# $CO_2$PipeHaz : Risk assessment decision support tools for $CO_2$ pipelines

Dr Laurence Cusco
HSL

# Health & Safety Laboratory

- Founded in 1911 to study explosions in coal mines
- Remit increased many times since
- Safety in Mines Research Board 1921
- Occupational Medicine Laboratory 1959
- Health & Safety at Work Act 1974
- An Agency of HSE since 1995

# CO2 pipelines – so what?

HEALTH & SAFETY LABORATORY

- Previous work by HSL has shown that:

- There are significant hazards:

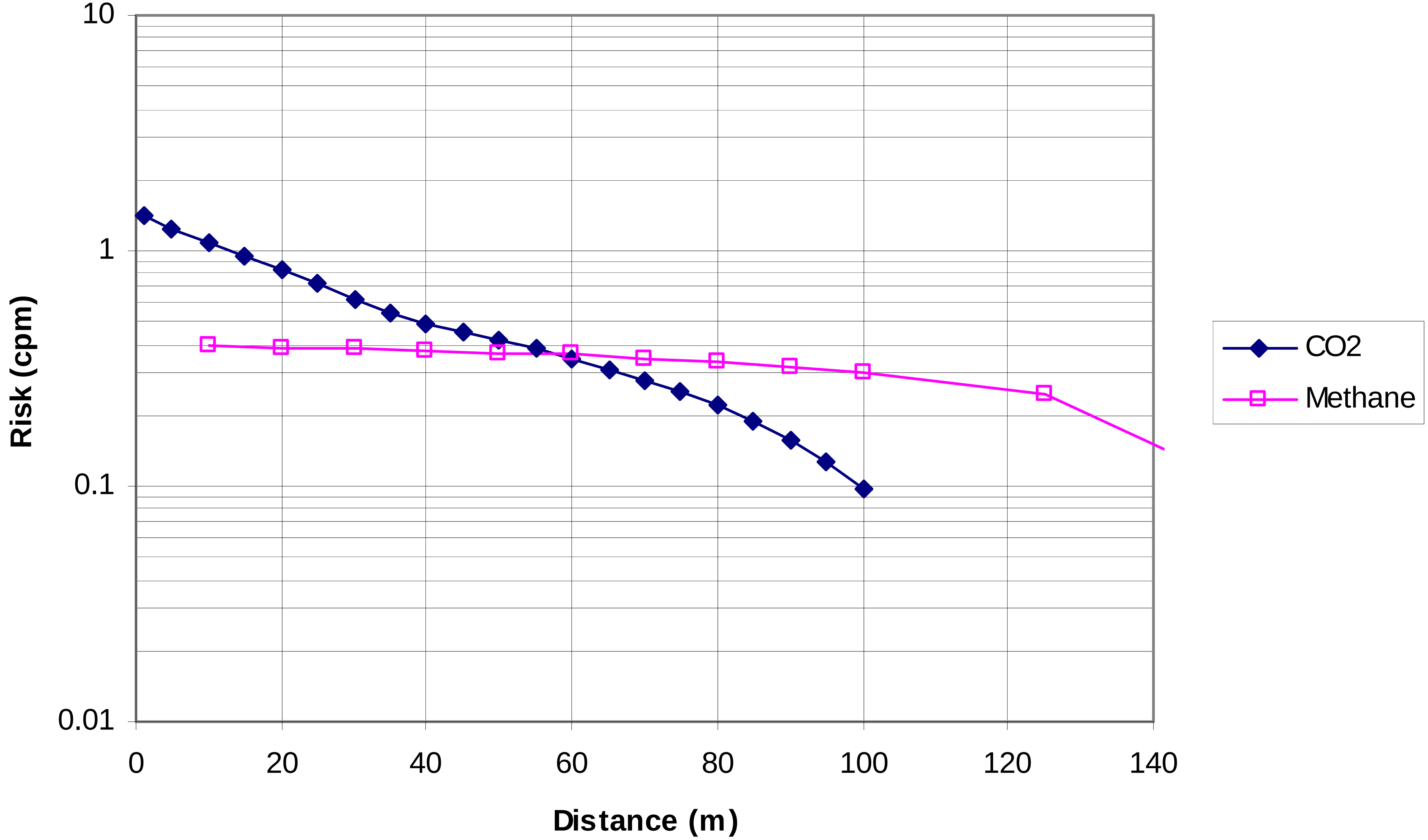
  Connolly & Cusco “Hazards from high pressure carbon dioxide releases during carbon dioxide sequestration processes”. 12th International Symposium on Loss Prevention and Safety Promotion in the Process Industries, Edinburgh, 22-24 May **2007**.

- There are significant risks:

  Wilday, McGillivray,Harper & Wardman “A Comparison of Hazard and Risks for CO2 and Natural Gas Pipelines” Hazards XXI Symposium, Manchester, 10-12 November **2009.**

# Comparison of $CO_2$ & natural gas pipelines (32 barg)

HEALTH & SAFETY LABORATORY



# $CO_2$ PipeHaz WP1.5

1. Geographical Information Systems and Computerised Fluid Dynamics integration
   - Transfer of terrain data from GIS into CFD
   - Transfer of concentration predictions from CFD into GIS

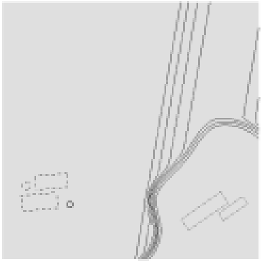
2. Far-Field Dispersion
   - Development of two-phase $CO_2$ dispersion CFX model to benchmark against FLACS
   - Validation using INERIS (France) and Dalian (China) experiments

3. Hypothetical Industrial $CO_2$ Release
   - Demonstration of CFD and GIS model capabilities using hypothetical industrial $CO_2$ release scenario

