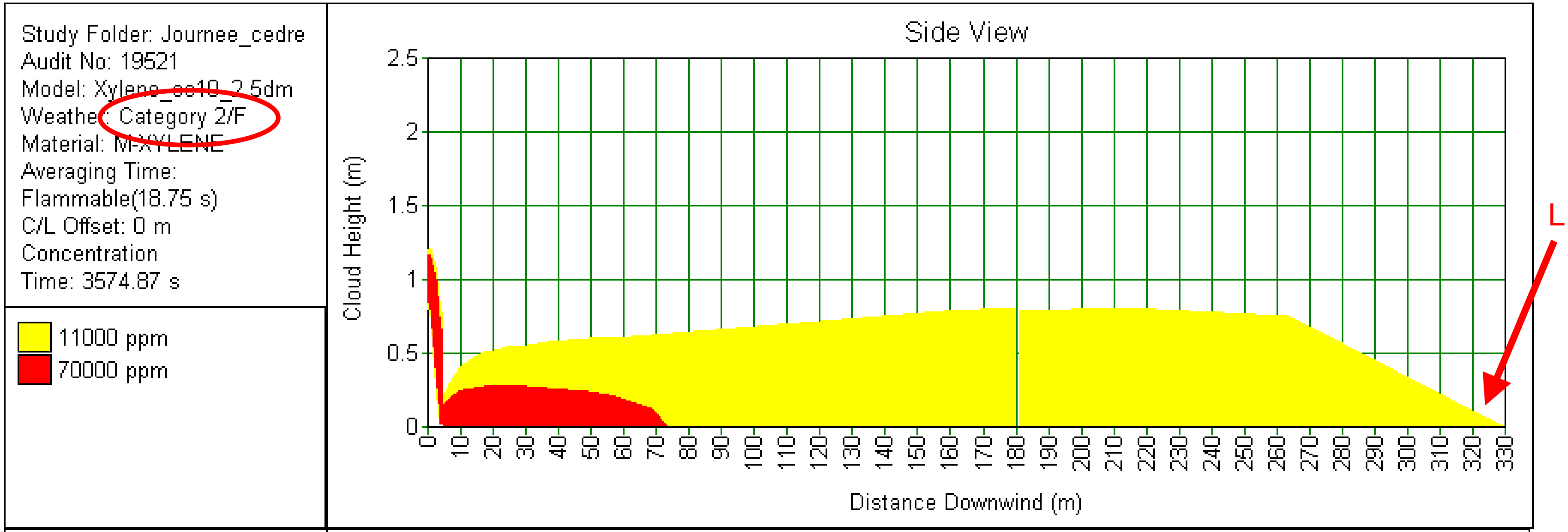
🟨 44000 ppm
🟥 165000 ppm



Study Folder: Journee_cedre
Audit No: 18611
Model: GNL_sc_30cm
Weather: Category 5/C
Material: METHANE
Averaging Time:
Flammable(18.75 s)
C/L Offset: 0 m
Concentration
Time: 75.3584 s

