Liquid hydrogen spill and evaporation modelling

ELVHYS

Series of workshops on safety of cryogenic hydrogen transfer technologies

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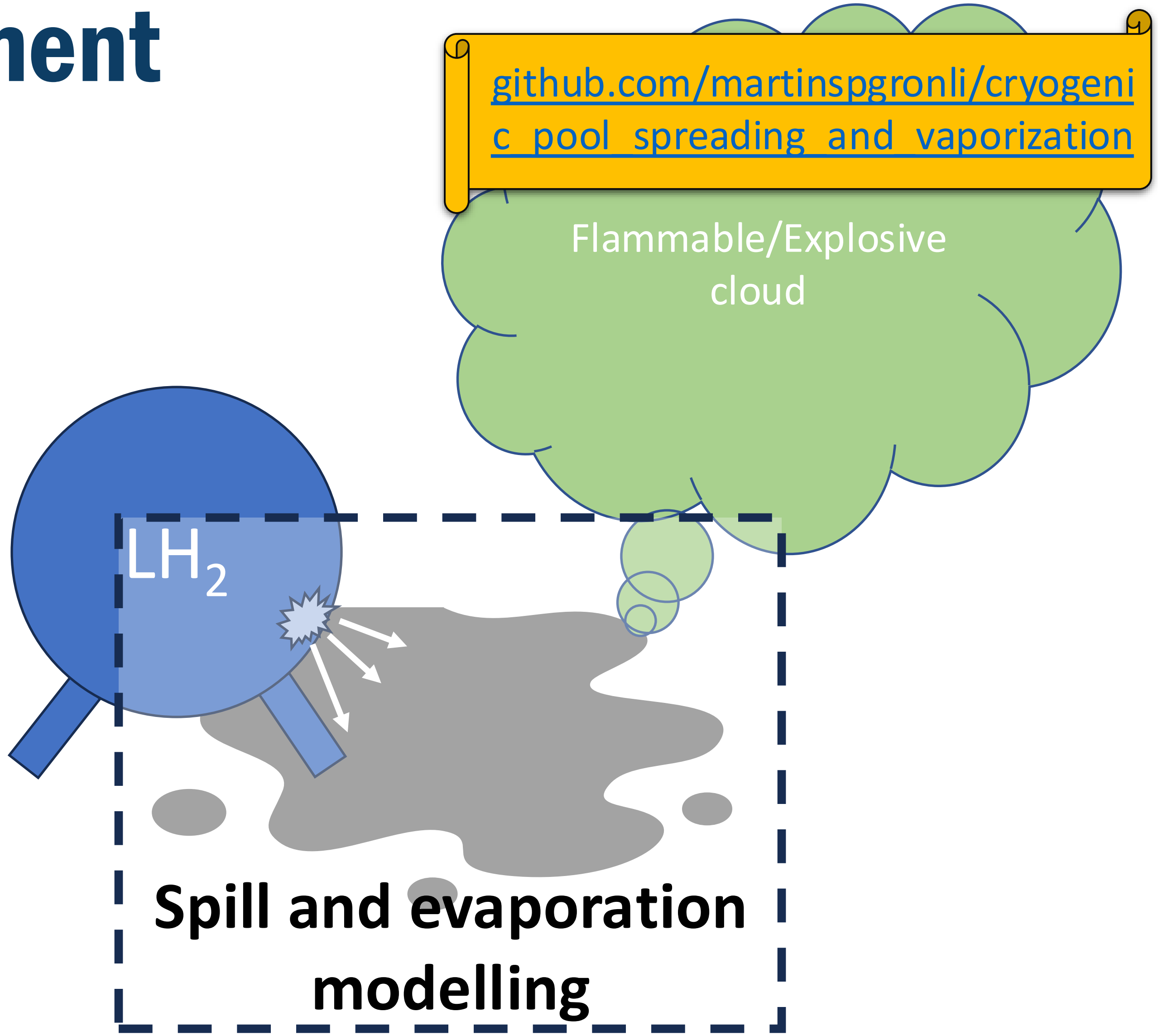
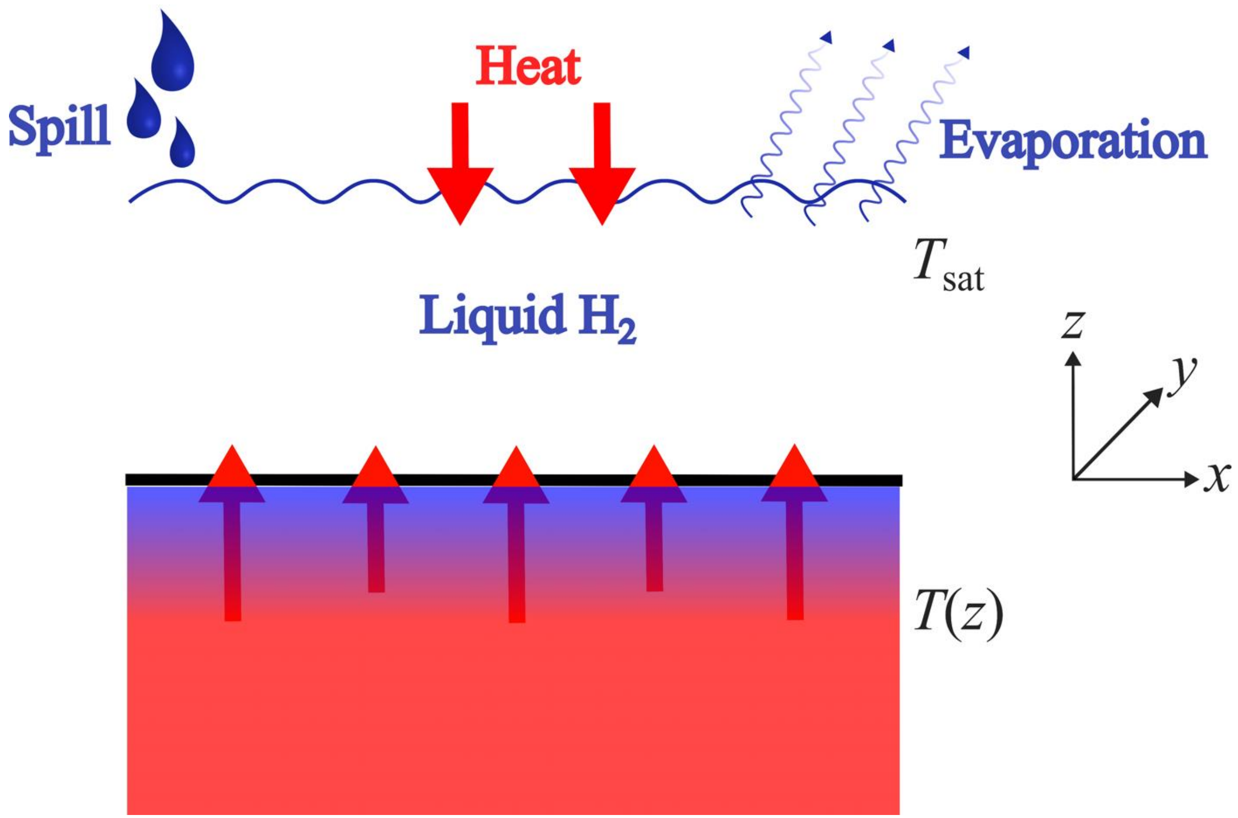
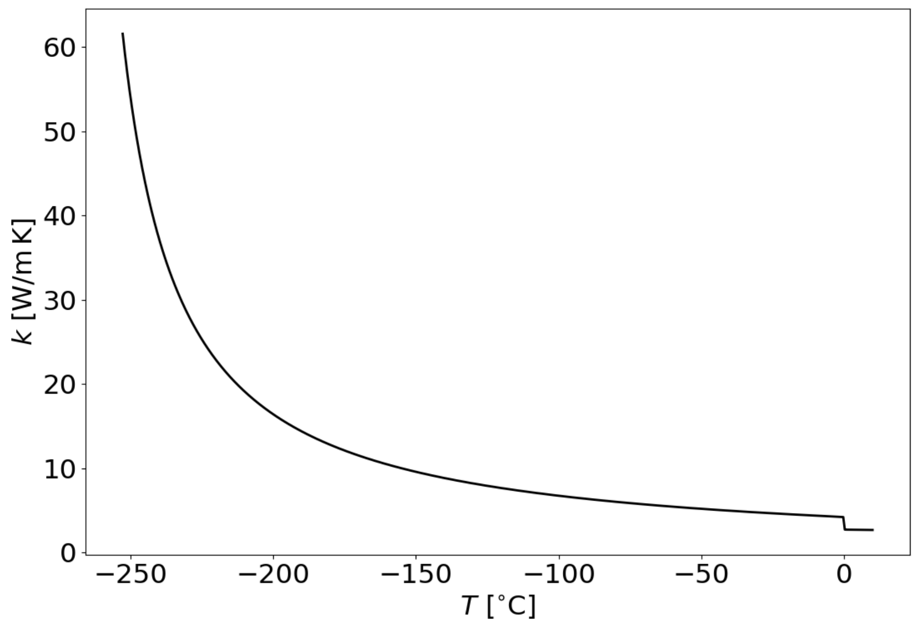
Safety and risk assessment