# GIS-CFD Integration

HEALTH & SAFETY LABORATORY

## GIS Topography



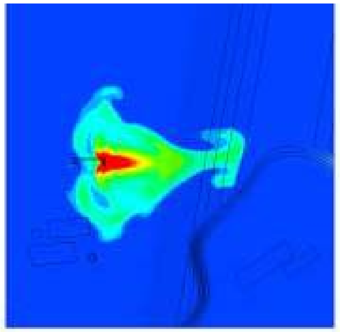
General terrain from map data

~ 2m resolution

## Release Geometry

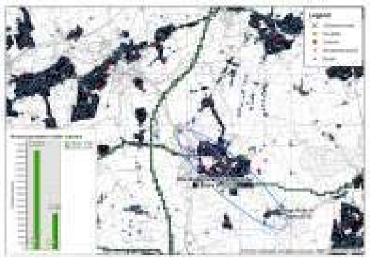
Detailed near-field e.g. 3D laser scan

## CFD



Vapour concentration field from dispersion simulation

## GIS

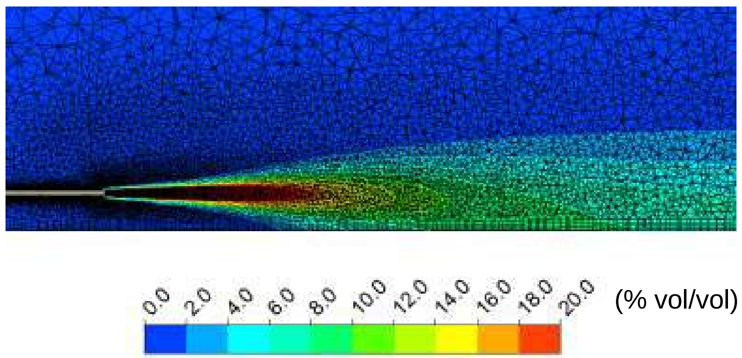


Assess hazard by overlaying vapour concentration and population density

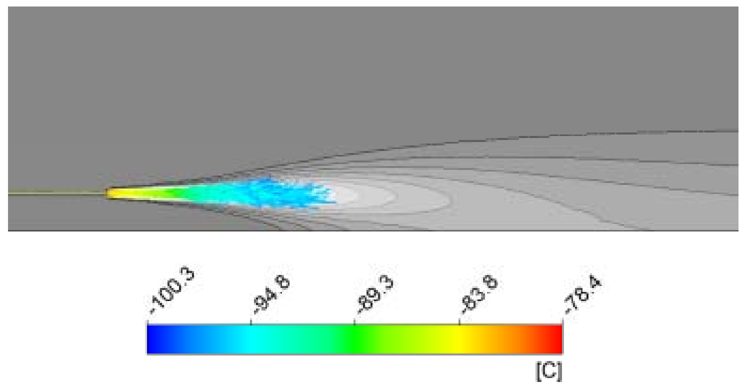
# CFD Model Development

- Modelled release (for initial experiments)
  - Orifice Diameter: 0.5 inch
  - $CO_2$ Reservoir Conditions:150 bar and 9 ºC
- Have obtained realistic representation of physics

