CFD Simulations of H_2S-Rich Plumes from Oil/Gas Well Blowouts

sandia.gov and noaa.gov

Stephen G. Zemba, PhD, PE

Robert S. Saikaly
Jared D. Newell
Jonathan E. Welch
Toros L. Maksoudian
Cynthia S. Hibbard
Kevin P. Molloy

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Background

- Oil and gas wells under high pressure can inadvertently "blowout" and release significant quantities of oil and gas
- Gas in some formations contains as much as 90% H_2S
- Blowout releases typically self-ignite or are intentionally ignited
- If not ignited, releases can behave as dense gases, and dangerous (toxic or lethal) H_2S concentrations persist for considerable distance

Setting

- Client involved in oil/gas well exploration in very rugged terrain
- Closest inhabitants a few km distant
- Goal: Design Emergency Response Planning Procedures to protect local populations
- Information uncertain
  - Reservoir characteristics
  - Meteorological data

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Available Models and Tools

- U.S. EPA Appendix W Modeling Guidance offers no *recommended* models for dense gas dispersion
- Alternative Models listed on EPA's Support Center for Regulatory Atmospheric Modeling (SCRAM) website list ADAM, DEGADIS, HGSYSTEM, PANEPR (PANACHE), and SLAB as candidate dense gas dispersion models
- Other options: ALOHA, ERCBH2S, and PHAST
- Of these candidates, only PANEPR is designed for application in complex terrain, and it was selected for this application

PANEPR Model

- Licensed by fluidyn
- Based on computational fluid dynamics (CFD)
  - Not a traditional Gaussian plume/puff approach
  - Solves basic mass, momentum, and energy equations using finite element discretization of a three-dimensional grid
  - Turbulence modeled based on fluid dynamics
- Considerable flexibility, numerous options

Source Modeling

- Based on representative reservoir properties, anticipated production rate, and gas-to-oil ratio (GOR)
- Simplified source parameterization
  - Interest focused on far-field predictions
  - Assume flashing evaporates oil-phase to produce a dense gas mixture
  - Mix the release into an elevated volume source
- Release properties
  - 0.28 kg/s H_2S emission rate (12.1% H_2S mixture)
  - 144 g/mol average molecular weight
  - Source concentration ~750 ppm (within volume source)

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Model Options

- Computational grid
  - Unstructured grid resolved in source region
  - 62 vertical layers (2000 m), 4616 cells per layer (~3 km × 4.5 km)
- Inflow boundary condition at upwind domain edge
- κ-ϵ turbulence model
- Meteorological conditions
  - Specified through surface heat flux and vertical temperature gradient
  - Two simulations
    - Pasquill-Gifford Class D, 10-m wind speed 2 m/s
    - Pasquill-Gifford Class E/F, 10-m wind speed 1 m/s

