Predicting the Atmospheric Dispersion of Carbon Dioxide from a Buried Ruptured Pipeline

Jennifer Wen, Hongen Jie and Pierre Le Fur

Warwick FIRE, School of Engineering, University of Warwick, Coventry, CV4 7AL, UK

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Outline

- Objectives
- CO_2FOAM
- The test case
- The blind validation
- Further analysis of the predictions
- Concluding remarks

Objectives

Provide further validations of **CO_2FOAM,** a dedicated solver for CO_2 dispersion in the framework of the open source CFD code OpenFOAM®.

CO_2FOAM

- **CO_2FOAM** – a dedicated solver for CO_2 dispersion in the framework of the open source CFD code OpenFOAM®

- Two options for CO_2 dispersion:

  - The Homogeneous Equilibrium Model (HEM)

    Jennifer Wen, Ali Heidari, Baopeng Xu and Hongen Jie, Dispersion of carbon dioxide from vertical vent and horizontal releases—A numerical study, Proc IMechE Part E: J Process Mechanical Engineering 227(2), 125-139, May~~,~~ 2013.

  - The Homogeneous Relaxation Model (HRM)

    Jennifer Wen, Ali Heidari, Baopeng Xu and Hongen Jie, Further development and validation of CO_2FOAM for the atmospheric dispersion of accidental releases from carbon dioxide pipelines, under consideration by International Journal of Greenhouse Gas Control, 2015.

CO_2FOAM with HRM

- Mixture equations accounting for all phases.
- A relaxation model is employed to handle the presence of solid CO_2 within the release and its continuing sublimation.
- Buoyancy effects are important and included.
- Unsteady Reynolds Averaged Navier Stokes (RANS) approach.
- k-ω SST turbulence model for Reynolds Stresses.

Test case considered

- Test 02 in Case Study 4 within the series of full scale tests commissioned by National Grid within the dense phase CO_2 PipeLine TRANSportation (COOLTRANS) research programme (Cooper, 2012).
- The test involved the release of dense phase CO_2 from a ruptured buried pipeline.

(Courtesy of National Grid)

Cooper R. National Grid's COOLTRANS research programme. J Pipeline Eng 2012; 11: 155–172.

Boundary conditions

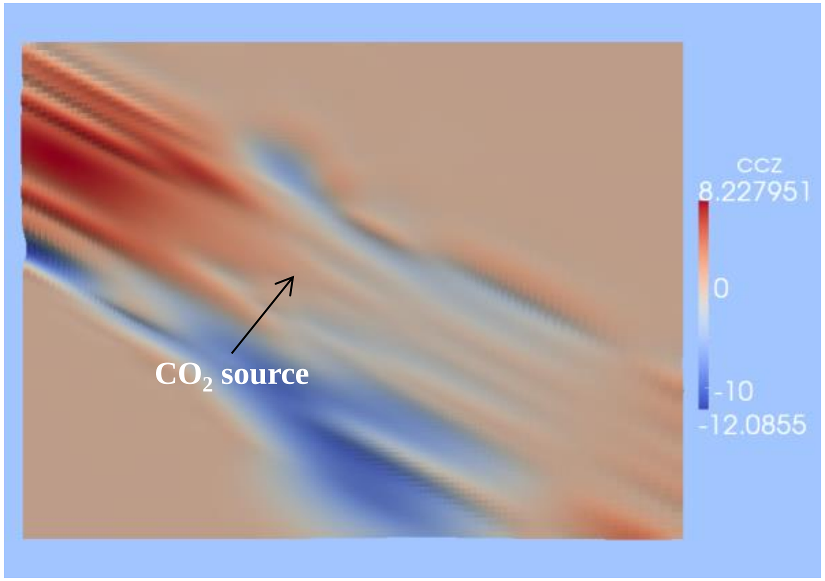
The parameters for the pseudo source of the released CO_2 supplied by DNV-GL

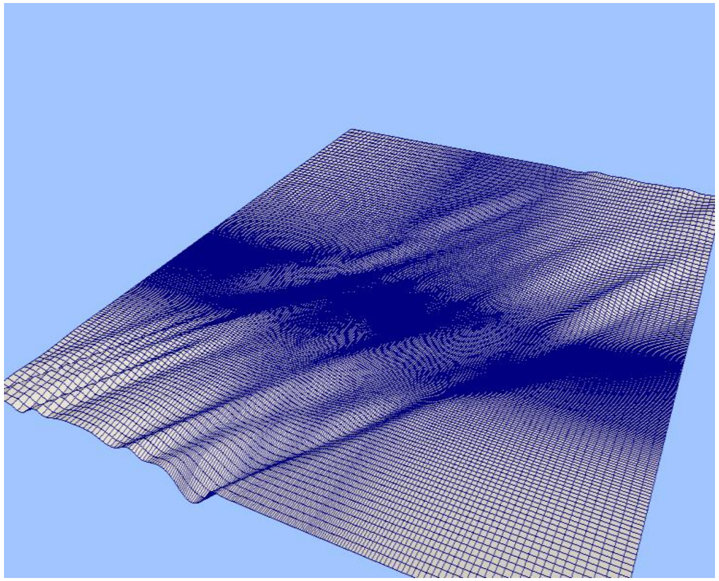
Parameters		**Case Study 4 Test 02**
Mass Flow CO_2 Vapour	kg/s	206.7
Mass Flow CO_2 Condensed	kg/s	86.3
Mass Flow Air	kg/s	174.3
Total Mass Flow	kg/s	467.3
Total Mass Flow CO_2	kg/s	293.0
Mass fraction of CO_2 Vapour	%	44.233
Mass fraction of CO_2 Condensed	%	18.468
Representative Crater Source Velocity	m/s	44.80
Representative Crater Source Diameter	M	2.145
Representative Crater Source Density	kg/m^3	2.887
Representative Crater Source Temperature	K	185.7