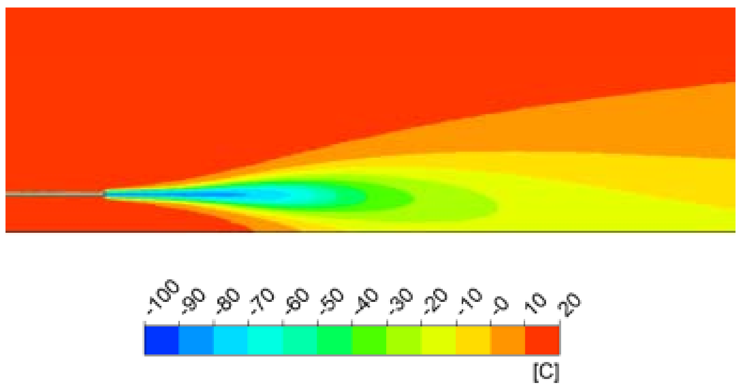
$CO_2$ Gas Concentration and Mesh



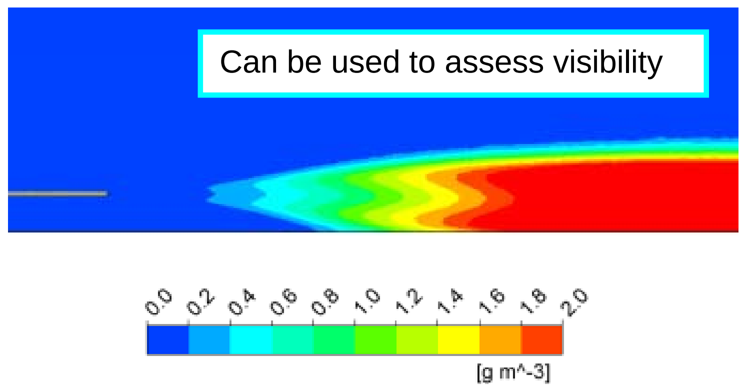

$CO_2$ Particle Temperature




Gas Temperature

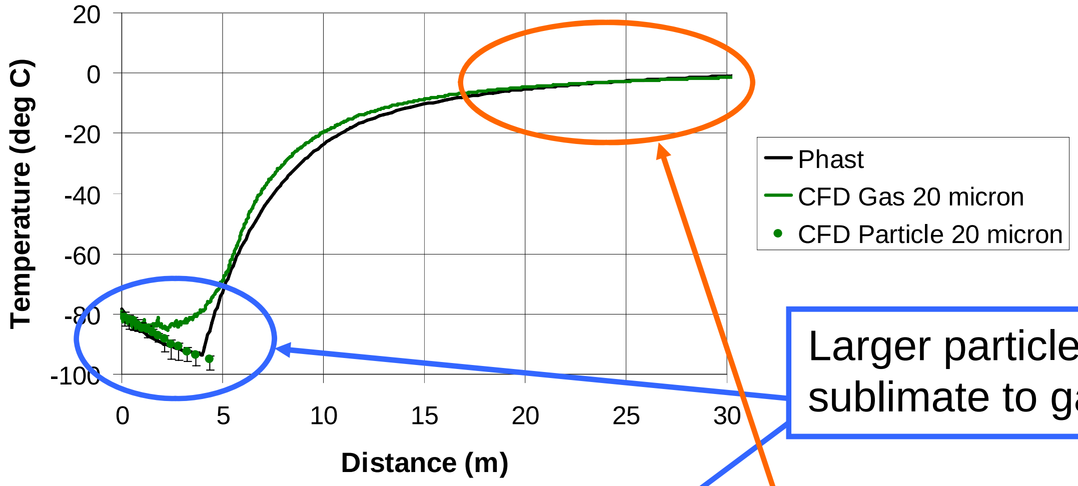



Water Droplet Concentration



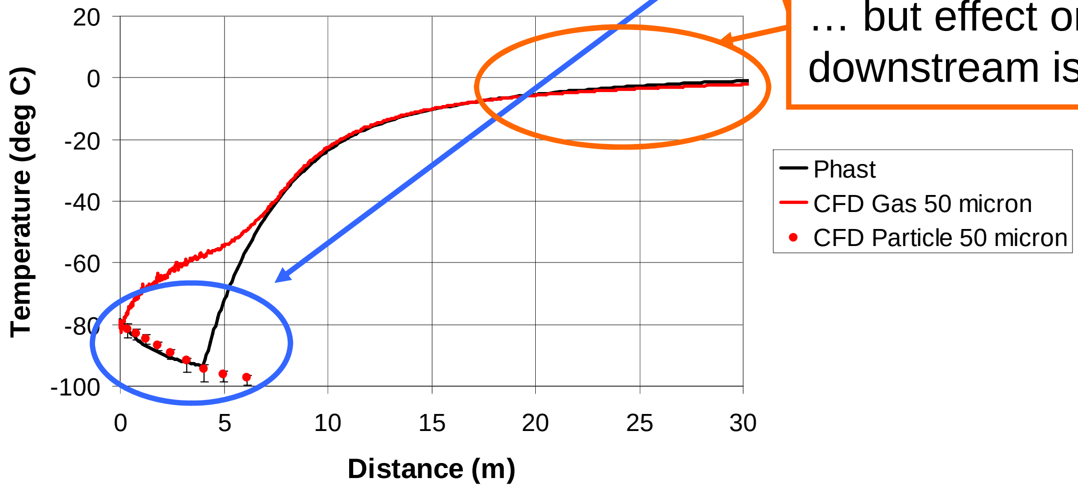
# CFD Model Development

- Effect of particle size on jet centreline temperature




Larger particles take longer to sublimate to gas …

… but effect on $CO_2$ jet further downstream is negligible



# Ongoing Work

HEALTH & SAFETY LABORATORY

- Validation of far-field dispersion model using experimental data from INERIS (France)
- Construction of 3D topographical model for hypothetical case based on a realistic industrial case with varied topography
