Development of a Practical Methodology for Assessing the Major Accident Risks associated with CO_2 in areas of Complex Terrain

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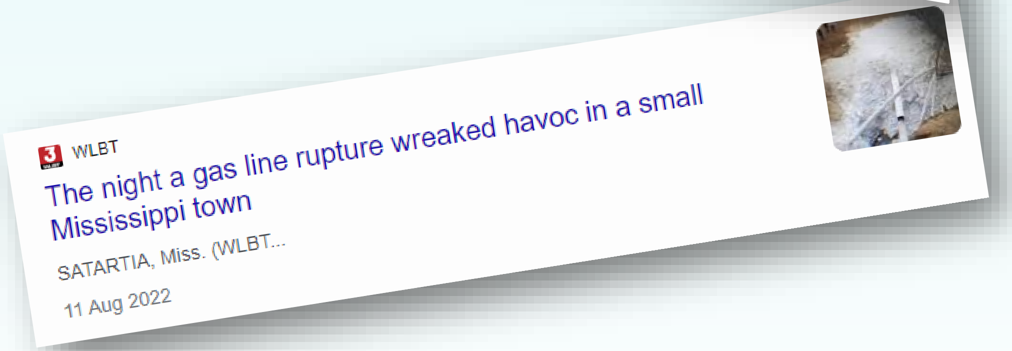
Hazards 33

Introduction

- Motivation
- Major Accident Hazard Potential of CO_2
- Case Study – Satartia, Mississippi
- CFD Model Set-up
- Comparison of Predicted Lethality – CFD v. Phast
- Lethality for Different Terrain (Simple Generic Slopes and Valleys)
- Conclusions and Further Work

Motivation

- Carbon Capture and Storage (CCS) projects are becoming more widespread;
- Key element is transportation of CO_2 by pipeline;
- Accidents have shown large CO_2 releases can affect significant numbers of people;
- Experience has shown terrain can have a significant effect on behaviour of dense gas releases such as CO_2;
- Understanding the risks is important in helping to determine pipeline routes and prevent headlines like these;
- Paper seeks to contribute to the effort to determine a practical approach for assessing the risks of CO_2 releases, accounting for terrain as CCS is critical to meeting climate change targets.



Carbon Dioxide Hazards

- Dense gas resulting in low lying clouds
- Odourless & colourless gas
- Asphyxiant but is also known to have toxic effects

- Classed as a 'substance hazardous to health' under the COSHH regulations & the HSE define workplace exposure limits (WELs) for CO_2 exposure.
  - Long-term exposure limit (8-hr reference period) of 5000 ppm
  - Short-term exposure limit (15 minute reference period) of 15000 ppm

- CO_2 is not currently classed as a dangerous substance in UK but when transported in high quantities it can cause a major accident hazard.

Satartia Case Study

Case Study – Satartia, Mississippi (1)

Summary

- Rupture of 24" CO_2 pipeline in February 2020.
- No deaths, but many hospitalisations due to gas inhalation.
- Cause of rupture was ground movement due to heavy rains.

Google Earth Pro. 2022

Reproduced from US Department of Transportation Pipeline and Hazardous Materials Safety Administration, Failure Investigation Report - Denbury Gulf Coast Pipelines, LLC 2022

Case Study – Satartia, Mississippi (2)

Questions

- Do the current dispersion modelling tools on the market predict that a dangerous dose could reach Satartia?
- What affect did terrain have on the dispersion profile?

Analysis

- Phast approximation of incident, using publicly available data.
- CFD approximation of the incident, using publicly available data.
- Comparison of predicted lethality – CFD v. Phast to help understand the impact of terrain.

Lethality

Lethality parameter	N	T_A	T_B	SLOT DTL ($ppm^n.min$)	SLOD DTL ($ppm^n.min$)
Value	8	-90.778	1.01	$1.5x10^{40}$	$1.5x10^{41}$

- Perhaps of greater interest to risk modelling than CO_2 concentration;
- SLOT – Specified Level of Toxicity (representing 1%-5% fatality in average population). We have assumed a SLOT dose may have reached Satartia
- SLOD – Significant Likelihood of Death. Typically represents 50% fatality probability.
- This calculation is available in Phast and can be calculated from integrating the results of a transient CFD simulation. Calculation done at 1.6 m above ground level