The atmospheric conditions

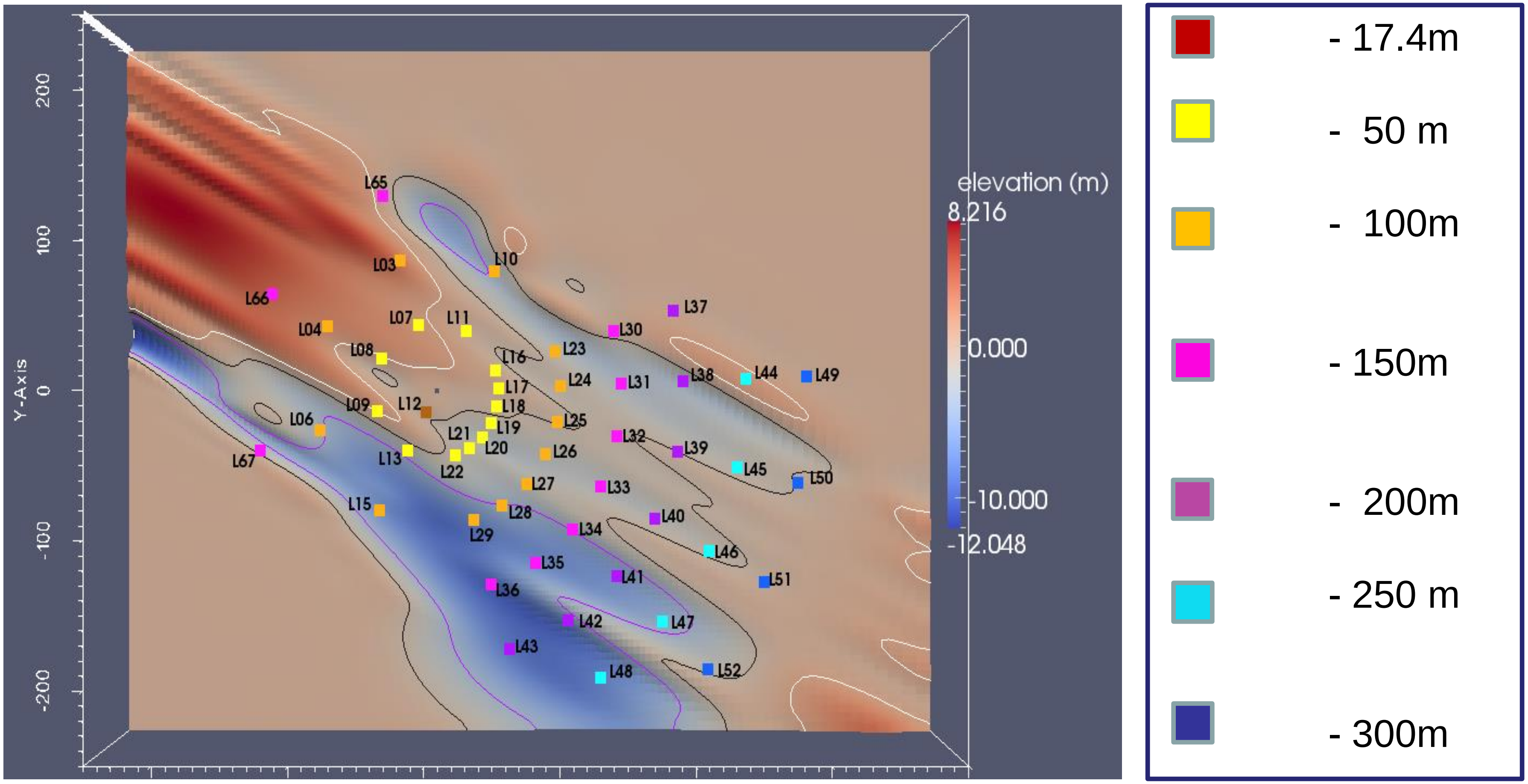
Parameters		Value
Field Temperature averaged over 45 measurements	°C	17.7
Relative humidity (average over all test)	%	73
Dew temperature	°C	12.76
Average of wind speed measured at four locations	m/s	2.5
Average of wind direction measured at four locations	°	242

The realistic terrain at the test site





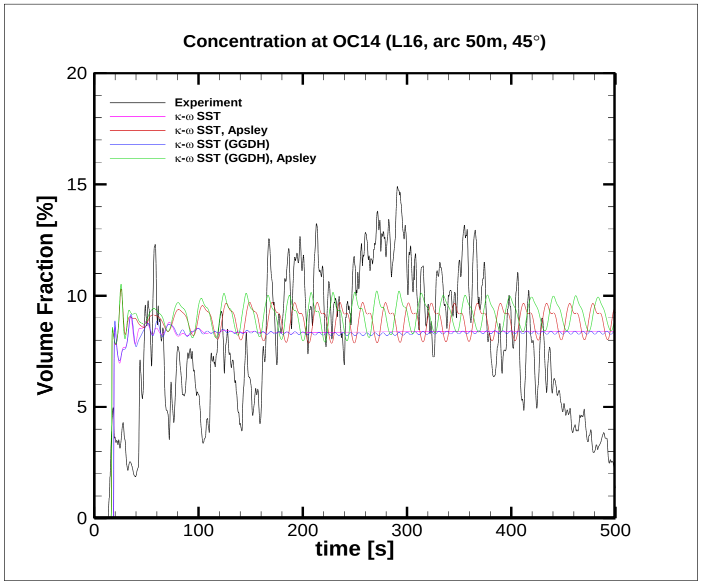
Locations of CO_2 concentration measurements