- Work is currently progressing to plan…

# Decision Support Tools

## WP3 Objectives

- Incorporate the predictive capabilities developed in previous Work Packages, as well as current knowledge and good practice, into decision support tools.

- Demonstrate the usefulness of tools to identify potential hazards and to assess their capability to predict and model consequences

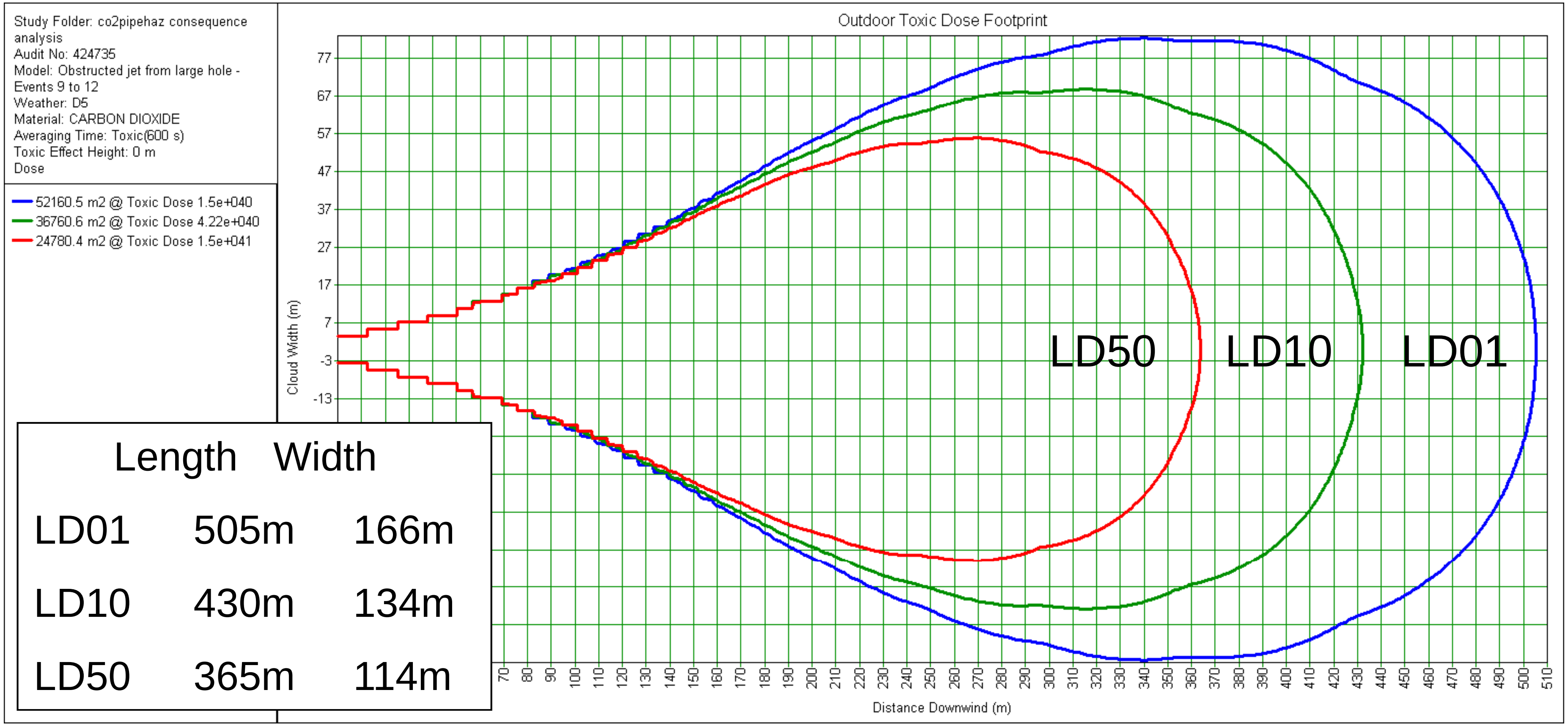
# WP3 Description of work

- 3.1 Review and refinement of good practice guidelines
- 3.2 Safety and risk assessment tools
  - Review of risk assessment approaches
  - Integral consequence assessment methodology
  - Risk assessment methodology based on ARAMIS
  - Short-cut risk assessment methodology incorporating topography
- 3.3 Test cases