- Describe how LH_2 spreads and evaporates on solid ground
- Account for soil moisture freezing and temperature dependent properties
- Local evaporation is an input parameter to dispersion analysis of hydrogen in the atmosphere
- Open-source spill-modelling tool
- Applicable to other fluids like LNH_3



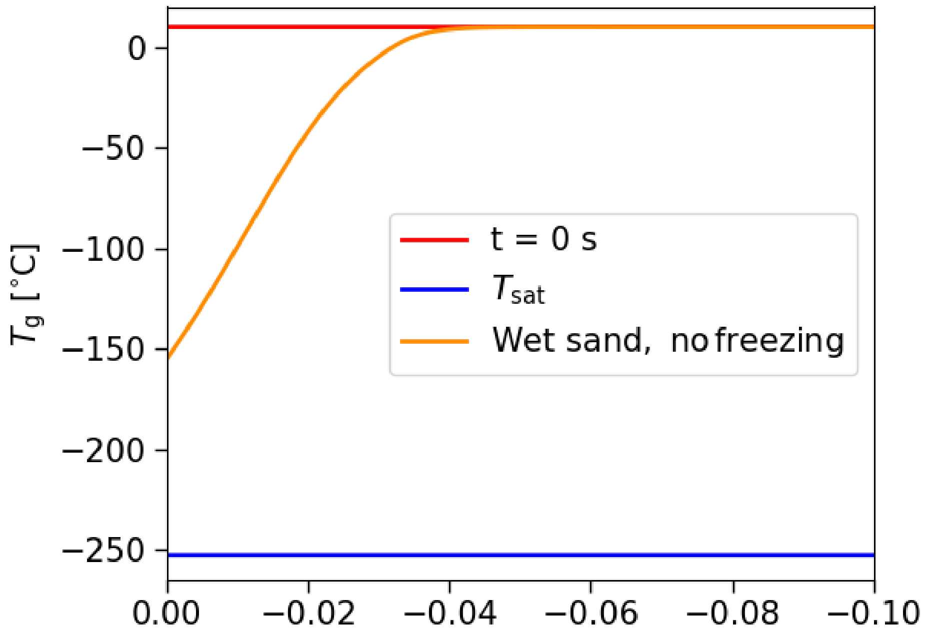
Modelling

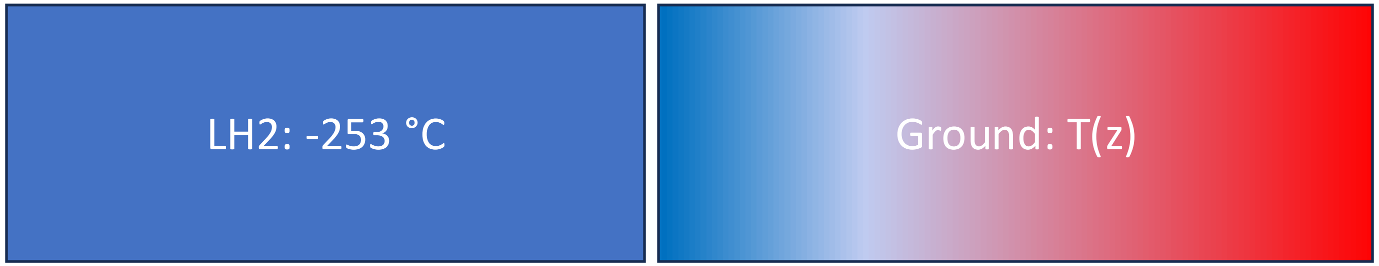

Spill
Heat
Evaporation
T_{sat}
Liquid H_2
z
y
x
$T(z)$


0
10
20
30
40
50
60
k [W/m K]
−250
−200
−150
−100
−50
0
T [°C]