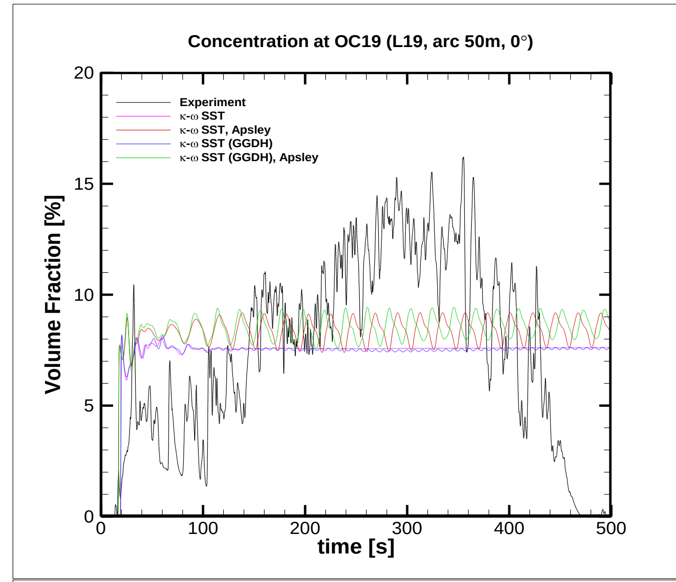


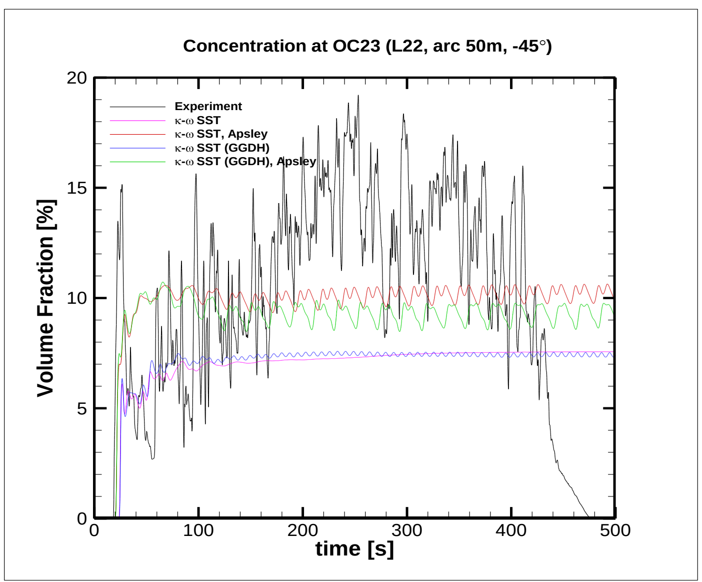
The locations of probes shown on top of the shaded contour of terrain height.

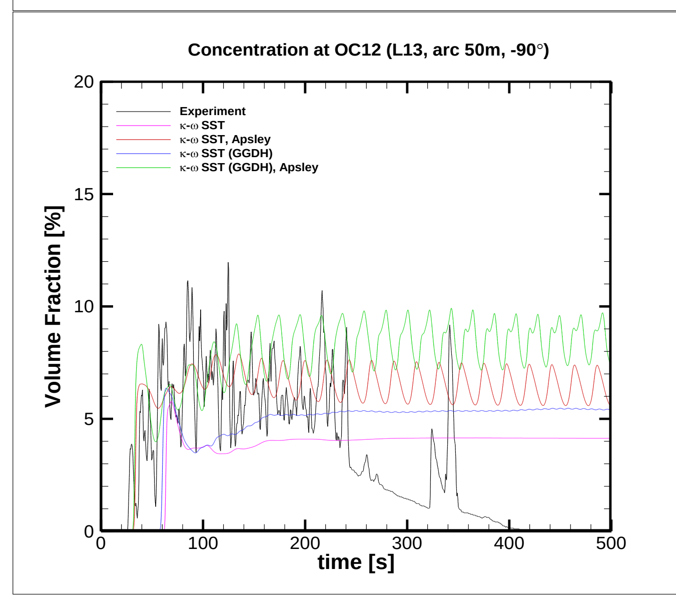
The predicted and measured CO_2 concentrations