# CO2 risk assessment

- **Overall aim: To develop a risk assessment methodology for $CO_2$ pipelines**
- Incorporate new knowledge from CFD and experiments
- Precautionary estimates applied and discussed for any remaining knowledge gaps
- To perform consequence modelling for a test case high pressure $CO_2$ pipeline using Phast and/or other appropriate tools if applicable
- Apply individual and societal risk assessments to the hazard footprints

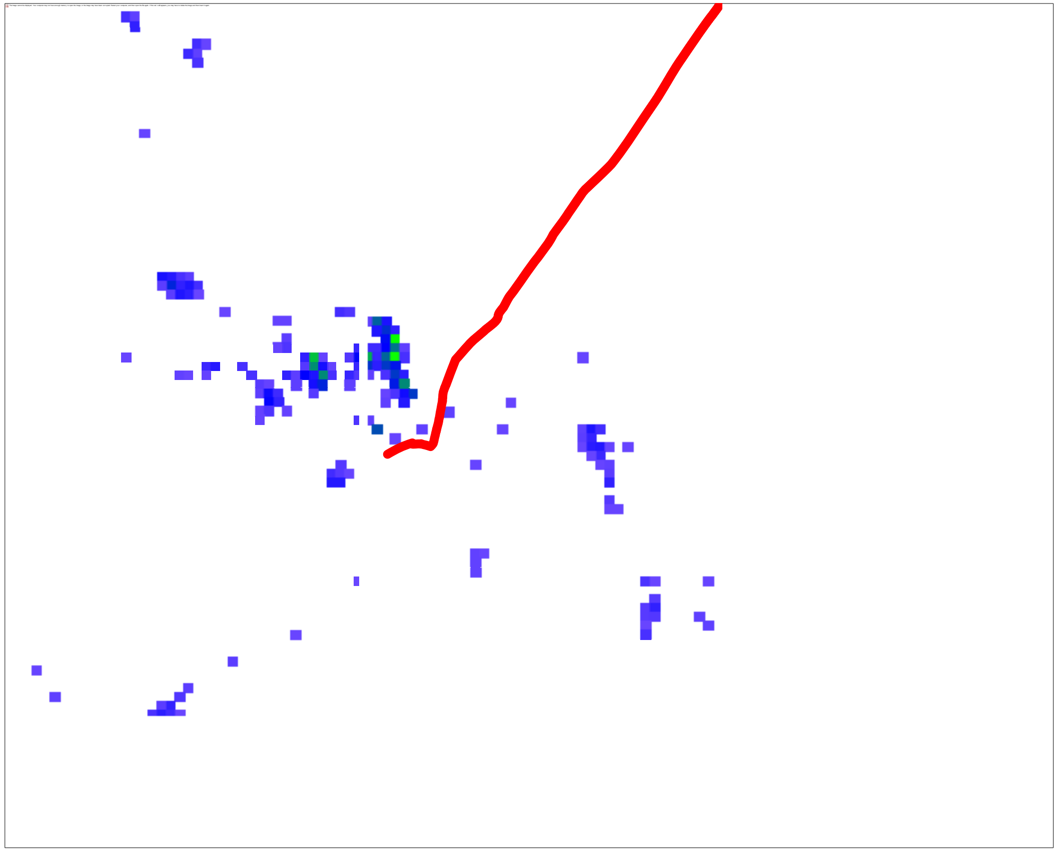
# Consequence results



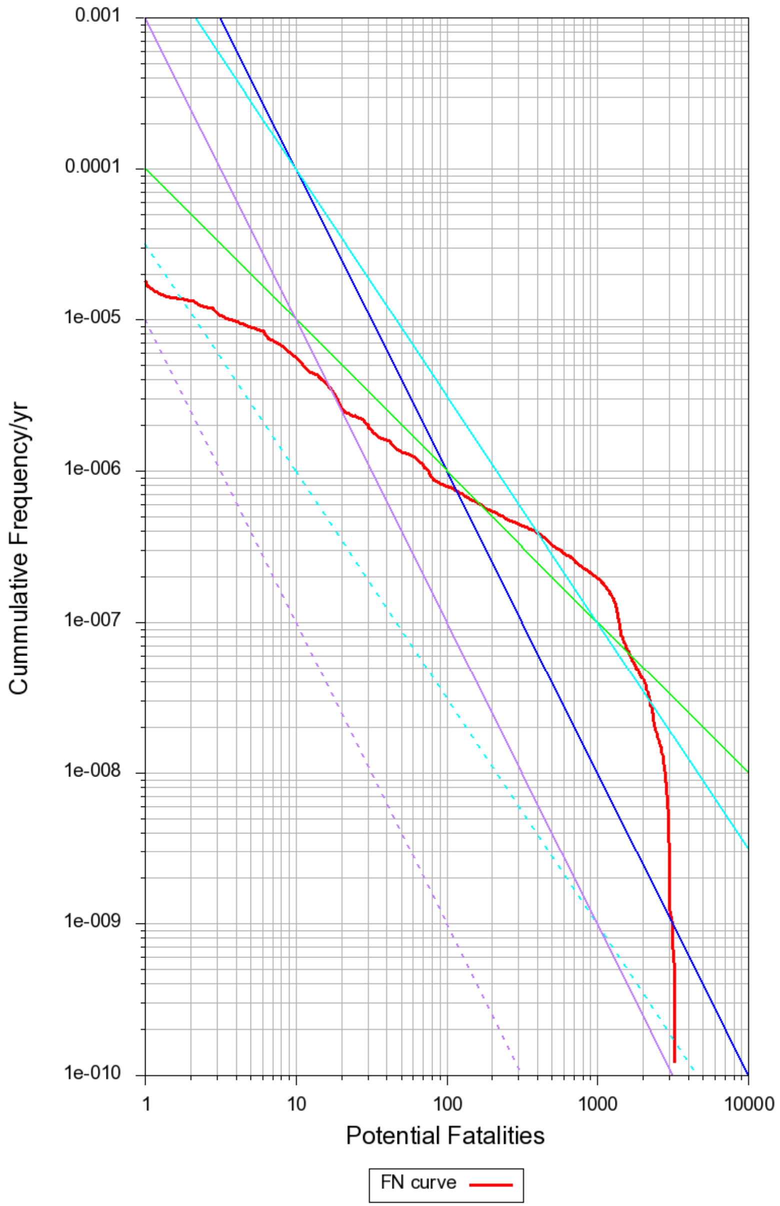

| | Length | Width |
|---|---|---|
| LD01 | 505m | 166m |
| LD10 | 430m | 134m |
| LD50 | 365m | 114m |

- Scenario: Obstructed jet released in D5 weather conditions for an outdoor recipient
- Pipeline details: 700 mm diameter, 140 barg, 10°C operating temperature and 16km long section

# Societal risk assessment



# Pipeline societal risk- FN curve



# Risk assessment incorporating topography

1) **Literature review**

   Identified two publicly available dispersion models for testing

   – **QUIC** (Los Alamos National Security, U.S. Department of Energy's)

   – **Twodee-2** (Hankin, 2003-04)

2) **Test models using wind tunnel data** (Schaztmann)

   – QUIC

   – TWODEE-2

   – CFD models

3) **Test case pipeline assessment**

4) **Dose calculation** and overlay with population data in **HSL risk assessment tool QuickRisk**

# Consequence modelling incorporating topography

- CFD models in pipeline QRA
  - along the trajectory of a long pipeline (e.g. >$10^2$ km)
  - calculations at regular intervals (e.g. 100m)
  - considering terrain at each release point and
  - a representative set of weather conditions (Pasquill atmospheric stability and wind speed combinations e.g. D5, F2; or D5,F2, D2,B2)
  - around a set of wind directions to provide sufficient resolution for QRA (eg. from 72 to 360)

= **2x72x1000 = 144,000** CFD simulations but preferably 4x360x1000=**14,400,000** simulations

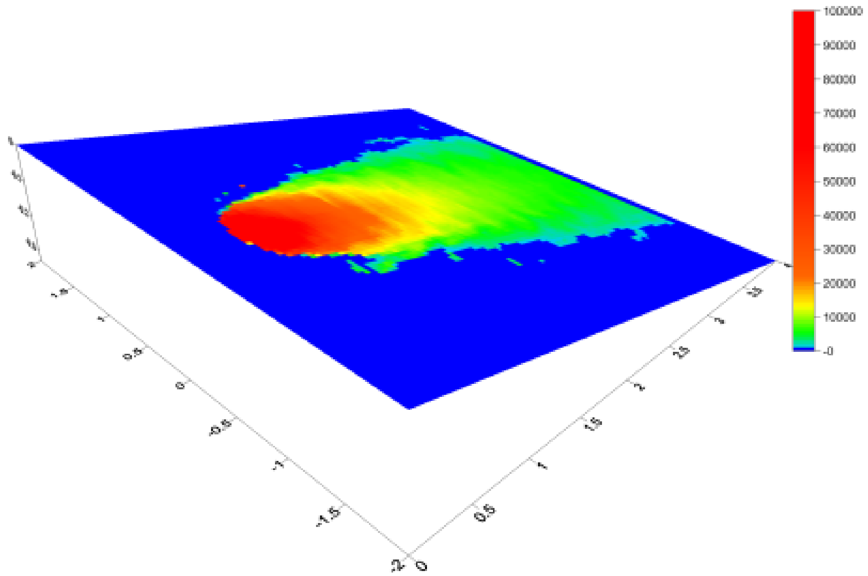
– need for short-cut models!

# Short-cut topography models

- TWODEE-2: Shallow layer model
  - PROS:
    - topography
    - open source
    - standard ASCII text format inputs and outputs
    - concentration and dose outputs (ASCII text grd file)
    - it can be run non-interactively
  - CONS:
    - mesh dependency; source term definition
    - run time increases with mesh resolution
    - queries on detail of earlier versions