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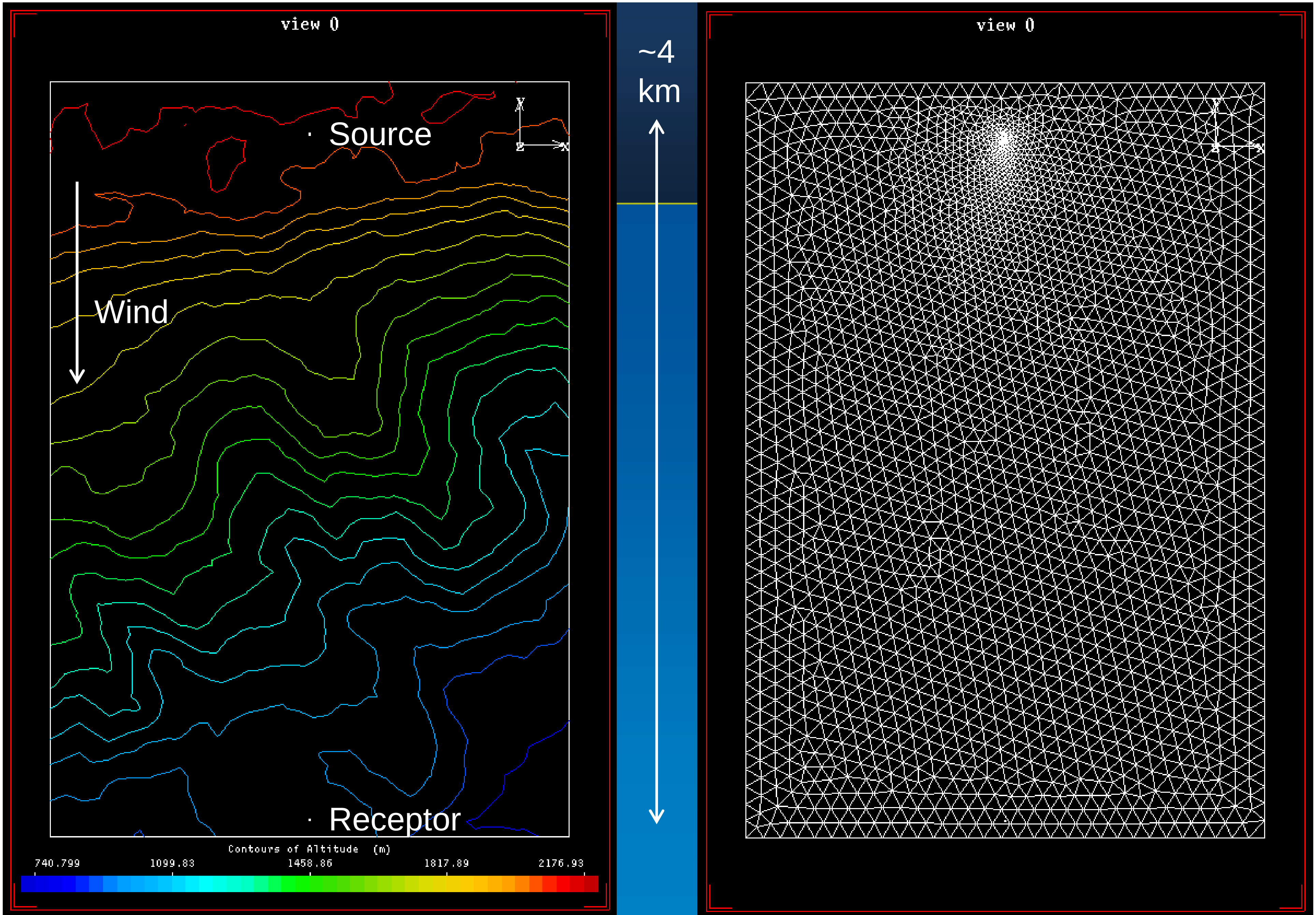