🟨 44000 ppm
🟥 165000 ppm

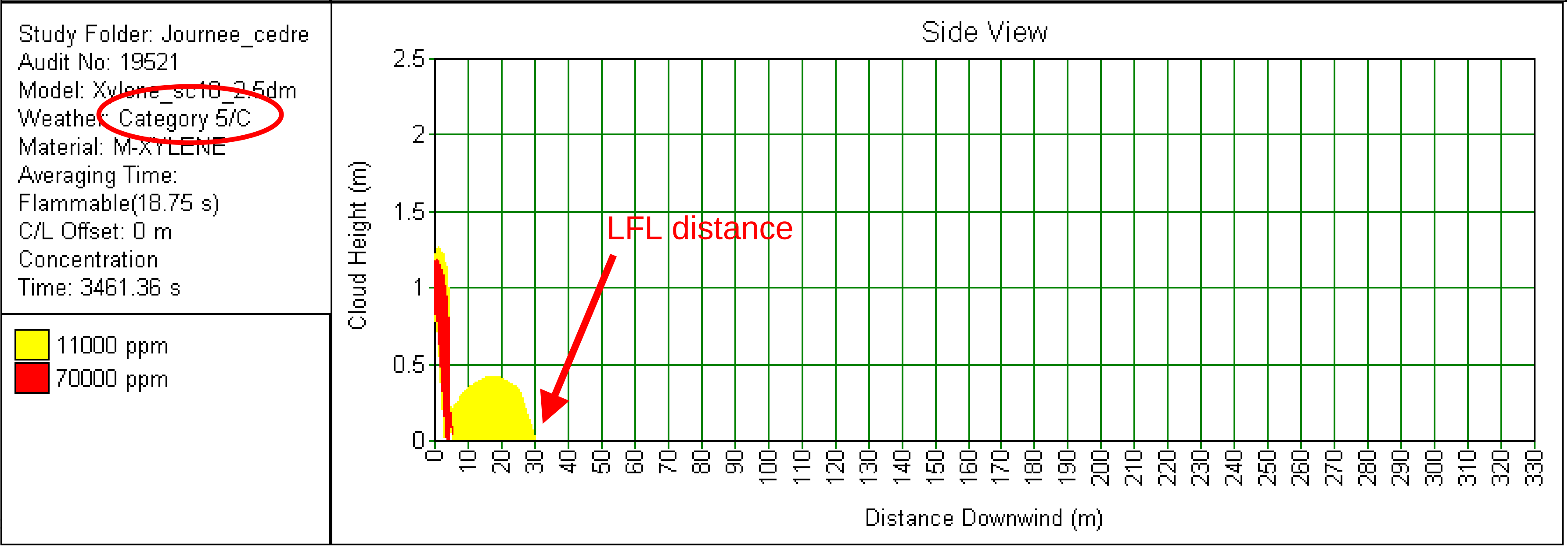
Exemple : simulation of aerial dispersion of Xylene over water with Phast



Study Folder: Journee_cedre
Audit No: 19521
Model: Xylene_sc10_2.5dm
Weather: Category 2/F
Material: M-XYLENE
Averaging Time:
Flammable(18.75 s)
C/L Offset: 0 m
Concentration
Time: 3574.87 s

🟨 11000 ppm
🟥 70000 ppm

LFL distance



Study Folder: Journee_cedre
Audit No: 19521
Model: Xylene_sc10_2.5dm
Weather: Category 5/C
Material: M-XYLENE
Averaging Time:
Flammable(18.75 s)
C/L Offset: 0 m
Concentration
Time: 3461.36 s

🟨 11000 ppm
🟥 70000 ppm

CFD-type models

Principle

- « Complete » resolution of fluid mechanics equations

Applications / Hypotheses

- Turbulent fluctuations, obstacles and relief

  ⇒ Simulation of complex environments
- If stakes request to refine the evaluation (expensive)

Limitations

- Numerous input and numerical parameters
- CPU time consuming

→ expensive

- Accuracy depends on resolution method, grids, selected models...