# Short-cut topography models

- TWODEE-2: Shallow layer model



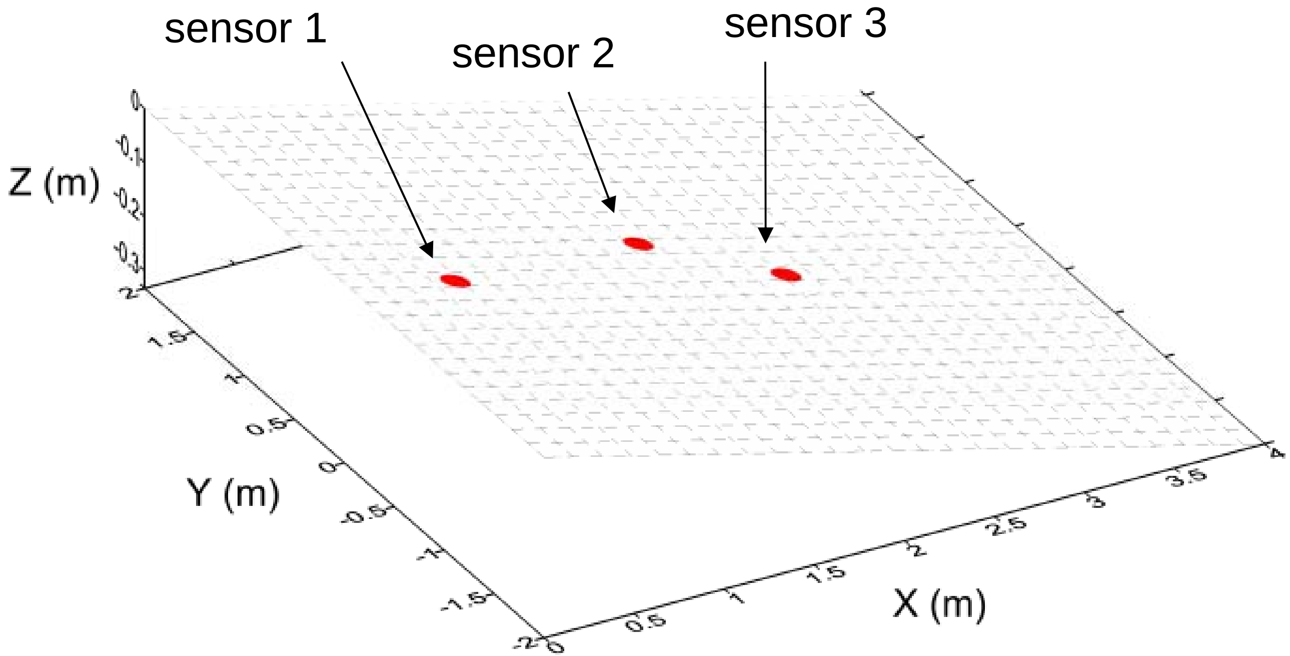

**Schatzmann's wind tunnel tests REDIPHEM database in RISO (2009)**

| Mesh | hh:mm |
|---|---|
| 100 x 100 | 00:02 |
| 200 x 200 | 00:14 |
| 400 x 400 | 02:16 |
| 800 x 800 | > 08:00 |

**Run time for different mesh sizes**

# Short-cut topography models

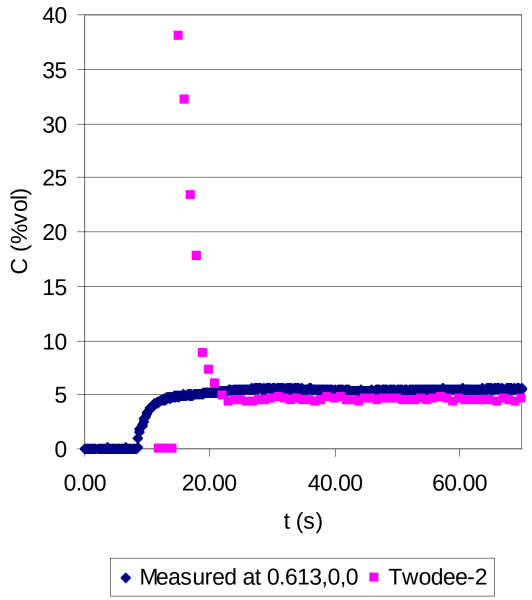
- Twodee-2 vs wind tunnel data: computational domain and location of sensors

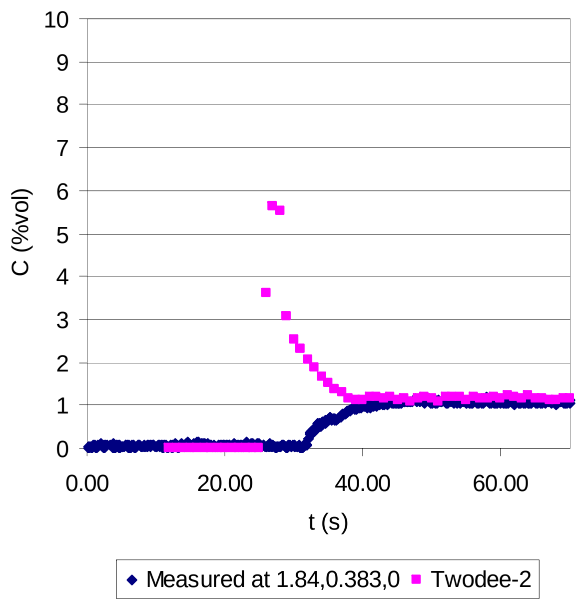


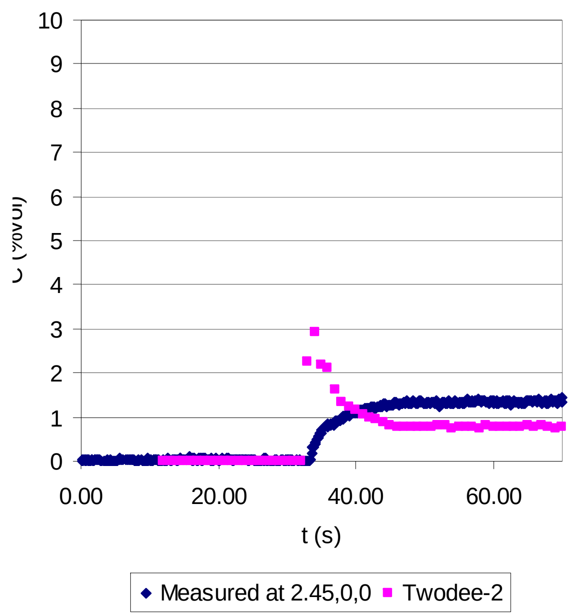

Schatzmann's wind tunnel tests REDIPHEM database in RISO (2009), releases of $SF_6$ at (0.5, 0) on a 4.8 degree slope. 100x100 grid (Dx=Dy=0.04m).

# Short-cut topography models

- Twodee-2 vs wind tunnel data



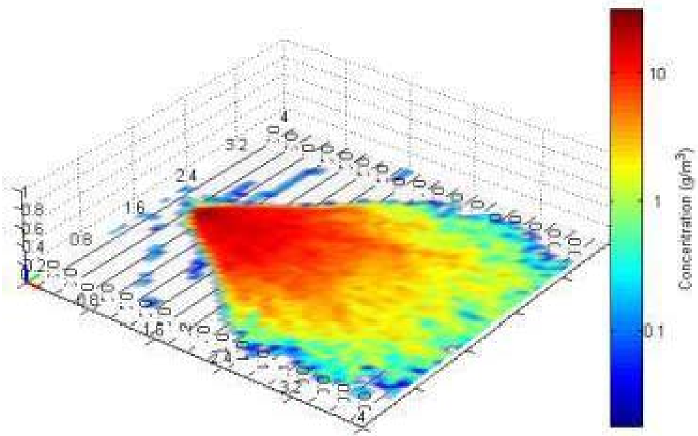




Comparison of measured concentration vs. concentrations predicted by Twodee-2. Schatzmann's wind tunnel tests REDIPHEM database in RISO (2009), releases of SF6 at (0.5, 0) on a 4.8 degree slope. 100x100 grid (Dx=Dy=0.04m). Running time = 62s.