Topography and Computational Grid

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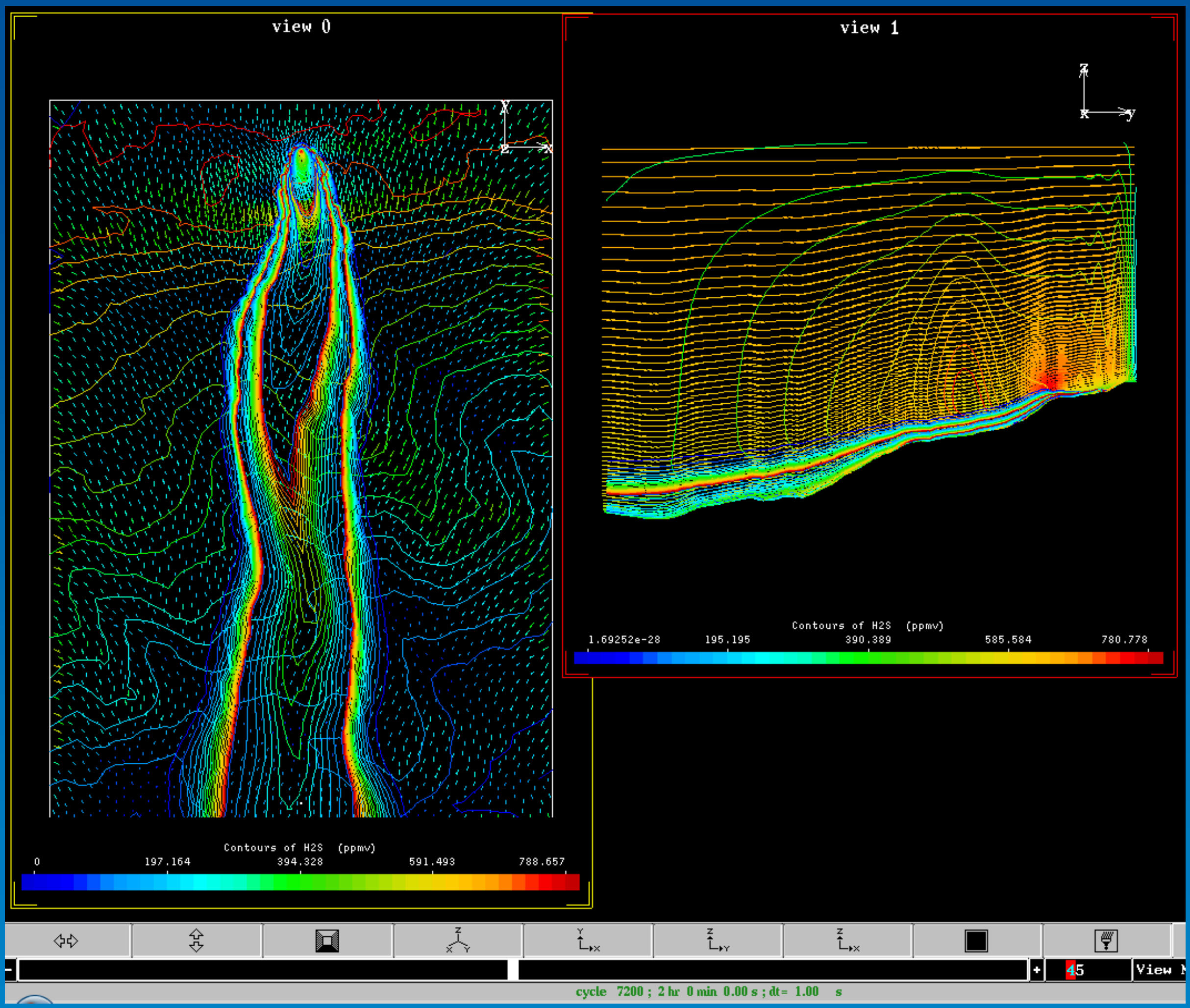
H_2S Toxicity Guidelines for Emergency Planning

H_2S Concentration (ppm)	Toxicity Guidelines American Conference of Industrial Hygienists (ACGIH) National Research Council (NRC) National Institute for Occupational Safety and Health (NIOSH) American Industrial Hygiene Association (AIHA)
1	ACGIH's recently revised 8-hour Threshold Limit Value (TLV) NRC's 90-day Emergency Exposure Guidance Level (EEGL)
10	ACGIH's former 8-hour TLV NRC's 24-hour EEGL NIOSH's 10-minute Recommended Exposure Limit (REL)
100	AIHA Emergency Response Planning Guideline (ERPG-3) <1 hour exposure not life threatening for most people NIOSH Immediately Dangerous To Life or Health (IDLH)

H_2S Odor Threshold ~0.001 ppm

Steady State Plume (Simulation time 2 hours) Stable (E/F) case, 1 m/s wind speed



- Ground-level plan view (left) and centerline vertical cross-section (right)
- Some influence of terrain on wind field
- Some influence of buoyancy in near field