Examples

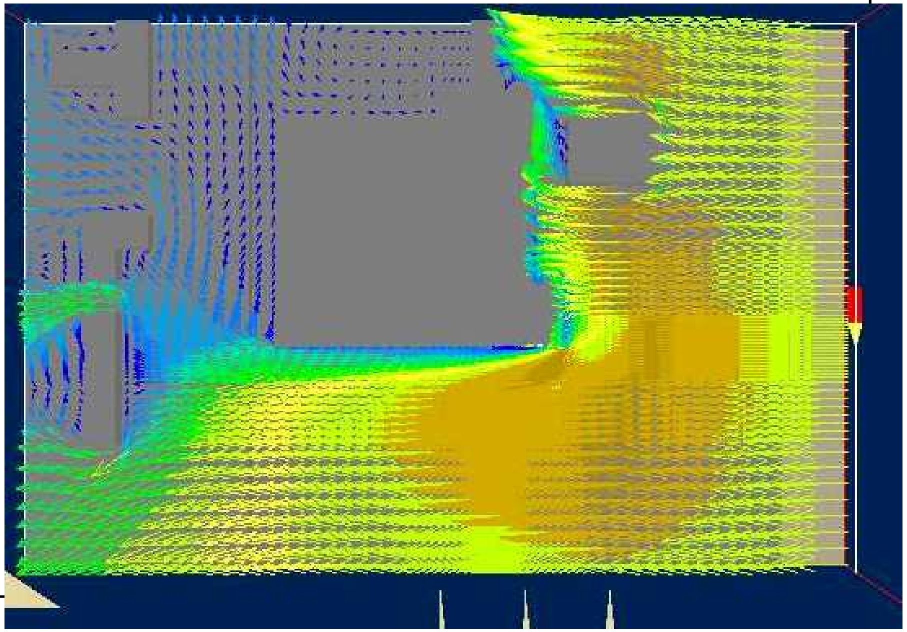
CFX, Fluent (Ansys) - *Generalist*

PHOENICS (Cham) - *Generalist*

Mercure (EdF) - *Atmospheric dispersion*

FLACS (GexCon) - *Dispersion and explosion*

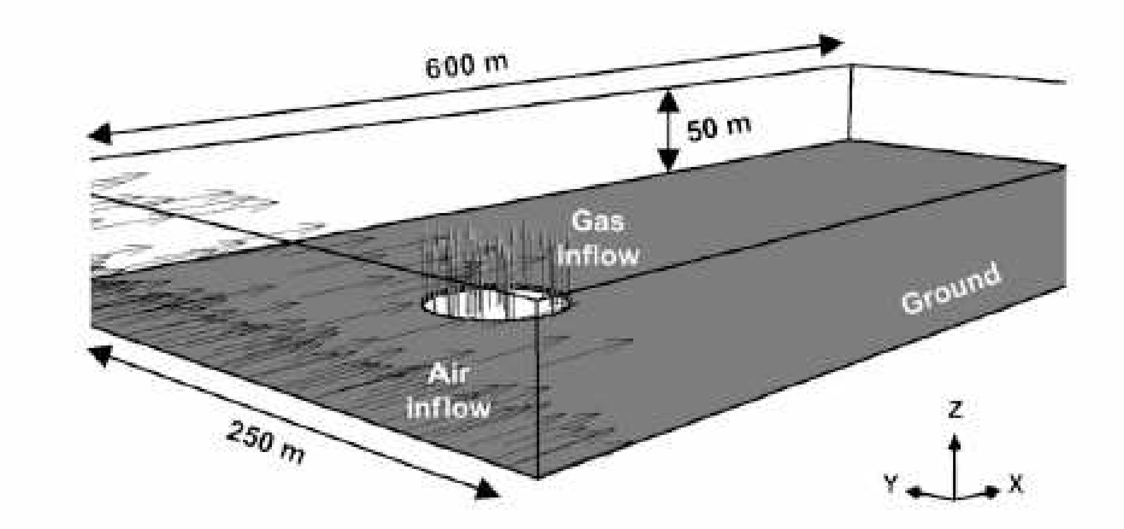
...