# Short-cut topography models

- QUIC: Lagrangian particle tracking;
  - PROS:
    - topography
    - running time after setup
    - ASCII text outputs
  - CONS:
    - Availability of continuous release model for project deliverable deadline?
    - Effect of source definition, mesh and time-step selection on results;
    - built around GUI inc. data extraction tool for concentration and dose outputs



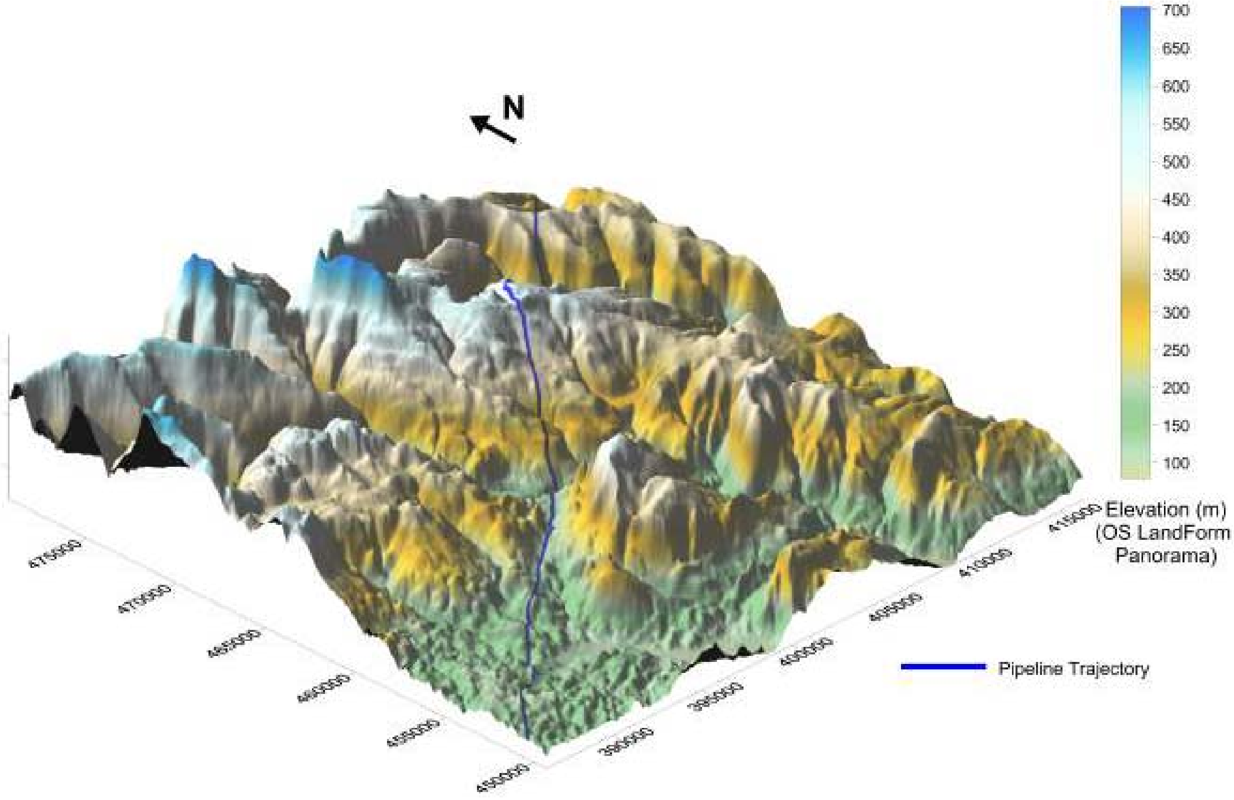

**Instantaneous release**

# Short-cut risk assessment methodology

- Inputs
  - Topography data
  - Population
  - Scenarios (frequency)
  - Dispersion modelling (Twodee-2, QUIC)
  - Dose contours
- Societal risk calculation (QuickRisk)