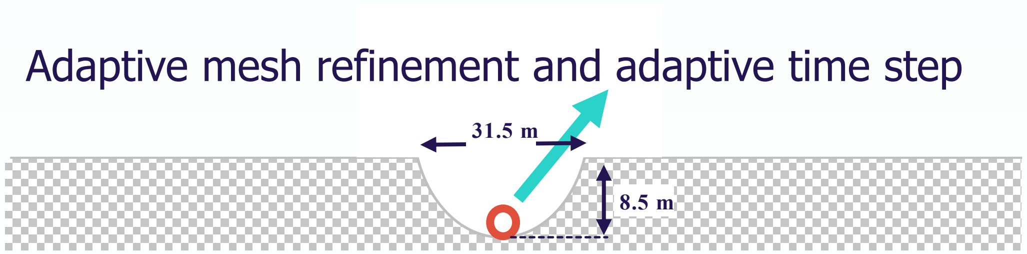
$$L = \int_0^T [C(t)]^N \, dt \qquad \text{Eq. 1}$$

$$P = T_A + T_B \ln L \qquad \text{Eq. 2}$$

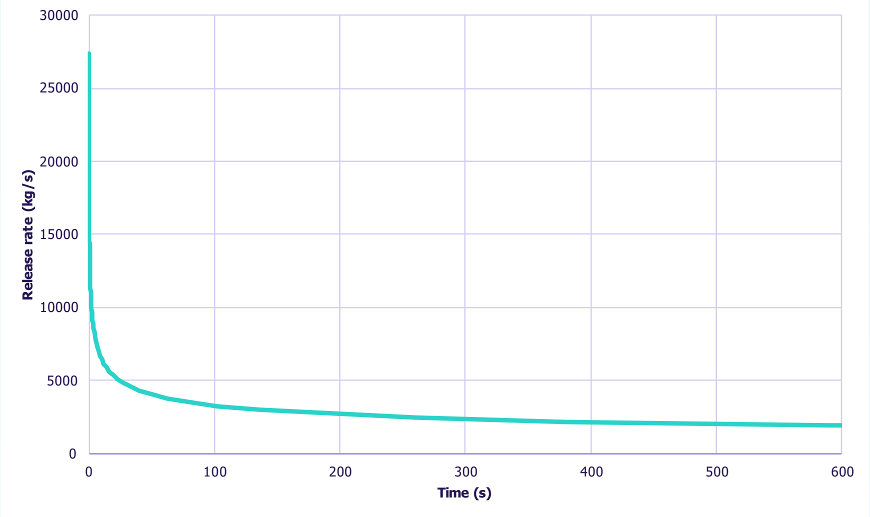
$$P_{Death} = \frac{1}{2}\left\{1 + \text{erf}\left[\frac{P-5}{\sqrt{2}}\right]\right\} \qquad \text{Eq. 3}$$

CFD model setup

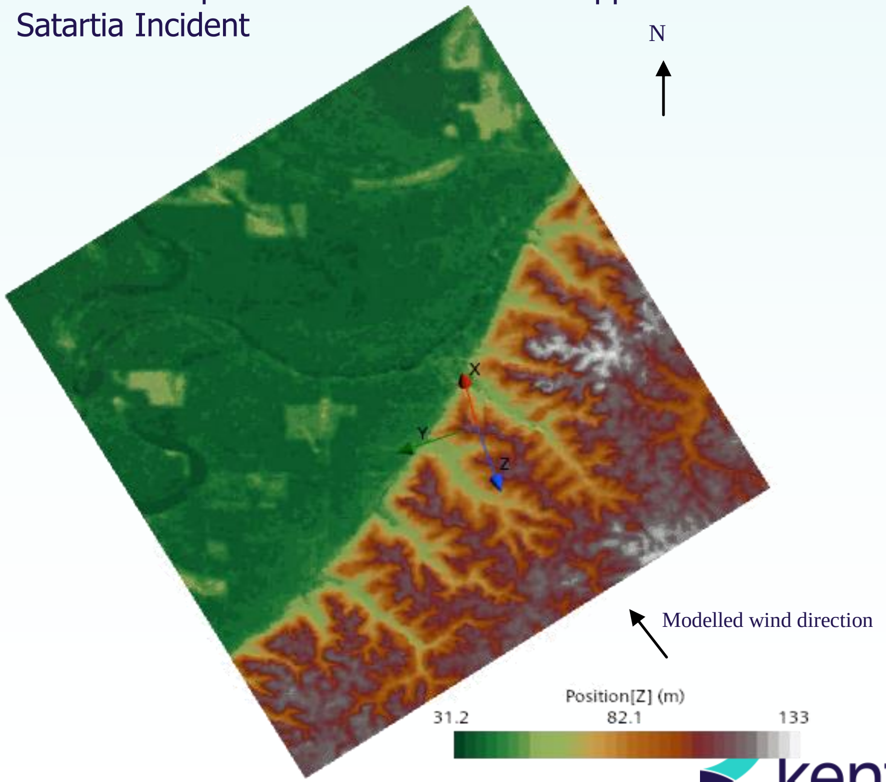
- Transient CFD modelling undertaken using STAR-CCM+ (Siemens)
- Terrain data included at a resolution of 30 m
- Low ambient wind condition (2 m/s)
- Transient release profile calculated from Phast
- Violent release forms a crater, free jet aimed to clear the lip of crater
- Appropriate time-varying source term used for leak (including representation of dry ice with droplet model)
- Adaptive mesh refinement and adaptive time step