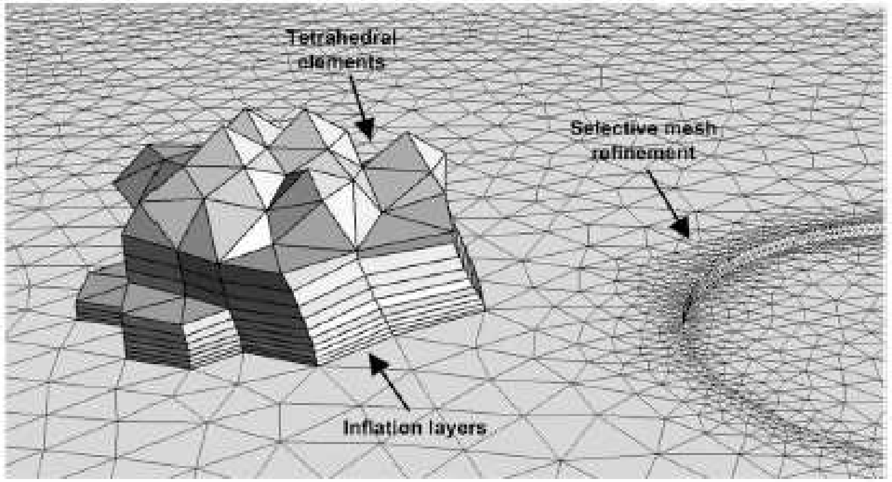


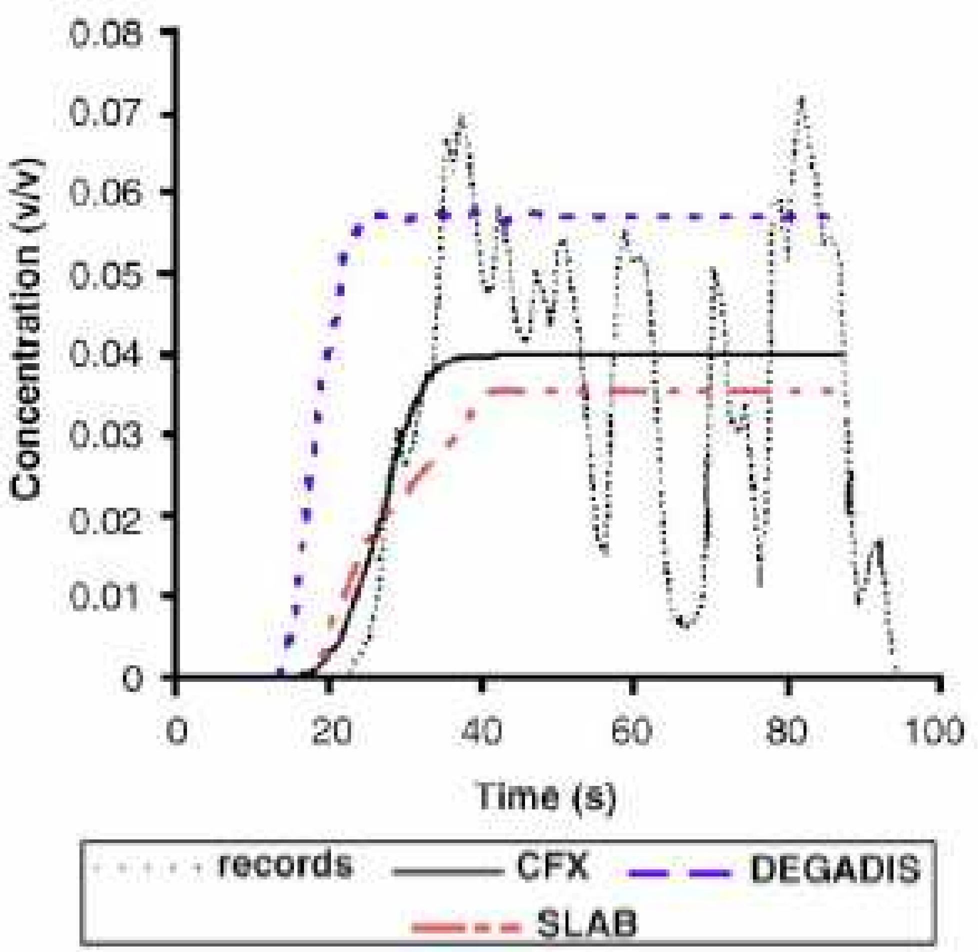
Example of comparison of CFD and integral models