50 m from the CO_2 source

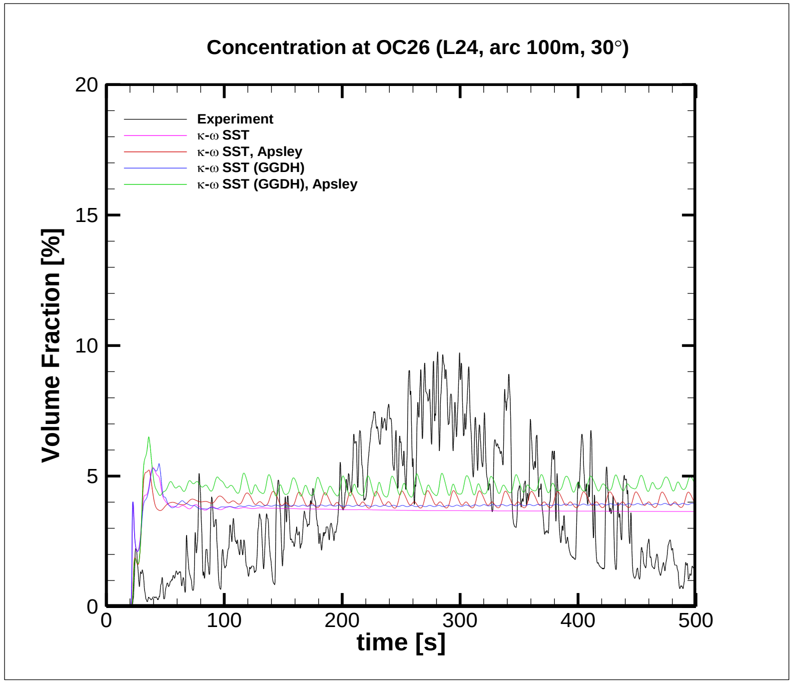




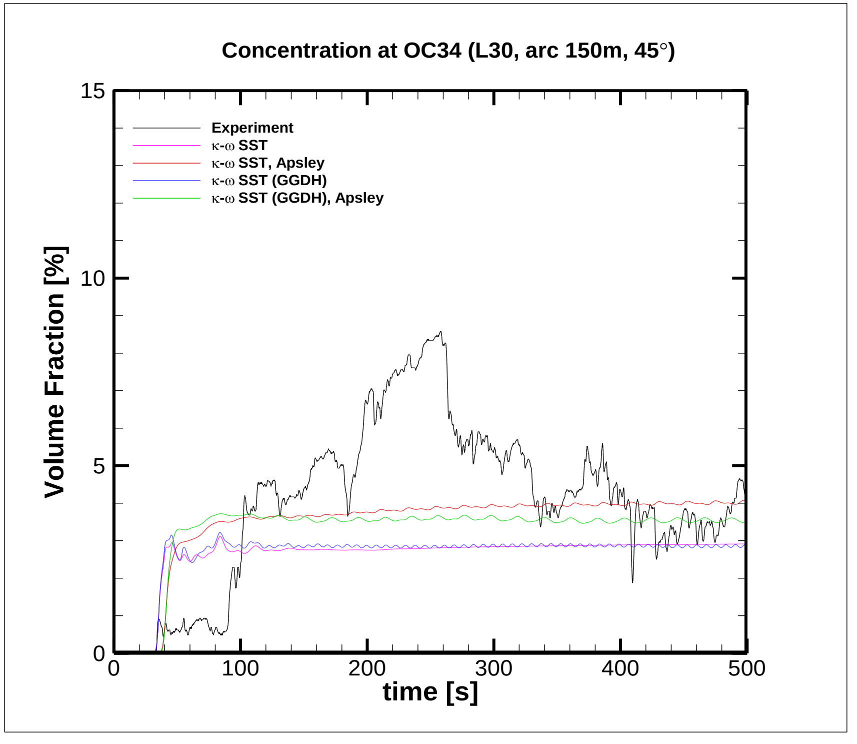




The predicted and measured CO_2 concentrations

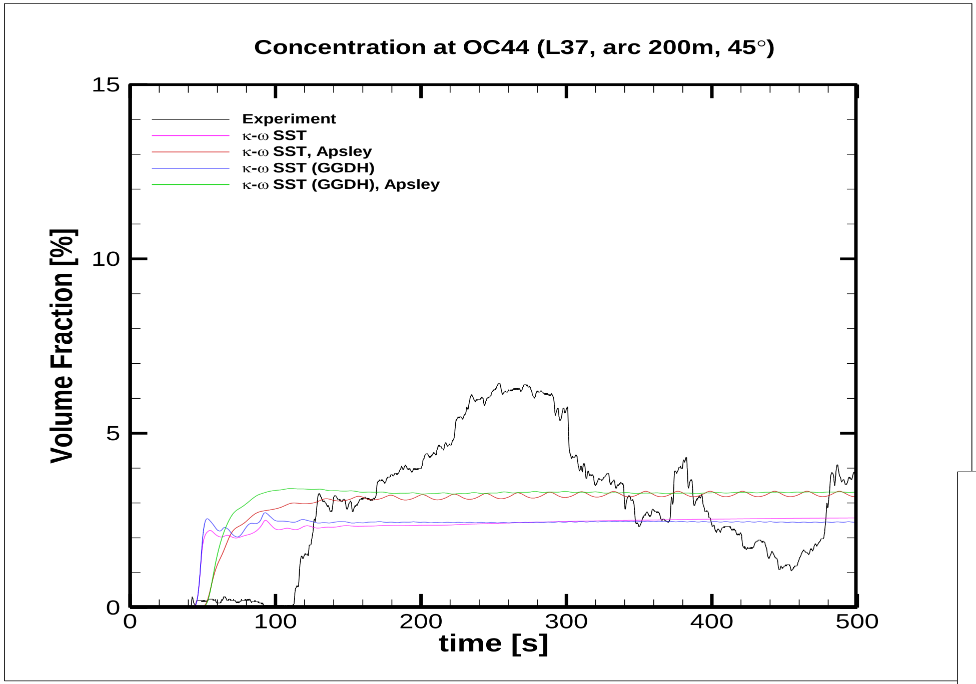


100 m from the CO_2 source



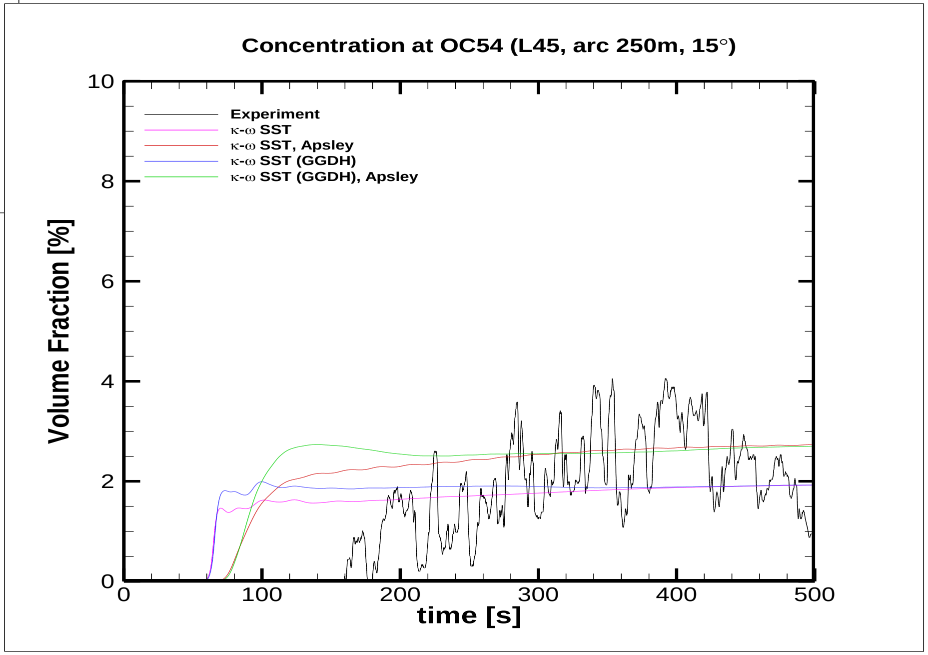
150 m from the CO_2 source

The predicted and measured CO_2 concentrations



200 m from the CO_2 source

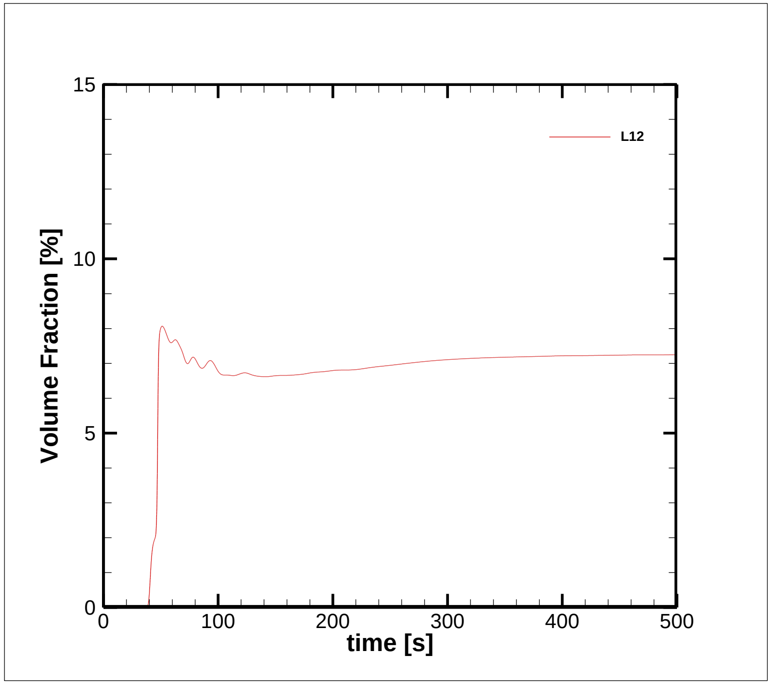
250 m from the CO_2 source



Threshold of unconsciousness

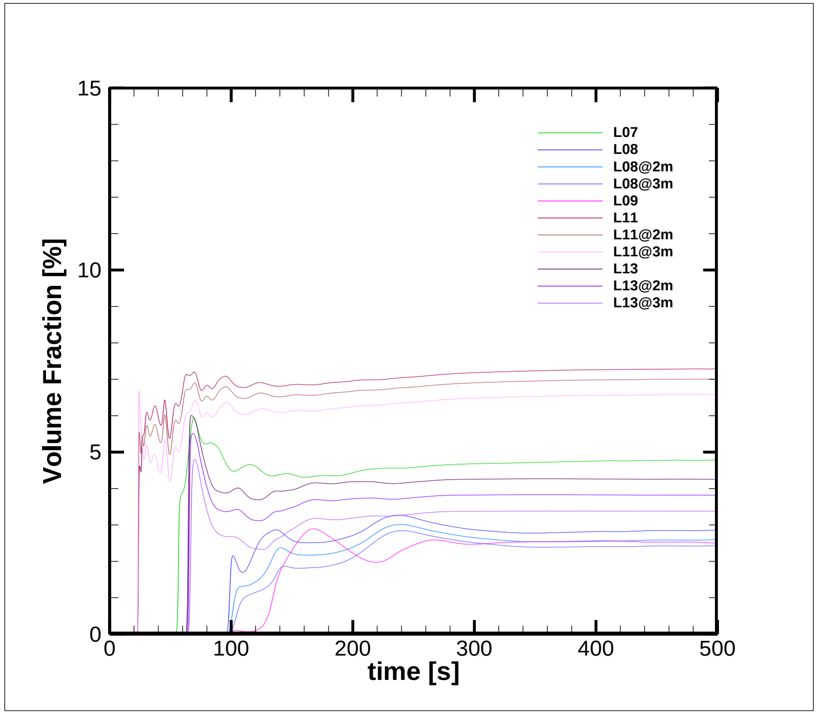
Concentration of carbon dioxide (ppm) / % v/v	Responses
45000 / 4.5 %	Reduced concentration capability for more than 8 hours exposure, adaptation possible