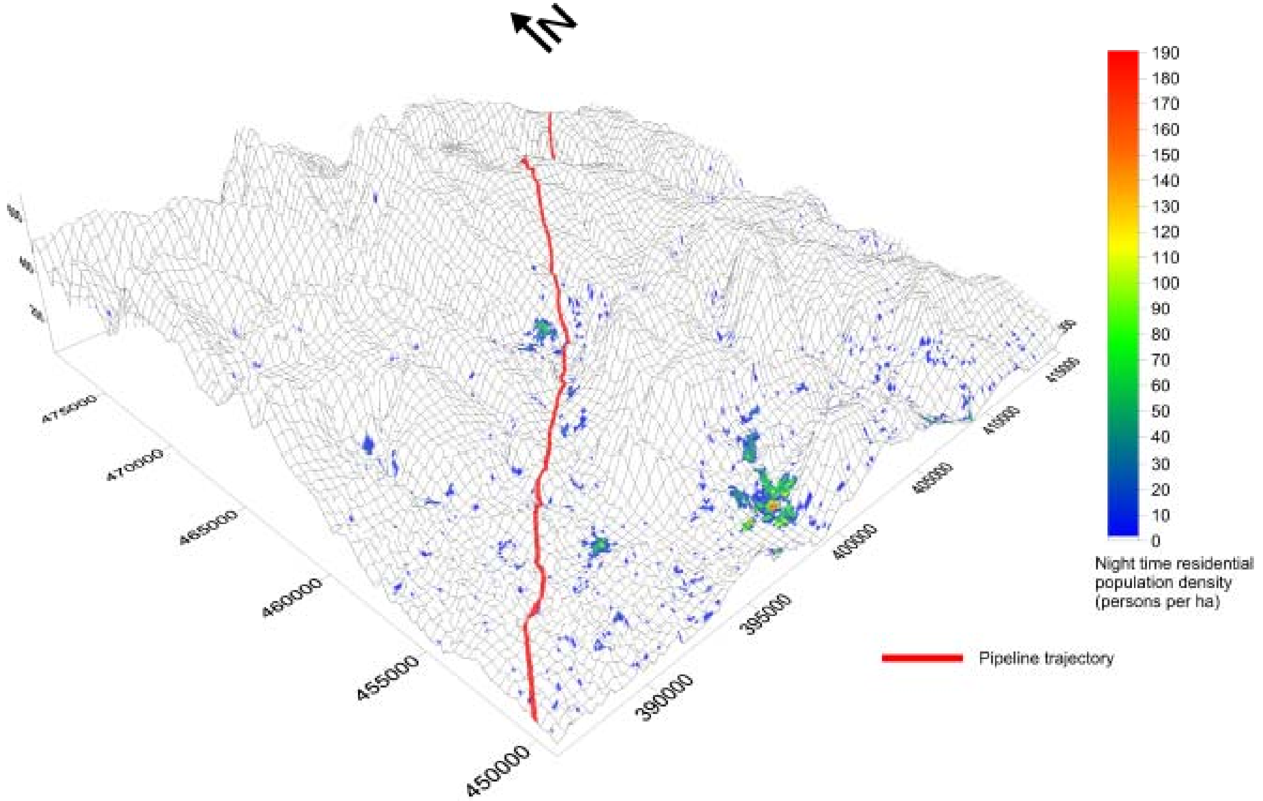
# Topography data

- OS LandForm Profile Plus (2x2x0.1) for detail near source (<3km)
- OS LandForm Panorama (50x50x1m) to 15 km from source



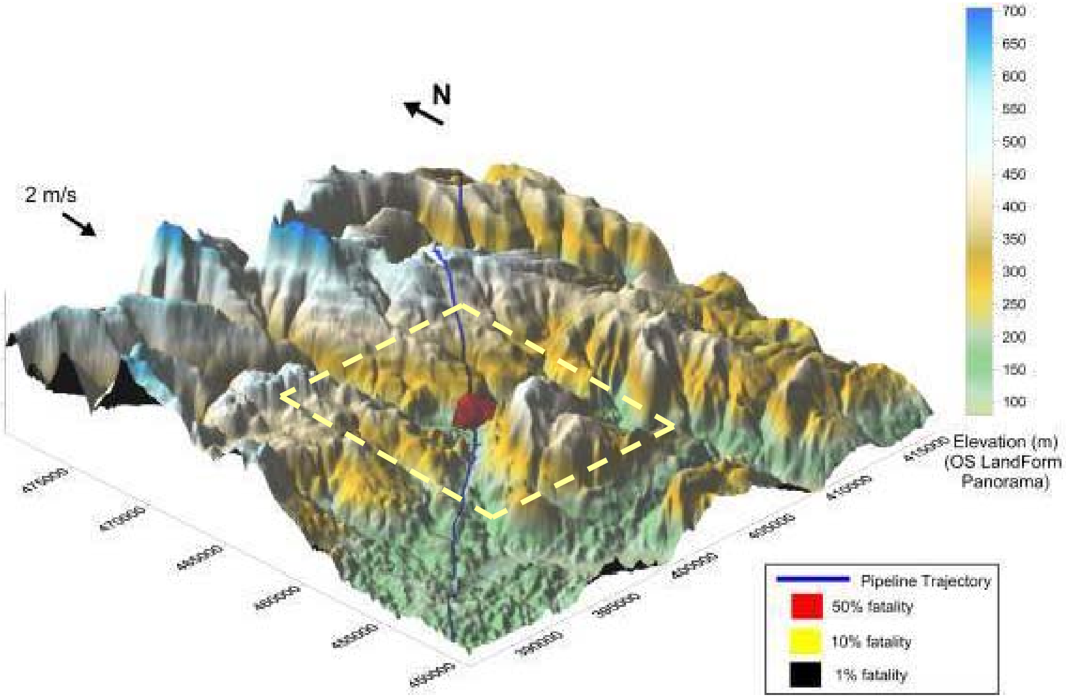
# Population data

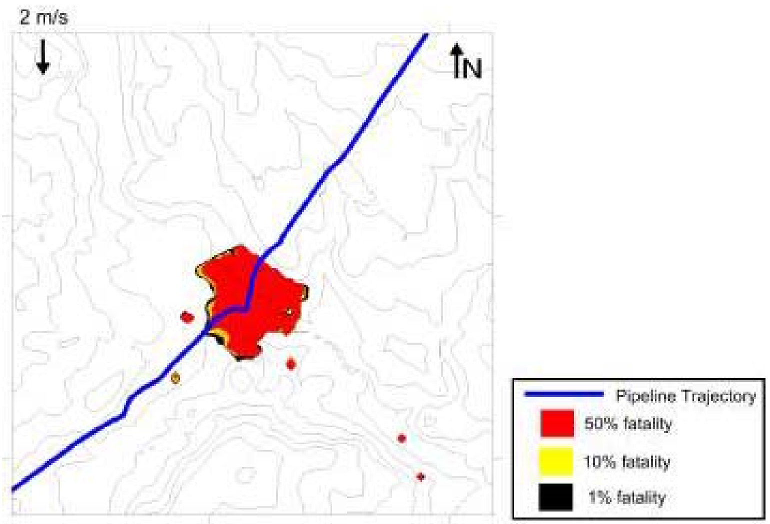
– UK's National Population Database (NPD)
  - Residential layers (Night time and Daytime), workplaces
  - Schools, Hospitals, Roads (average, peak flow),



# Dispersion modelling and dose contouring

- shallow layer model Twodee-2
- area source
- example release rate (source term and crater model to be developed to address this)
- 1%, 10% and 50% fatality contours



# Conclusions

- Methodology developed for combining consequence models + topology + dose calculations + population = risk
- For the integral consequence modelling assessment, the pipeline risk calculation is being developed as part of CO2PipeHaz project and will be implemented soon.
- Aim ultimately will be better Land Use Planning advice around CO2 pipelines utilising empirical models. Options:
  a) Hazard range
  b) Individual risk
  c) Individual risk + geographic topography features
  d) Risk + topography + populations

# Acknowledgements

- Colleagues in HSL:
  - Simon Gant
  - Diego Lisbona
  - Alison McGillivray
  - Mike Wardman

- Partners in the CO2PipeHaz project

# Many Thanks