Schematic showing the crater dimensions used in the CFD model approximating the Satartia Incident



Release rate profile from Phast used to approximate the Satartia Incident



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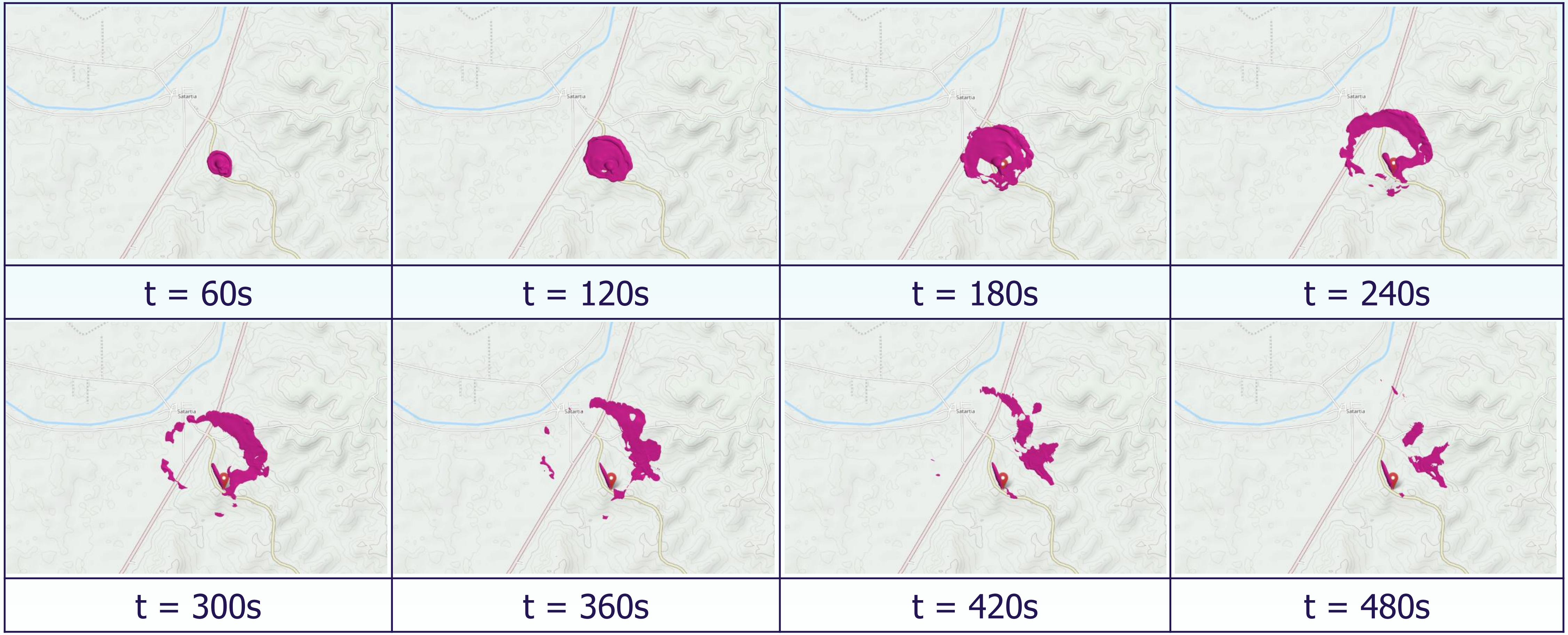
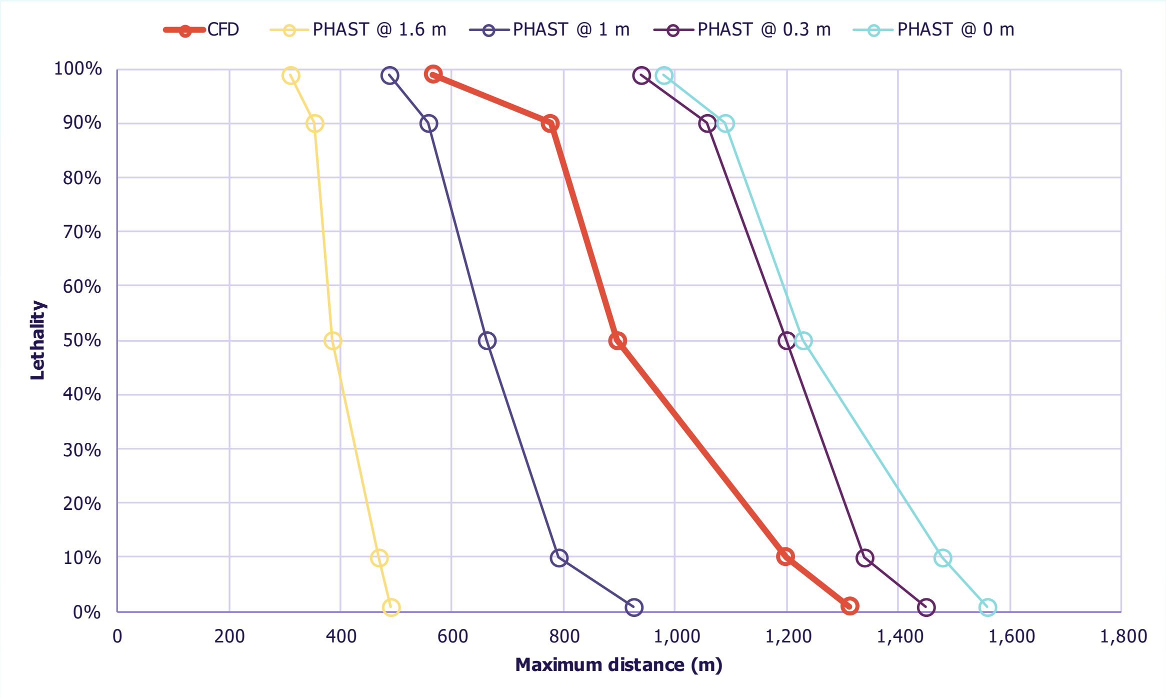
Transient release