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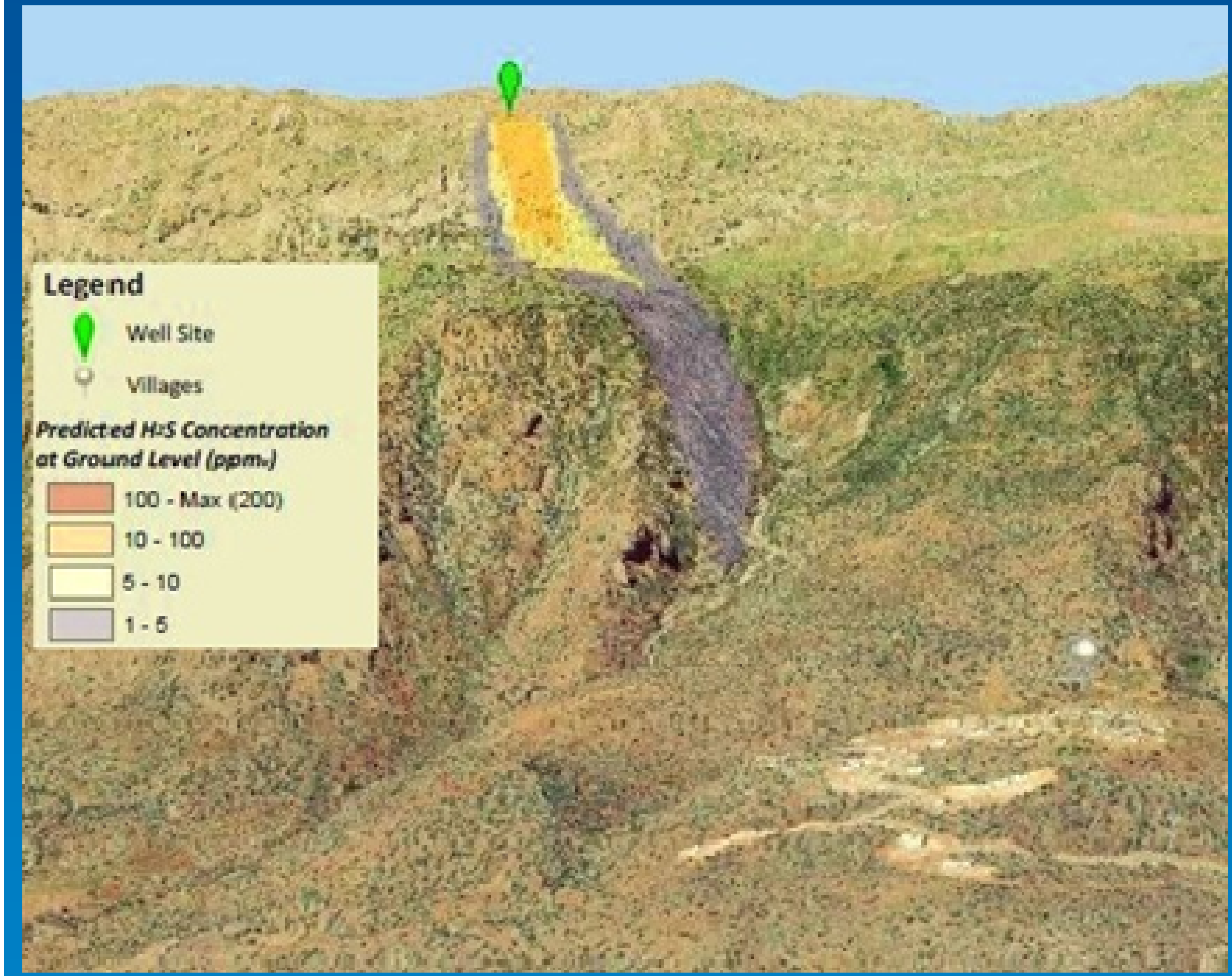
Example Results (GIS Version)