Heat flux calculations

- Solve heat equation in the ground
  - LH_2 at boiling point (-253 °C)





Heat flux calculations

- Solve heat equation in the ground
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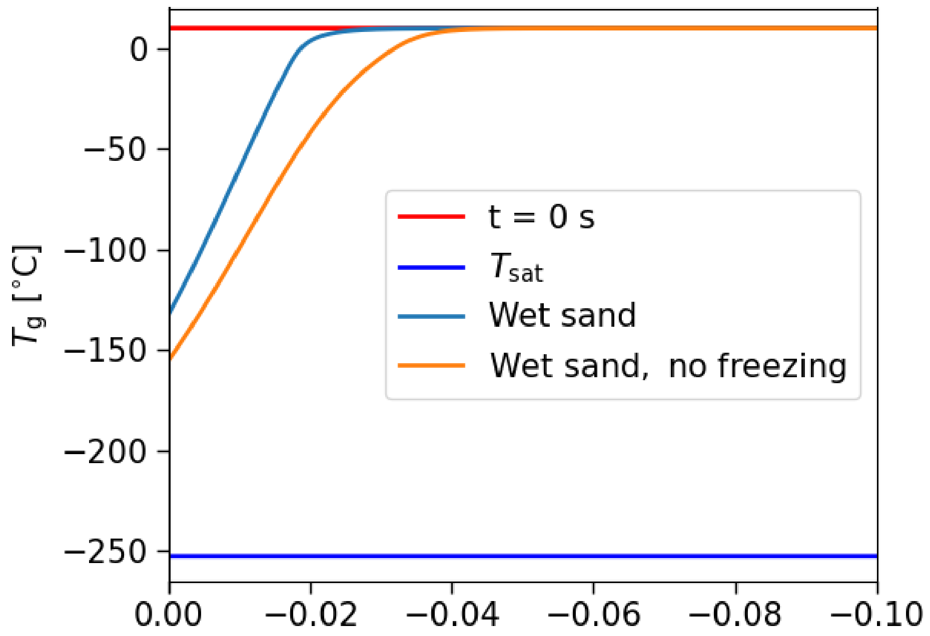
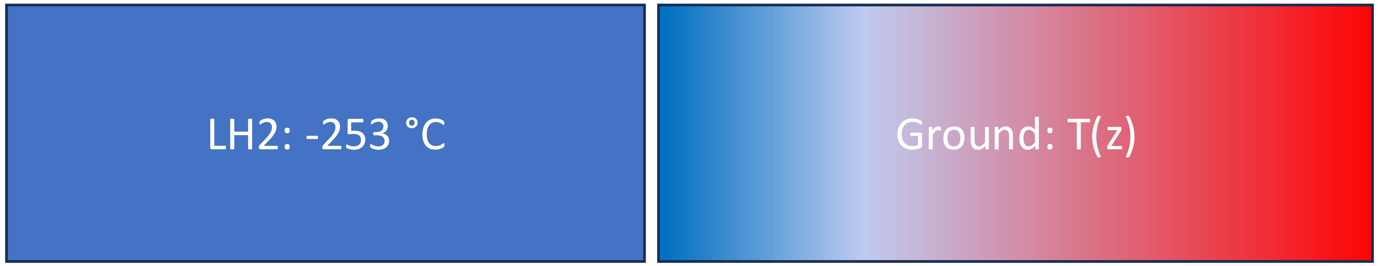
  - Include freezing of ground moisture which releases heat





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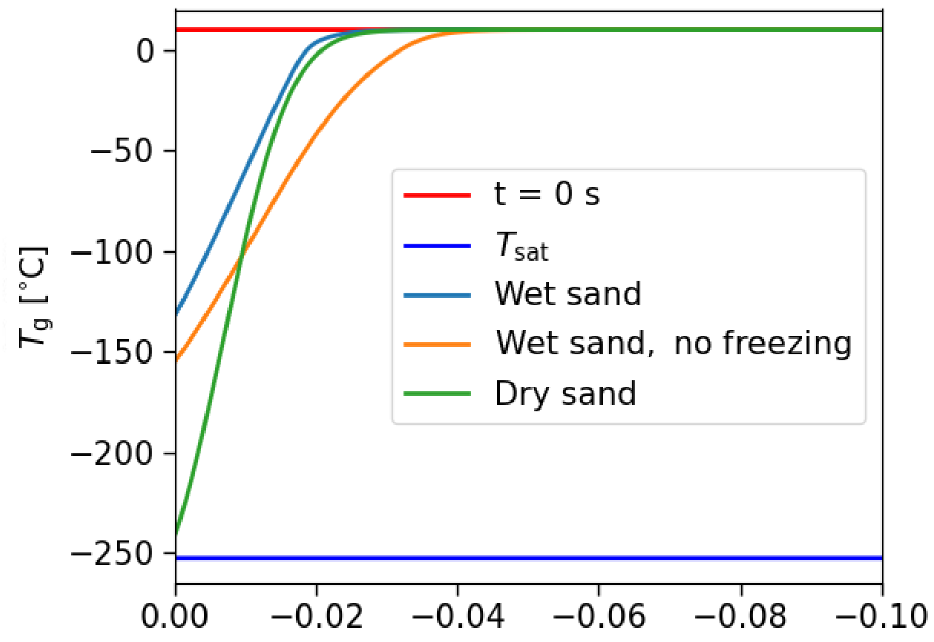
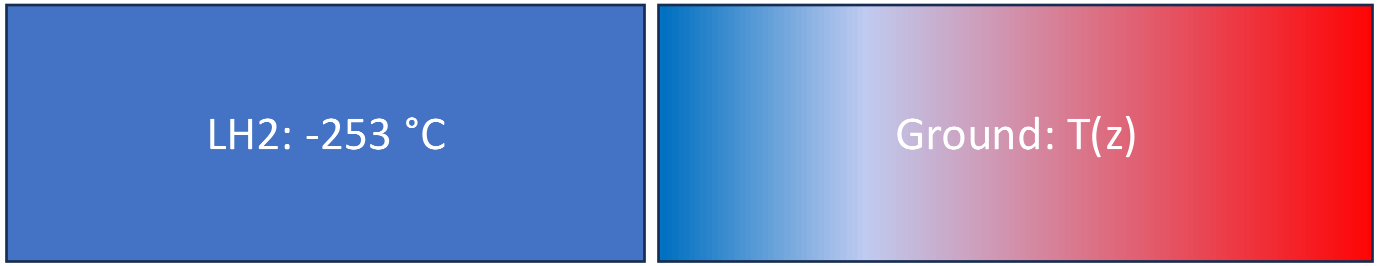
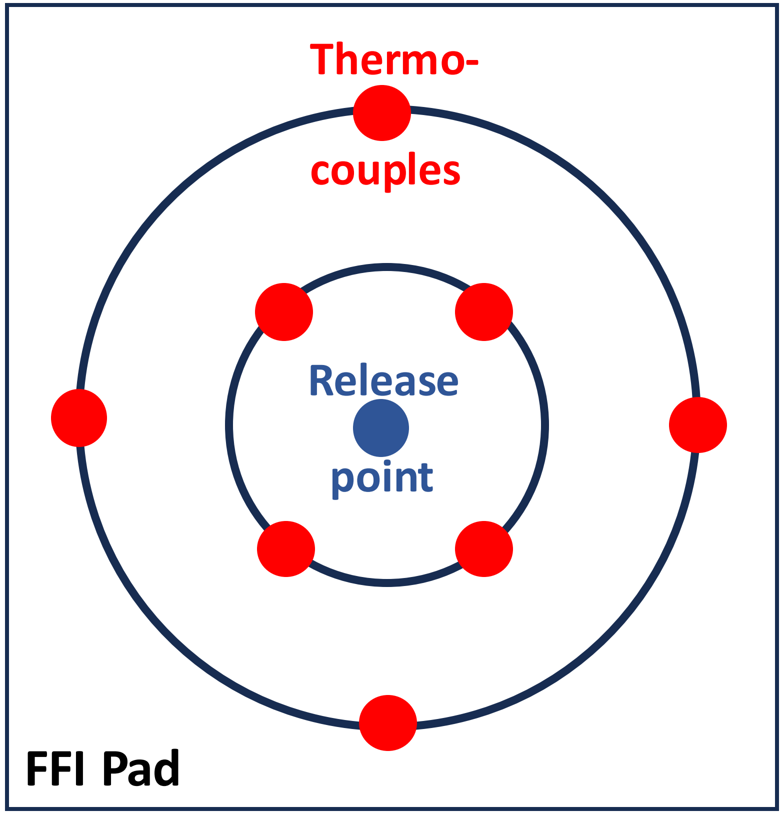