55000 / 5.5%	Breathing difficulty, headache and increased heart rate after 1 hour
65000 / 6.5%	Dizziness, and confusion after 15 minutes exposure
70000 / 7.0%	Anxiety caused by breathing difficulty effects becoming severe after 6 minutes exposure
100 000 / 10%	Approaches threshold of unconsciousness in 30 minutes
120 000 / 12%	Threshold of unconsciousness reached in 5 minutes
150 000 / 15%	Exposure limit 1 minutes
200 000 / 20%	Unconsciousness occurs in less than 1 minute

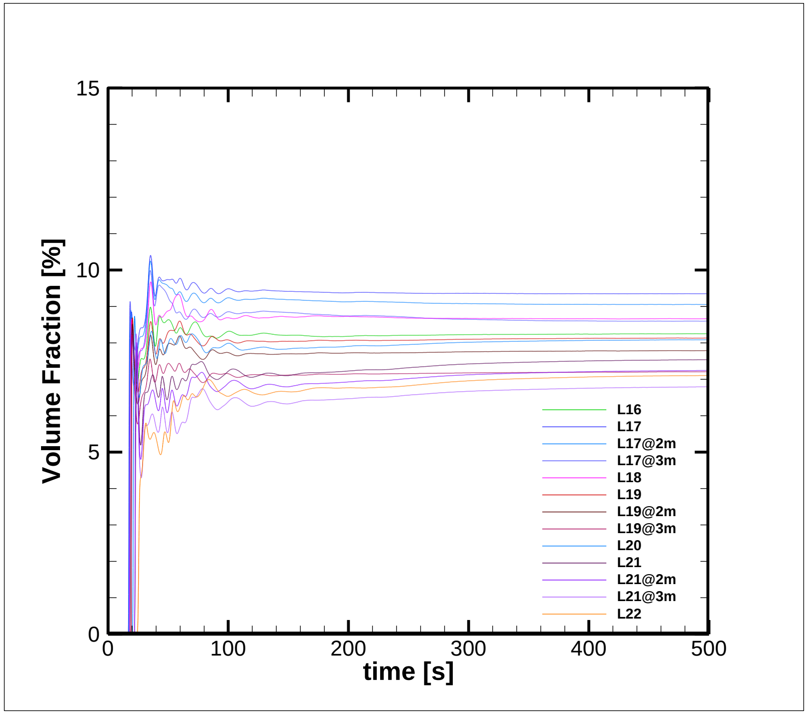
The predicted CO_2 volume fractions



The concentration of CO_2 at probe L12 on Arc 17.5m.