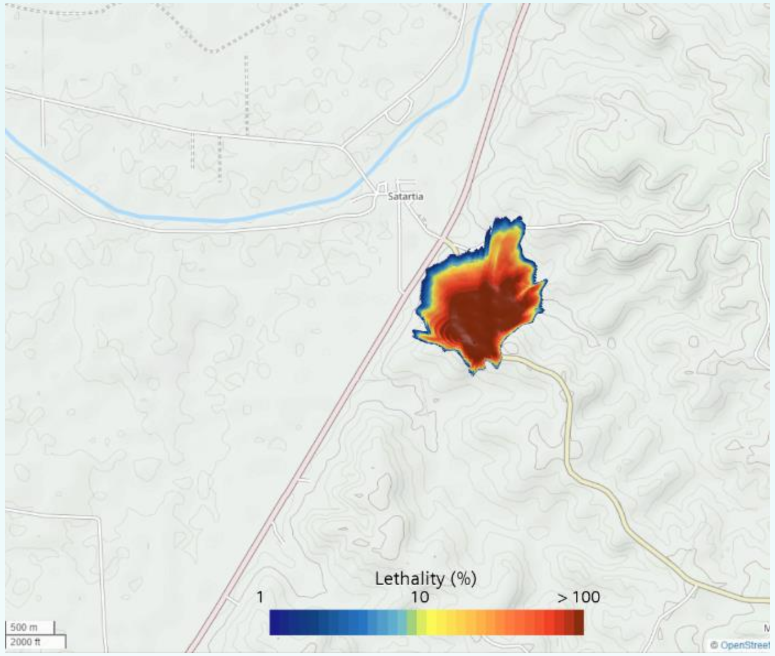
Evolution of the 63,000 ppm iso-surface of CO_2 of a release approximating the Satartia incident