Validation against FFI experiments

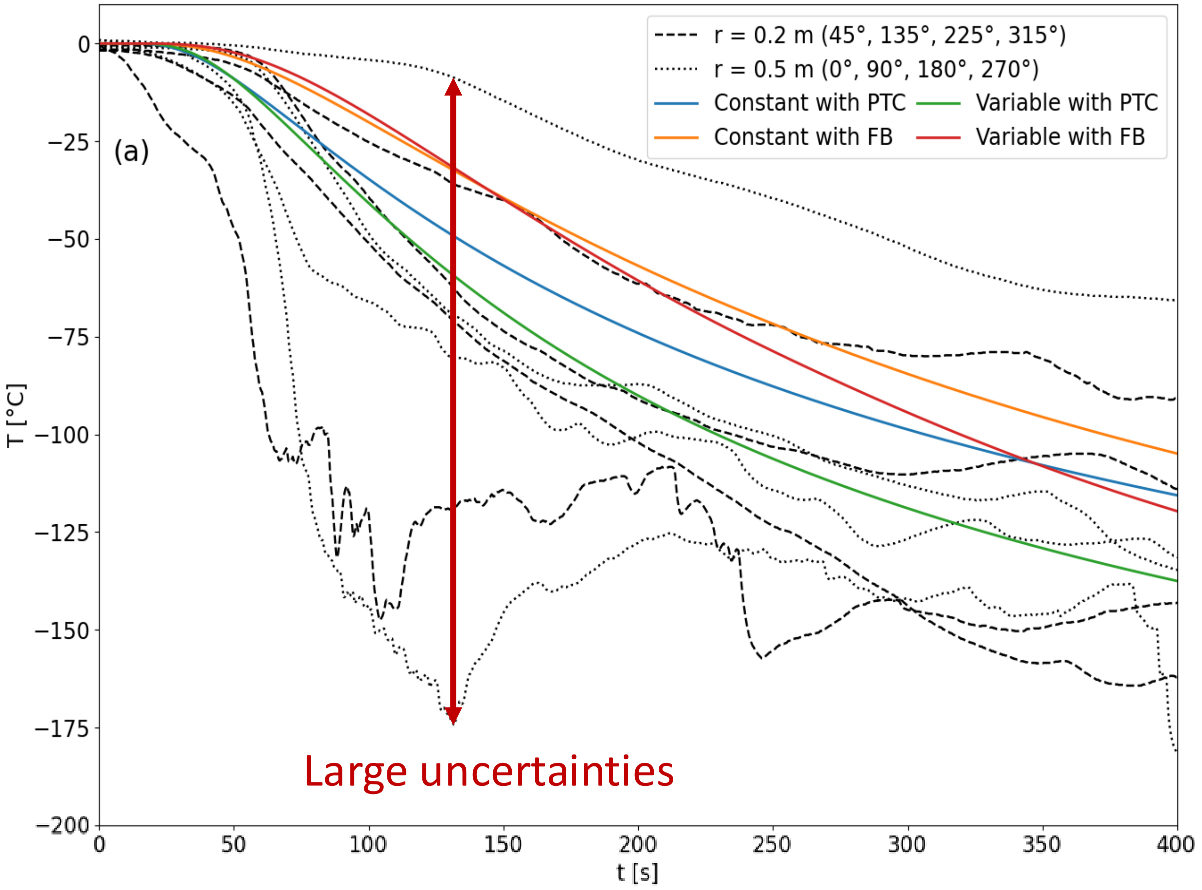
- LH_2 released onto concrete
- Thermocouples at different positions and depths into the ground
- Temperature profile in the ground governs the heat flux, significantly influencing evaporation rate