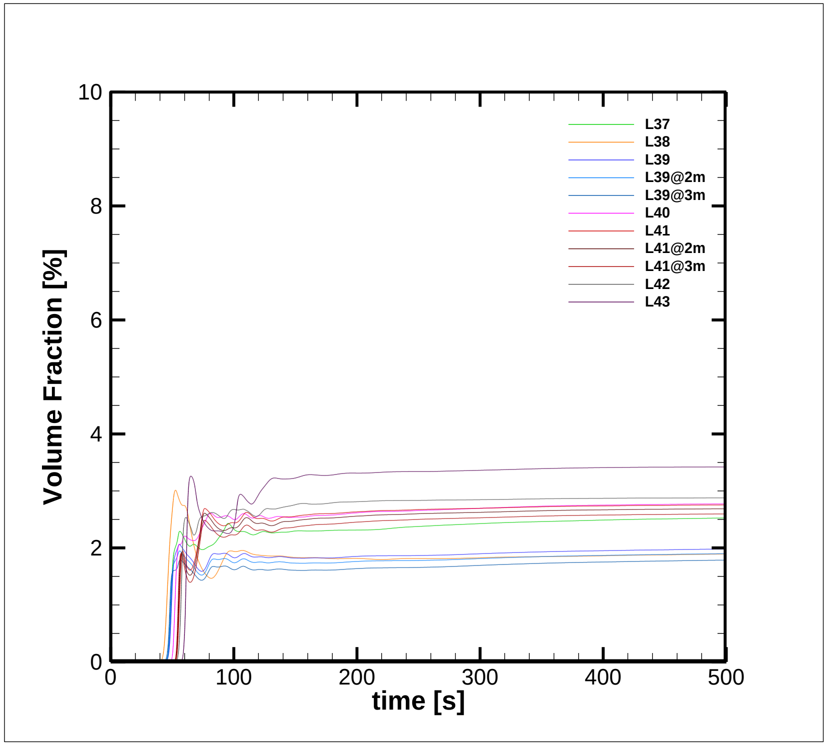
The predicted CO_2 volume fractions

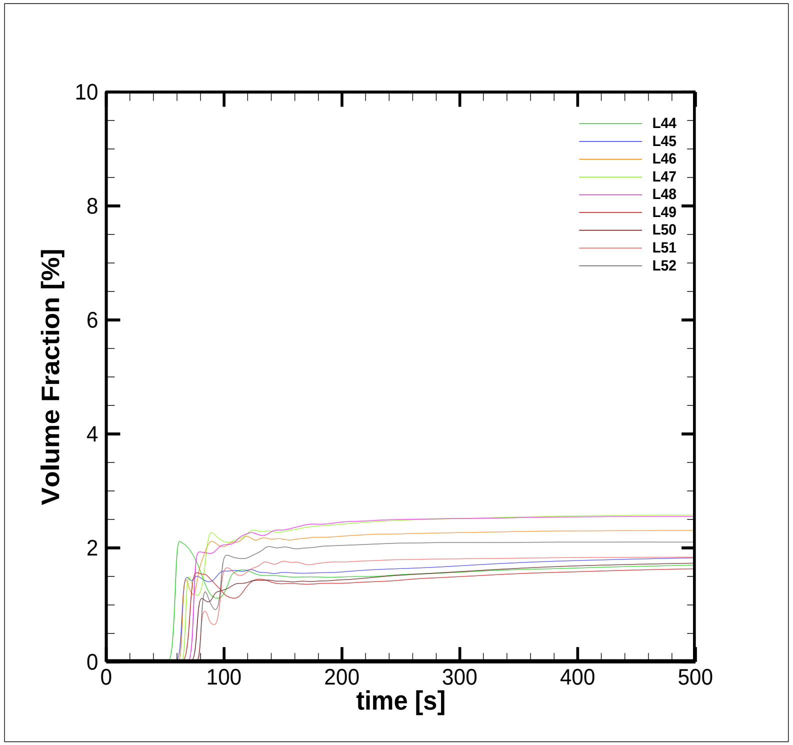




The concentration of CO_2 at probes on Arc 50m (left: upstream; right: (downstream)