Hazard Extents - Lethality

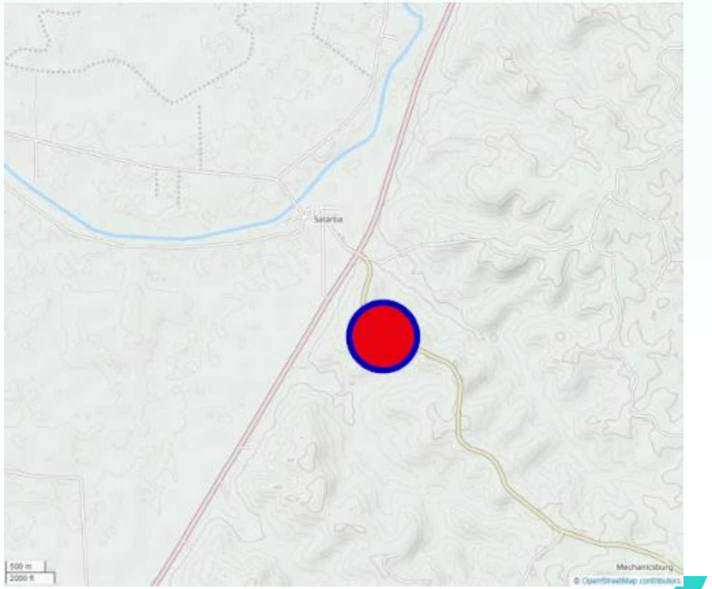


CFD Maximum extents of lethality for release approximating the Satartia Incident using CFD (at 1.6 m above ground level). SLOT reaches HWY 3 (outskirts of Satartia). SLOD at HWY 433. Tallies well with observations.

Phast Downwind distances at a range of receptor heights above ground level. SLOT dose extent < 500 m at 1.6 m head height – does not reach Satartia. However, can process at lower receptor heights – in this case a height of 0.3-0.5 may be conservative.