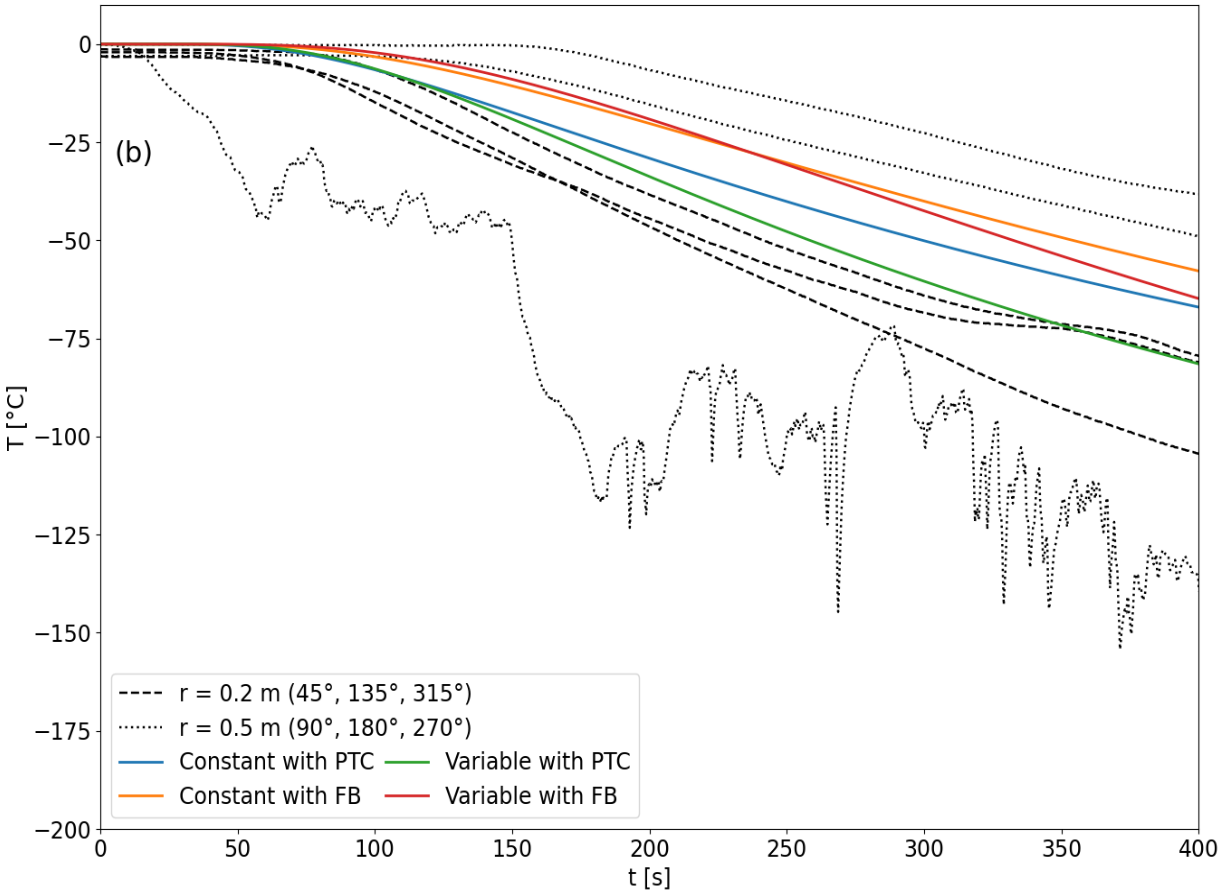
J. Aaneby, T. Gjesdal, Ø. A. Voie, Large scale leakage of liquid hydrogen (LH2) – tests related to bunkering and maritime use of liquid hydrogen, FFI-Report 20/03101, Norwegian Defence Research Establishment (2021).

Validation against FFI experiments

Depth = 20 mm

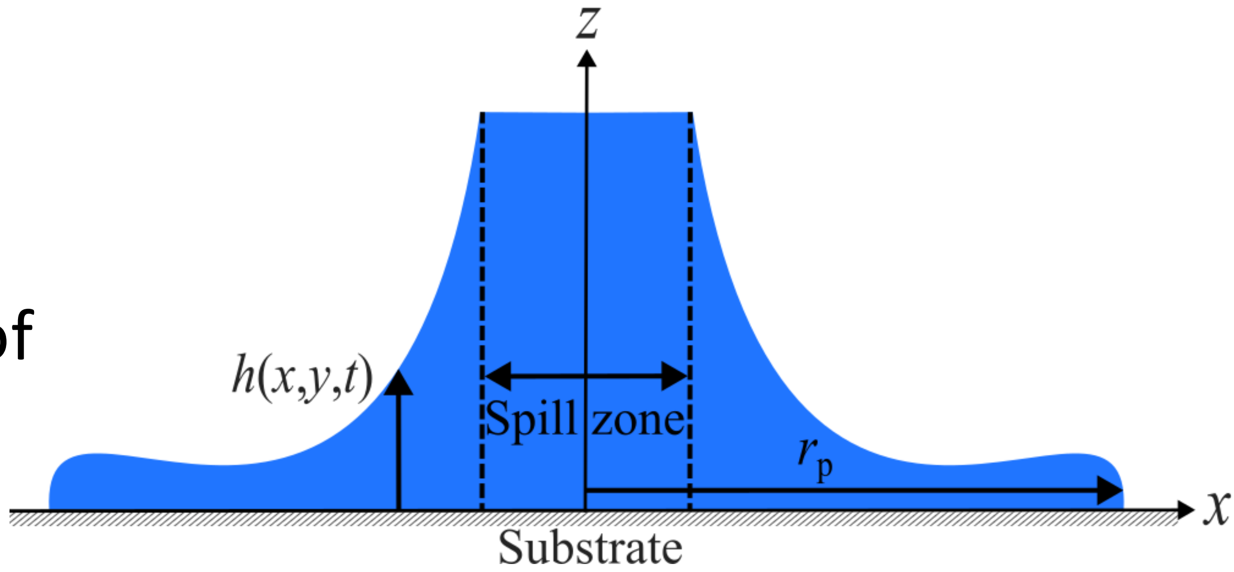


Depth = 30 mm



Clawpack

- Open-source code solving 2D shallow water equations
- Flexible geometry: allows for spills of arbitrary shape and size
- Obstacles of any shape can also be included
- Allow for initial velocity of spill
- Evaporation removes liquid