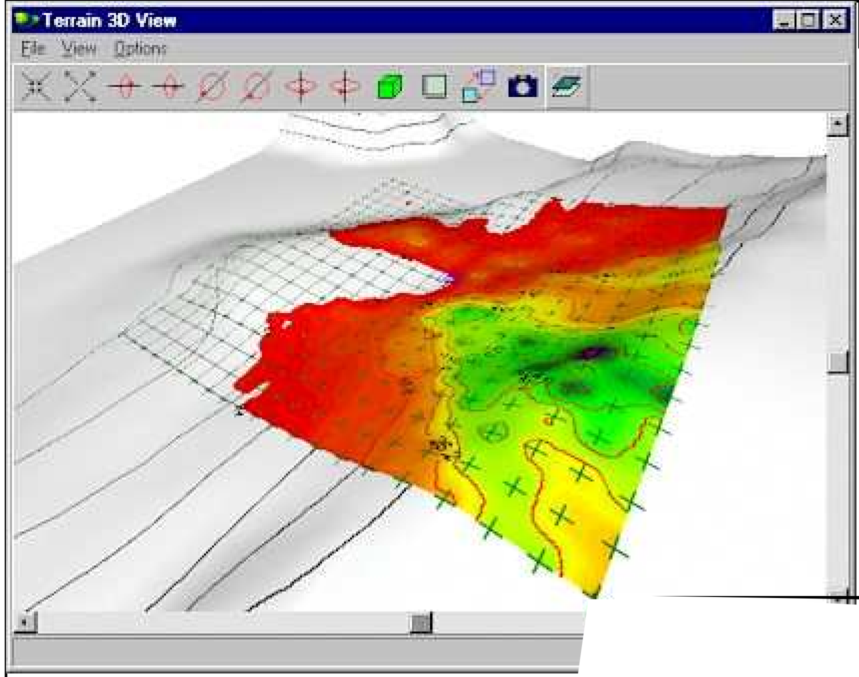
Liquefied Natural Gas pool evaporation and atmospheric dispersion

(d’après Sklavounos & Rigas, 2006)







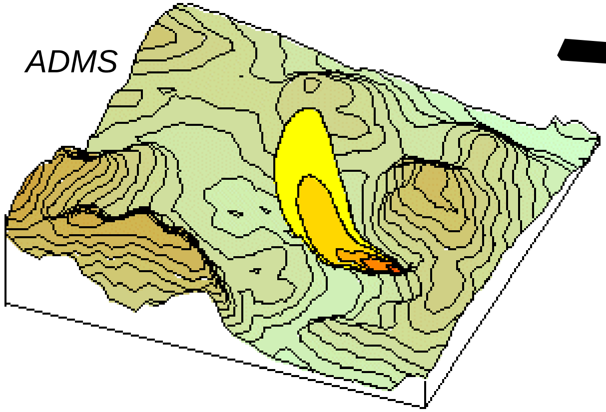


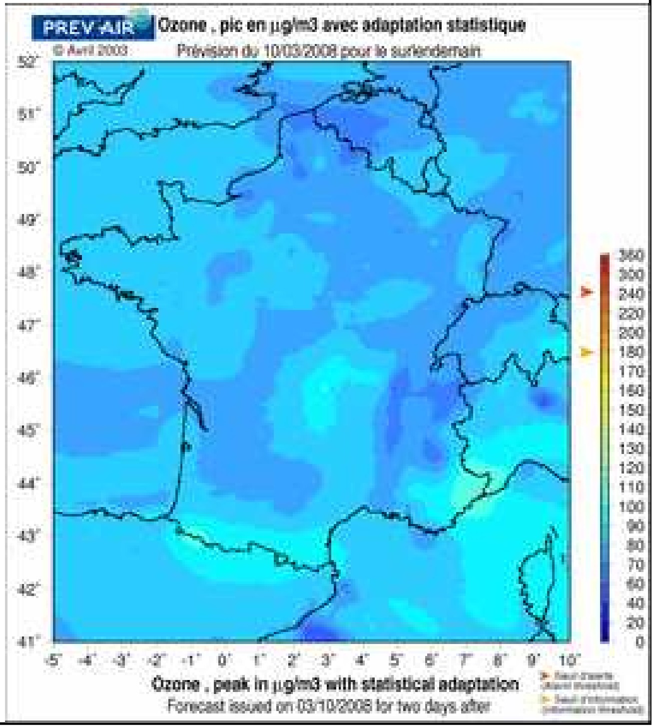
ISC-AERMOD View

Breeze
CALPUFF

Thanks for your attention

ADMS





PREV 'AIR