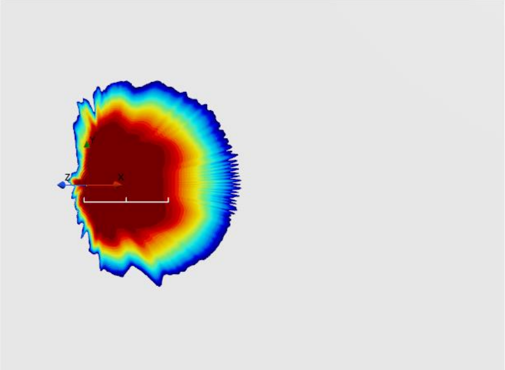
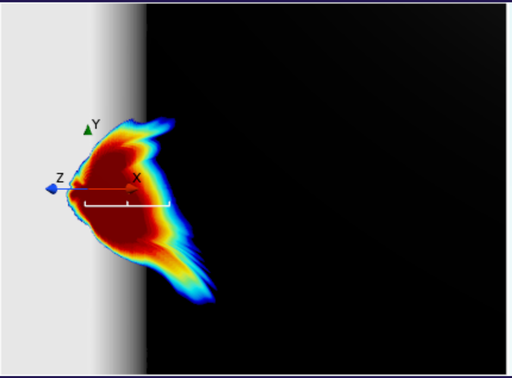
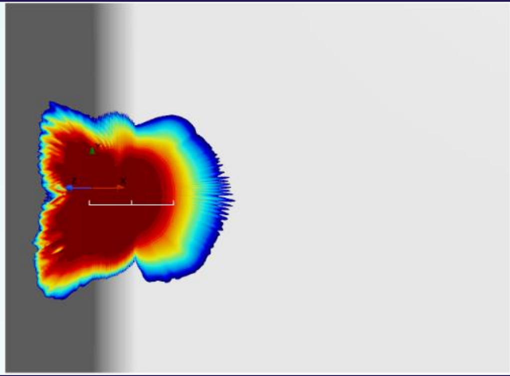
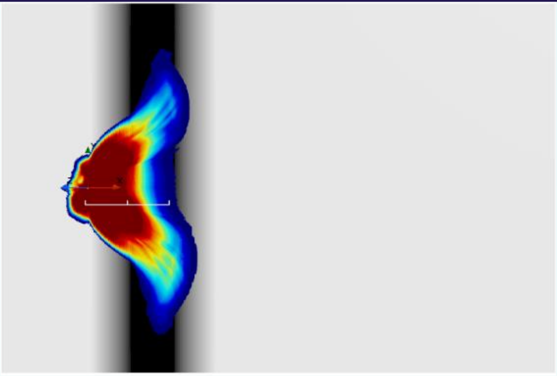
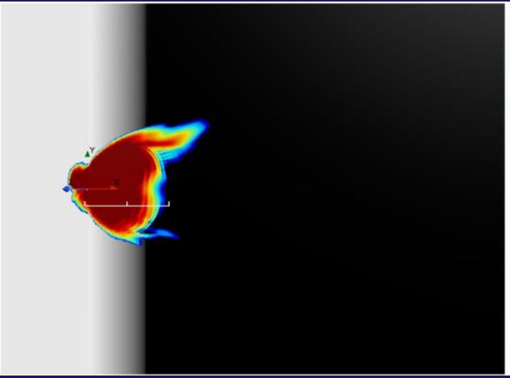
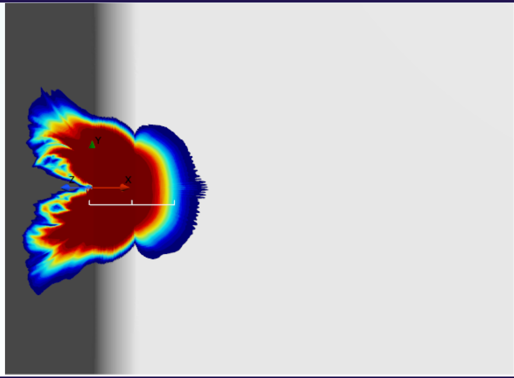
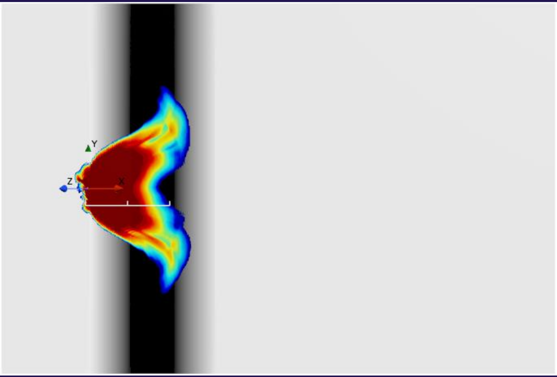
Predicted extent of lethality with CFD



Predicted extent of lethality with Phast SLOT – blue and SLOD – red

Idealized Terrains

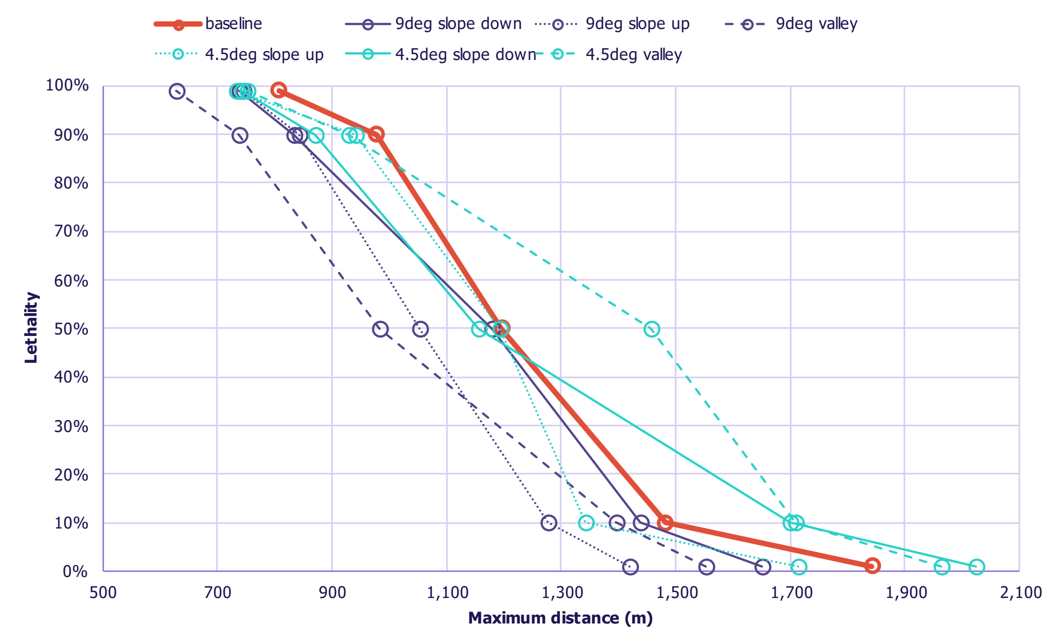
Lethality Contours for Idealised Terrain