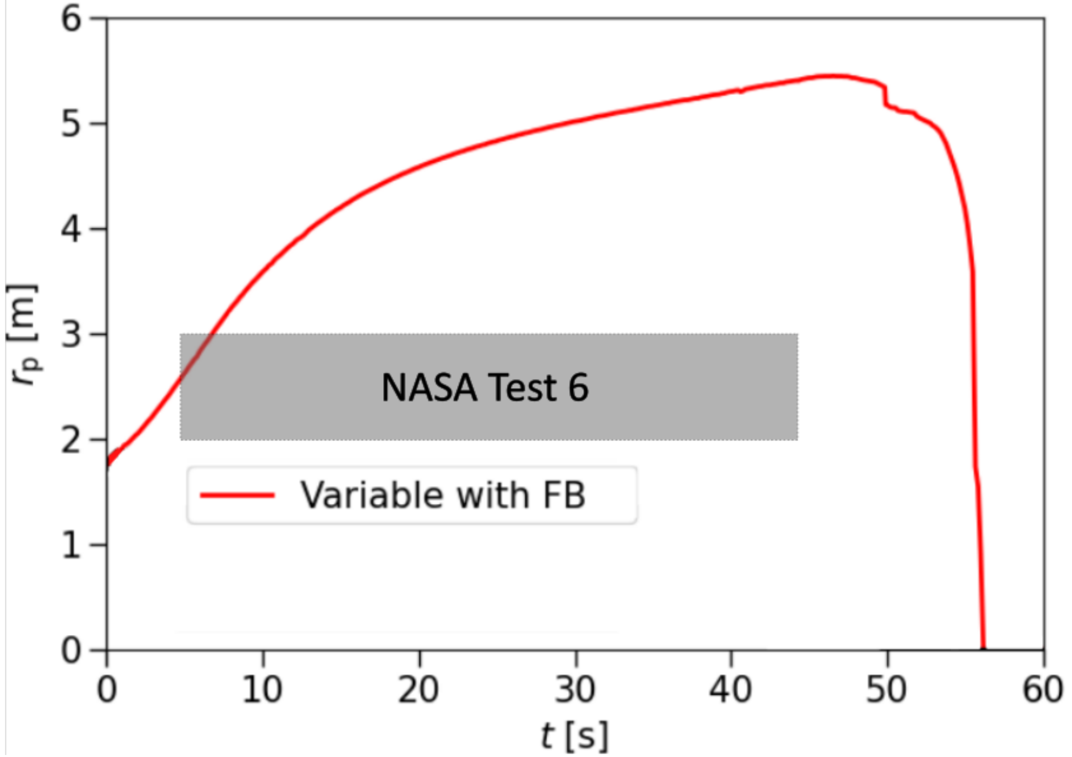
$$(h)_t + (hu)_x + (hv)_y = 0,$$

$$(hu)_t + (hu^2 + \frac{1}{2}gh^2)_x + (huv)_y = -\gamma(hu) - ghb_x$$

$$(hv)_t + (hv^2 + \frac{1}{2}gh^2)_y + (huv)_x = -\gamma(hv) - ghb_y$$

Validation against NASA experiments

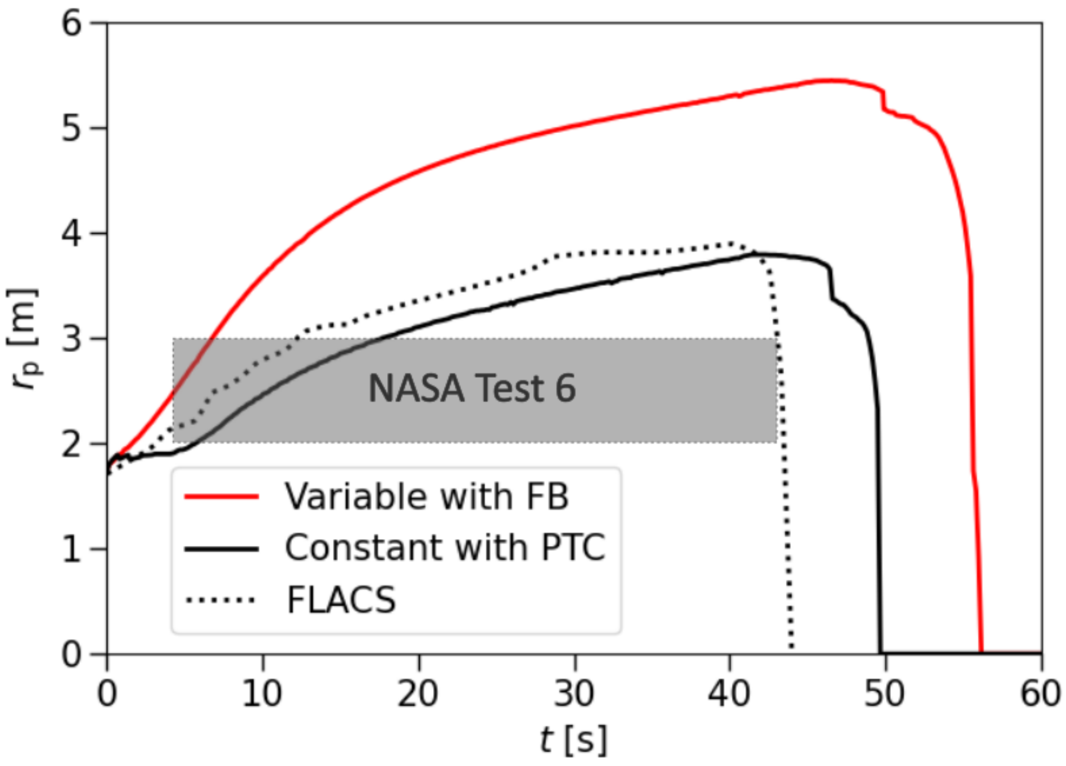
- LH_2 continuously released onto compacted sand
- Radius of 2-3 m reported in NASA Test 6
- Overestimation of radius when not accounting for flashing and splashing



R. D. Witcofski, J. E. Chirivella, Experimental and analytical analyses of the mechanisms governing the dispersion of flammable clouds formed by liquid hydrogen spills, International Journal of Hydrogen Energy 9 (5) (1984) 425–435.