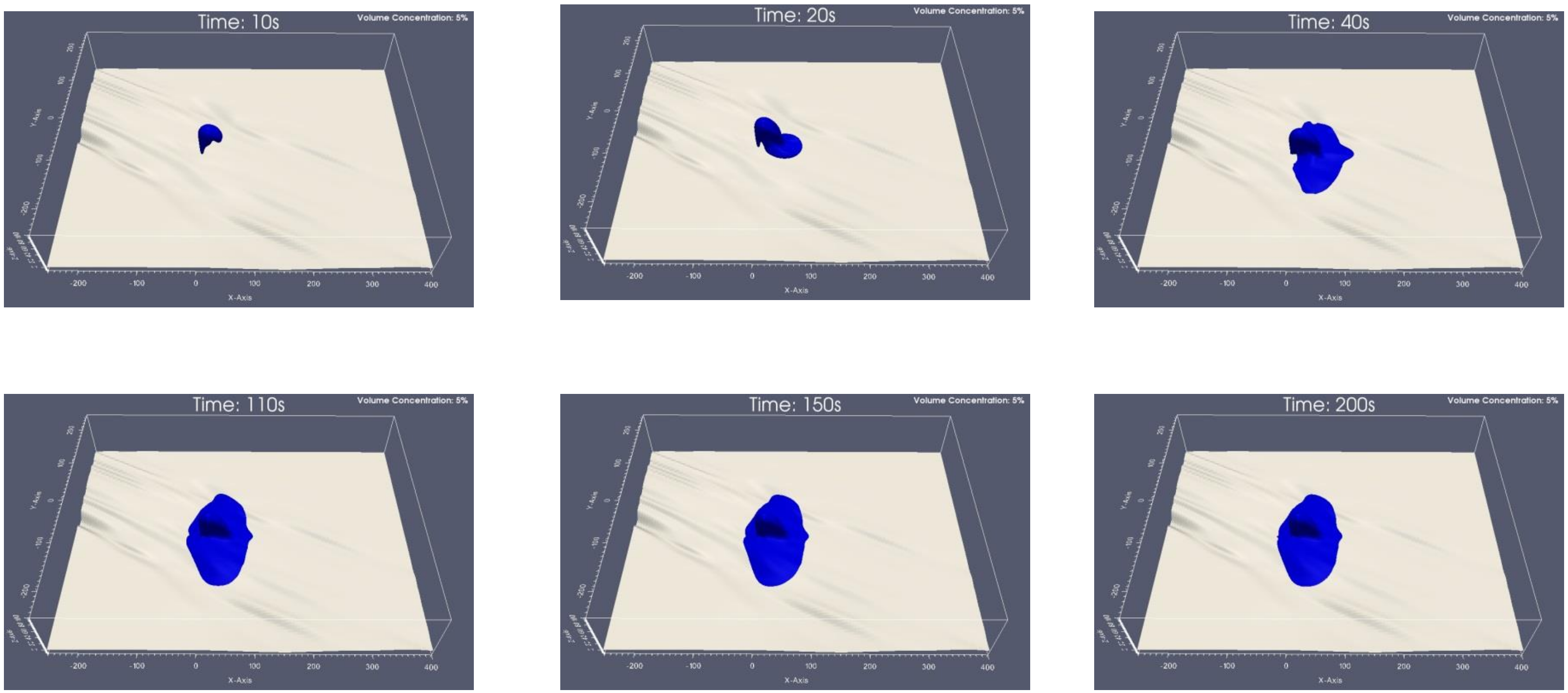
The predicted CO_2 volume fractions





The concentration of CO_2 at probes on Arc 200 m (left) and Arcs 250m and 300m (right).

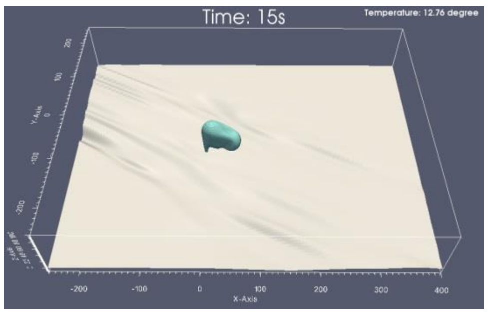
The predicted footprint of 5% CO_2 concentration

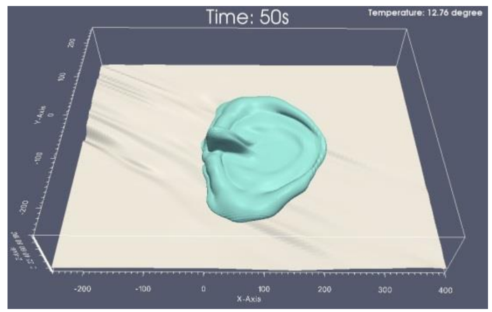


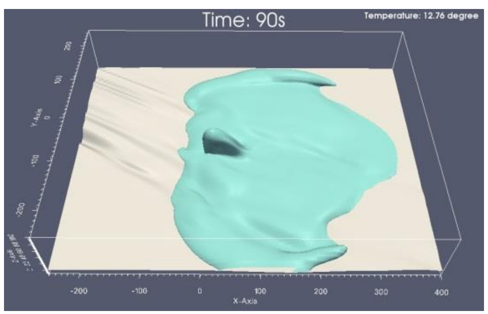
The stable cloud covers a length of 105m in the wind direction (25m and 80m at the upstream and downstream directions respectively) and a width of 225m in the crosswind direction (110m and 115m at the positive and negative y direction, respectively).