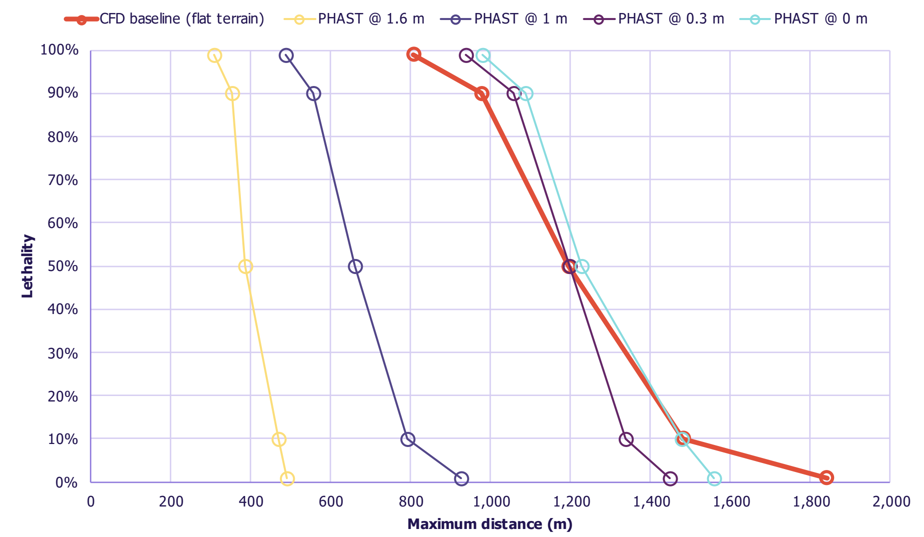
			
Baseline (flat plate)	4.5° downward slope	4.5° upward slope	4.5° valley
			
	9° downward slope	9° upward slope	9° valley

Lethality results, taken at 1.6 m above ground level after 10 minutes

Lethality for idealised terrain (continued)

- Plots show maximum extents of lethality from CFD, and downwind distances from Phast;
- Terrain can have a significant impact on extent and shape of lethality contour;
- Maximum extent of flat terrain case exceeds that of most other terrain considered, particularly at higher lethality levels.
- Valley cases significantly altered the shape of the contour as CO_2 collected within the valley.
- Phast modelling downwind distances significantly shorter than CFD. Phast is highly sensitive to receptor height for this type of release, difference between Phast and CFD can be addressed by reducing receptor height.





Conclusions

- Possible to model fully transient buried pipeline releases of CO_2 over realistic terrain using CFD.
- The CFD case approximating the Satartia Incident correlate well with findings from the PHMSA Incident Report.
- The study found that in the cases considered, using Phast was non-conservative compared to CFD.
- The study found that that the impact of terrain can be significant, but it is difficult to draw clear conclusions on simple measures that account for complex terrain.
- It was found that for most cases considered, a flat terrain gave conservative results, particularly at higher levels of lethality.
- CFD is considered well able to capture the effect of terrain. If simpler tools such as Phast are used in a conservative way (effectively using flat terrain) as a screening exercise, should be possible to use CFD to refine the results in areas identified to be adversely impacted.
- From the small number of cases undertaken in this study, the evidence is that Phast results can generally be made conservative by reducing the receptor height of the lethality cut used to 0.3-0.5 m.

Further Work

It should be noted that this work is not exhaustive but rather designed to contribute to the discussion on the impact of terrain on CO_2 dispersion.

Further work:

- Post-process CFD simulations for different receptor heights across varying terrains.
- Refine how best to use Phast for such analyses and develop rulesets to apply to Phast results to take account of terrain based on CFD modelling.
- Incorporation of such rulesets in practical risk models.
- Review experimental data as it becomes available.

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Acknowledgements

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Any questions?

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