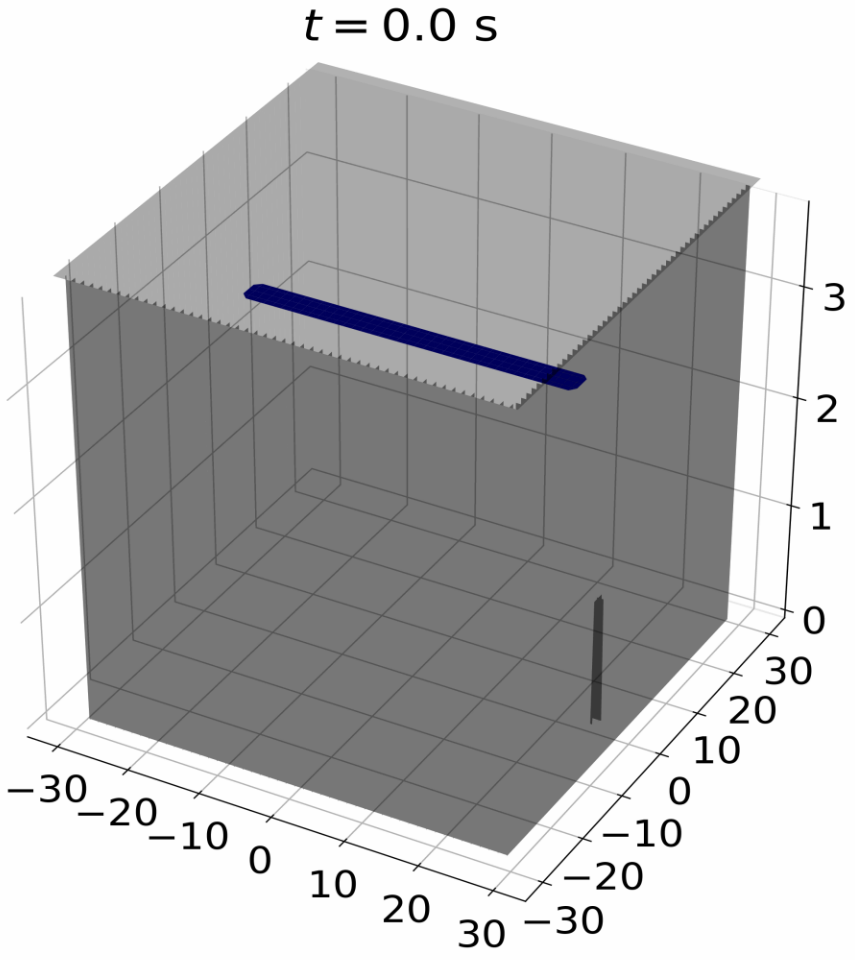
Comparison to FLACS simulations

- Holborn et al. simulated NASA Test 6 in FLACS
- Employing the same simplifications as in FLACS gives very similar results



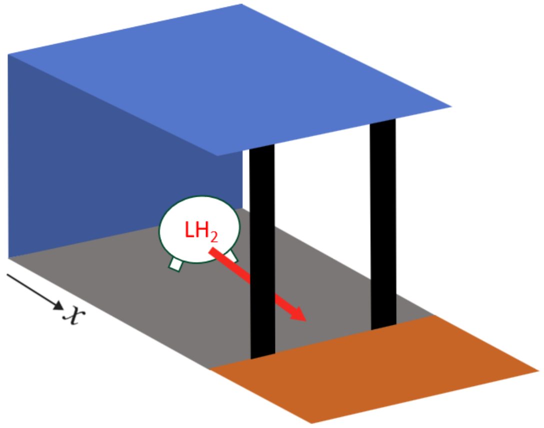
P. G. Holborn, C. M. Benson, J. M. Ingram, Modelling hazardous distances for large-scale liquid hydrogen pool releases, International Journal of Hydrogen Energy 45 (43) (2020) 23851–23871.