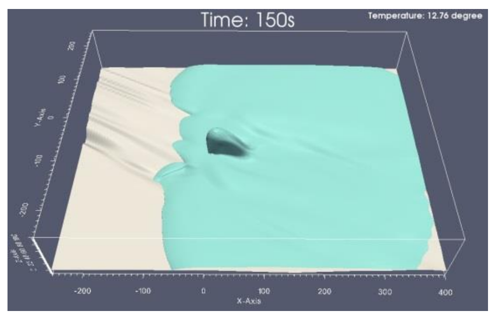
The visibility of the CO_2 cloud

The ISO-contour of the CO_2 at the dew temperature

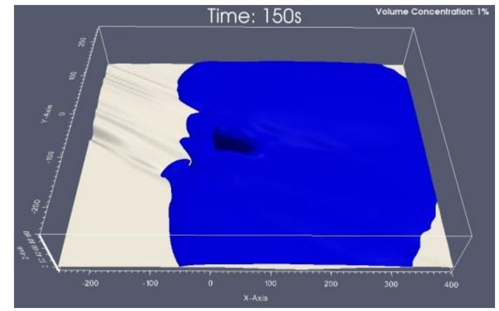




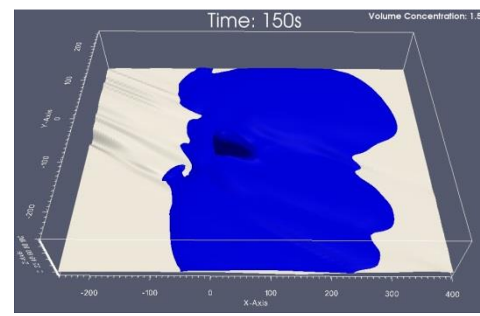




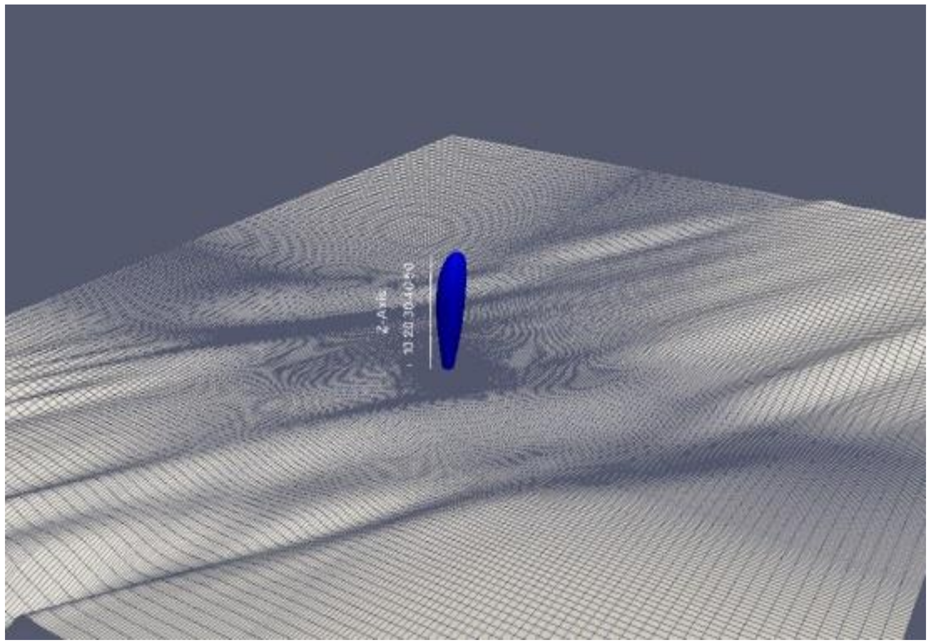
The footprint of CO_2 cloud at 1% volumetric fraction



The footprint of CO_2 cloud at 1.5% volumetric fraction

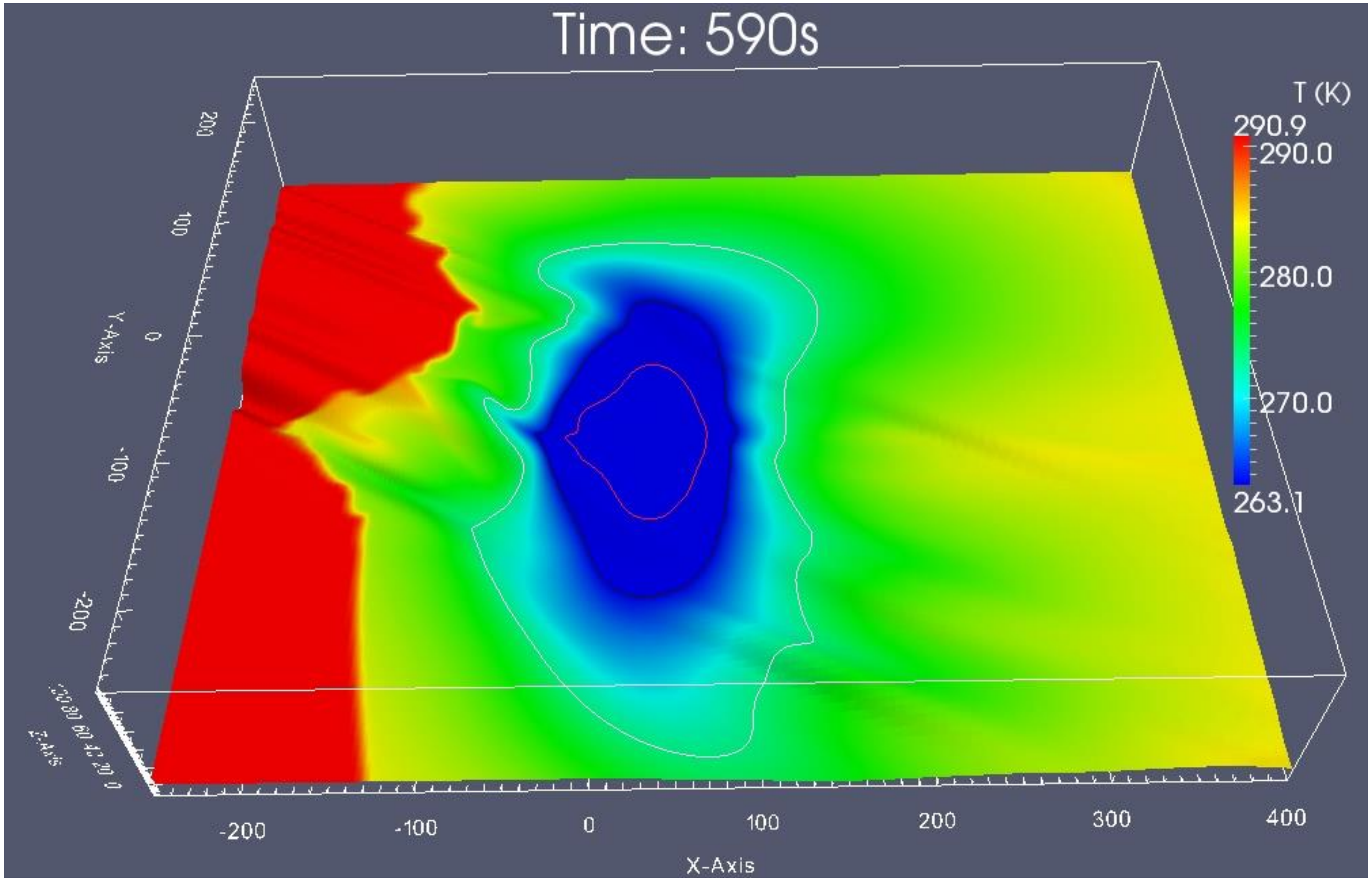


Dry ice



The predicted solid CO_2 with mass fraction greater than 0.1% after the CO_2 cloud stabilizes.

Ground temperature



The temperature close to the ground after the CO_2 cloud stabilizes at 200 s (Red line: -20°C, Black line: -10°C, White line: 0°C).

Concluding Remarks

- CO_2FOAM, a dedicated solver for CO_2 dispersion was used to predict the dispersion of CO_2 released from a buried ruptured pipeline <u>before</u> the release of the experimental measurements.
- The predicted CO_2 concentrations are in reasonably good agreement with the data.
- The terrain was found to have some effect on the behaviour of the CO_2 cloud; and the effect is more obvious for large cloud.
- The CO_2 cloud was found to stabilize shortly after the release, and in this particular case it stabilises after 200 s, indicating that the extent of the cloud with potential harmful CO_2 concentrations is limited.
- Solid CO_2 was predicted only close to the source and sublimates rapidly.