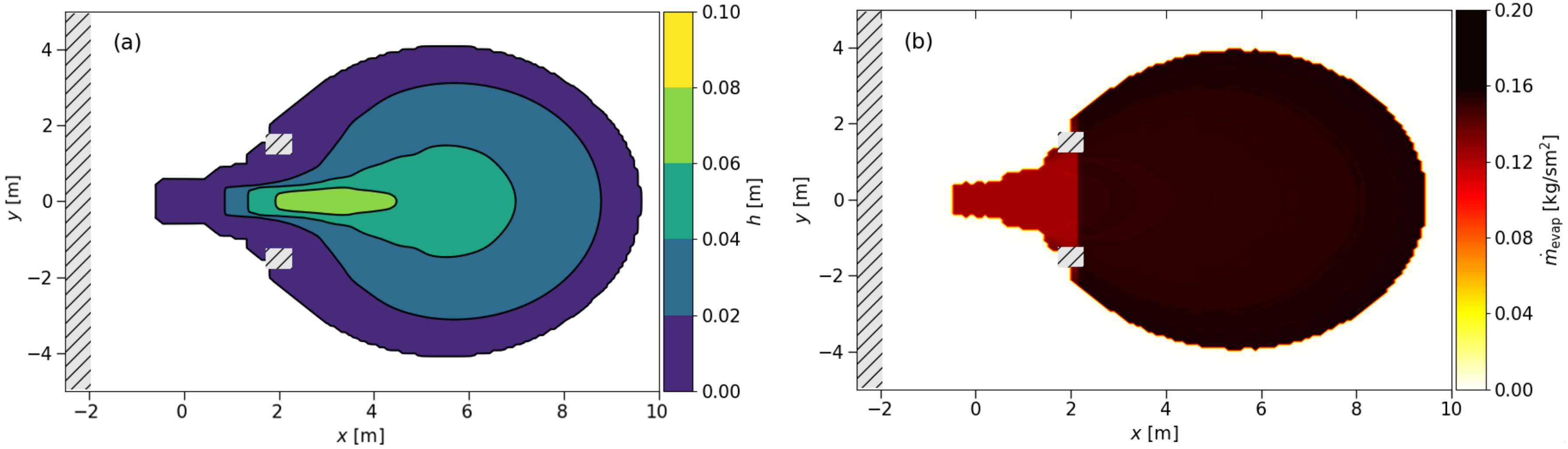
Dam break



LH_2 bunkering scenarios

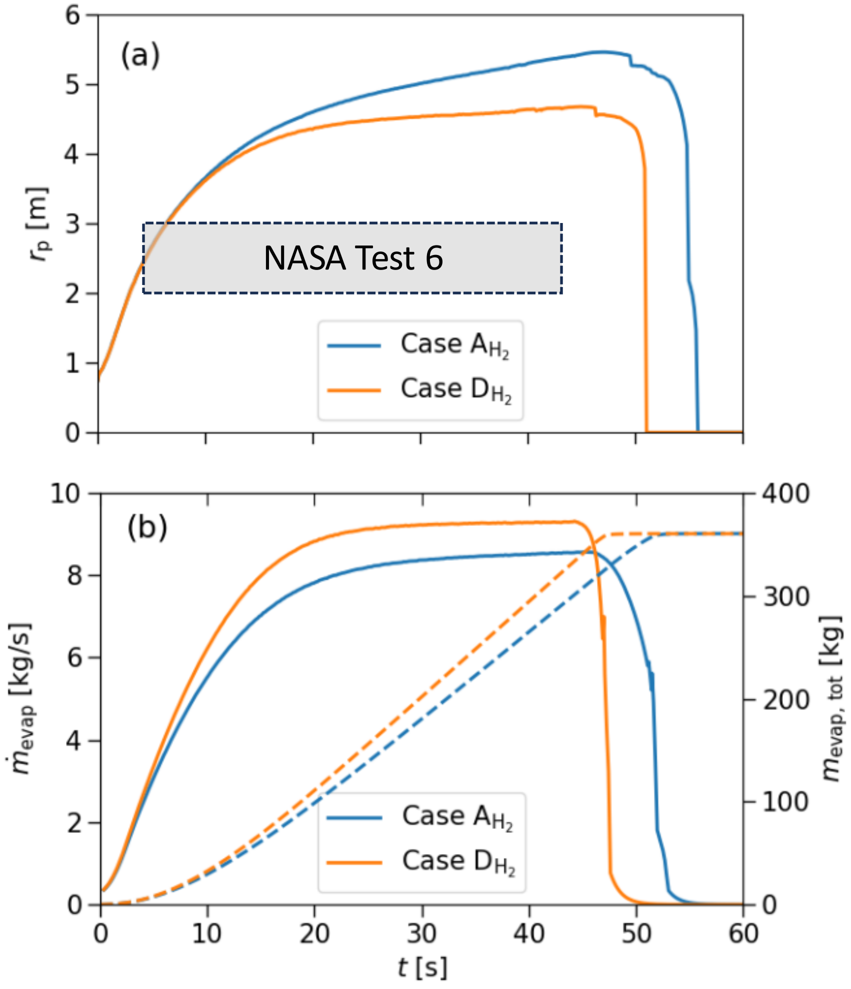
- Time-dependent continuous spill of LH_2 (kg/s)
  $\dot{m}_\ell = 15 - 0.25t$
- Rectangular spill domain $x \times y = 1\ \mathrm{m} \times 0.75\ \mathrm{m}$
- Initial velocity $u_0 = 1$ m/s
- Dry sand (grey, $x < 2.1$ m) and wet sand (brown, $x \geq 2.1$ m)





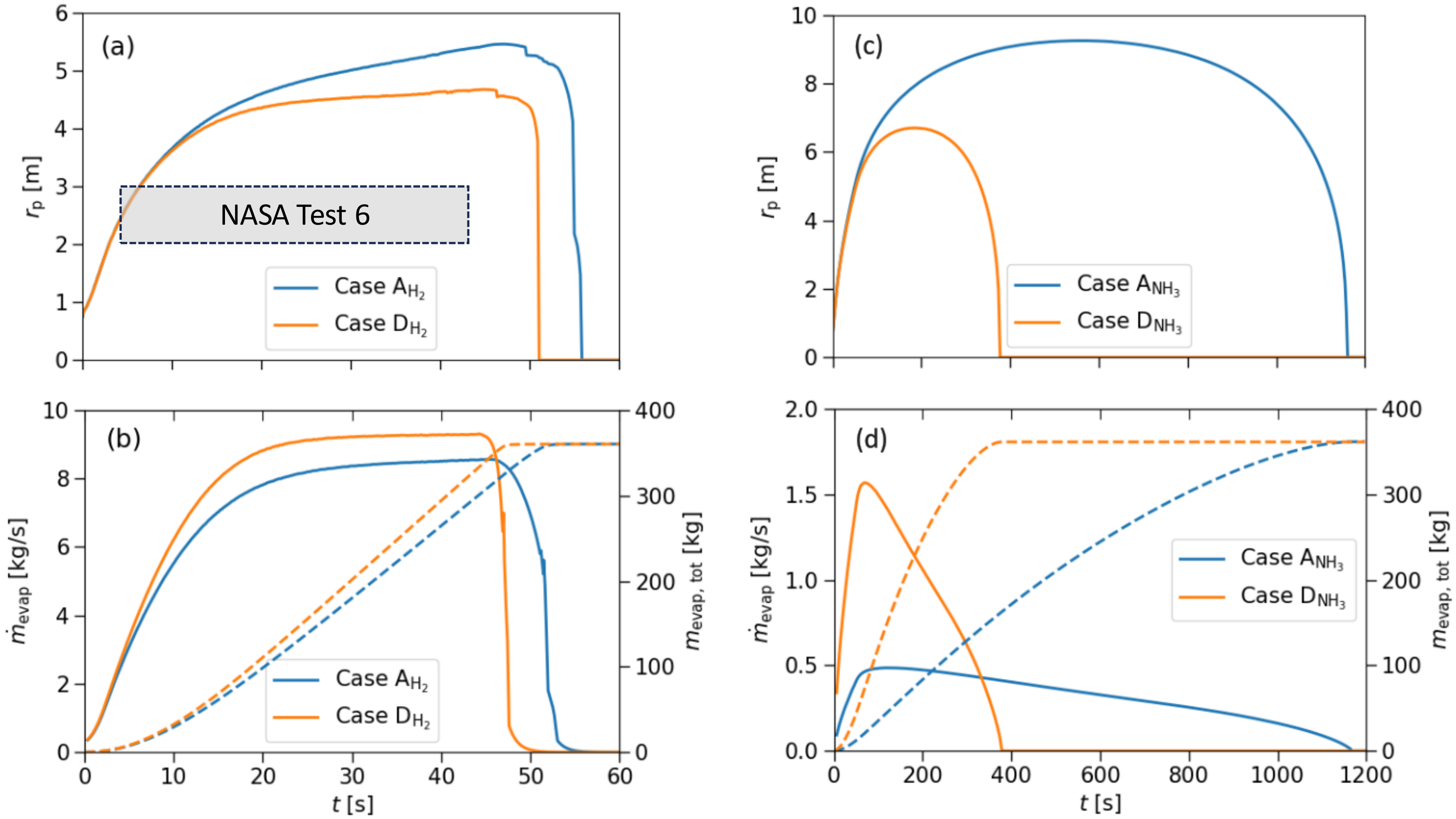
Pool radius and evaporation rate

- Dry sand (A)
- Wet sand (D)



Pool radius and evaporation rate

- Dry sand (A)
- Wet sand (D)
- Highly dependent on fluid and substrate



Summary

- Open-source spill-modelling tool for continuous and dam break spills
- Determines radius and local evaporation rate
- Accounts for soil moisture freezing and temperature dependent properties
- Flexible geometry
- Easy to implement new features