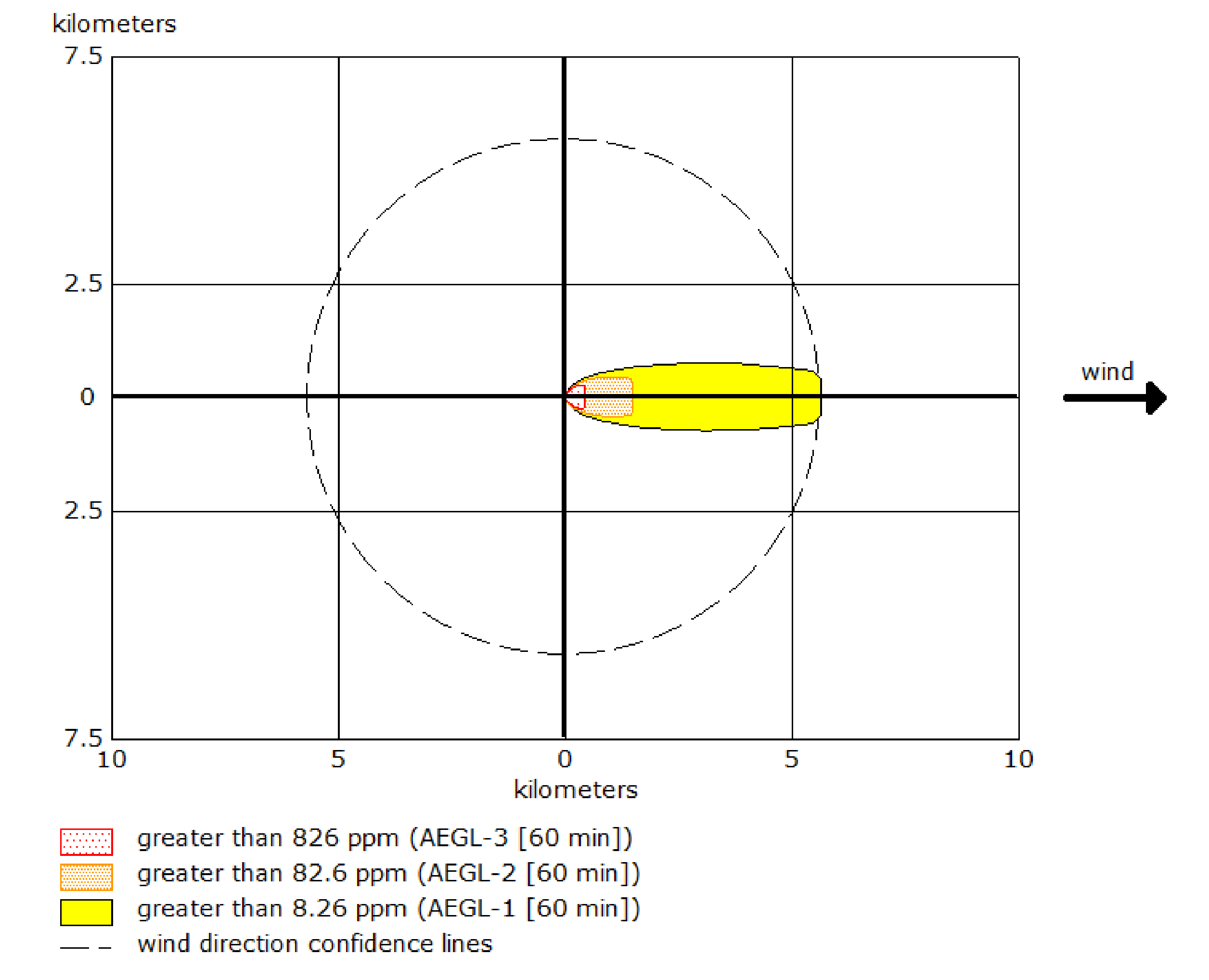


- Class D simulation

fluidyn PANEPR Model Predictions

Scenario	Maximum Concentration (ppm)	Downwind extent of H_2S concentration (km) at end of simulation			
		100 ppm	10 ppm	5 ppm	1 ppm
Stable (Class E/F) 1 m/s wind	790	0.35	2.1	3.3	> 4
Neutrally stable (Class D) 2 m/s wind	202	0.2	0.7	1.2	2.1

ALOHA Model Predictions
Similar source parameters



- User-defined chemical with thresholds adjusted to match 100, 10, and 1 ppm H_2S levels
- Simulation at left matches stable (Class E), 1 m/s wind speed

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Comparison of PANEPR and ALOHA Models

Scenario	Model	Downwind extent of H_2S concentration (km)		
		100 ppm	10 ppm	1 ppm
Stable (Class E/F) 1 m/s wind	PANEPR	0.35	2.1	> 4
	ALOHA	0.46-0.53	1.5-1.7	5.7-6.2
Neutrally stable (Class D) 2 m/s wind	PANEPR	0.2	0.7	2.1
	ALOHA	0.28	1.1	4.6

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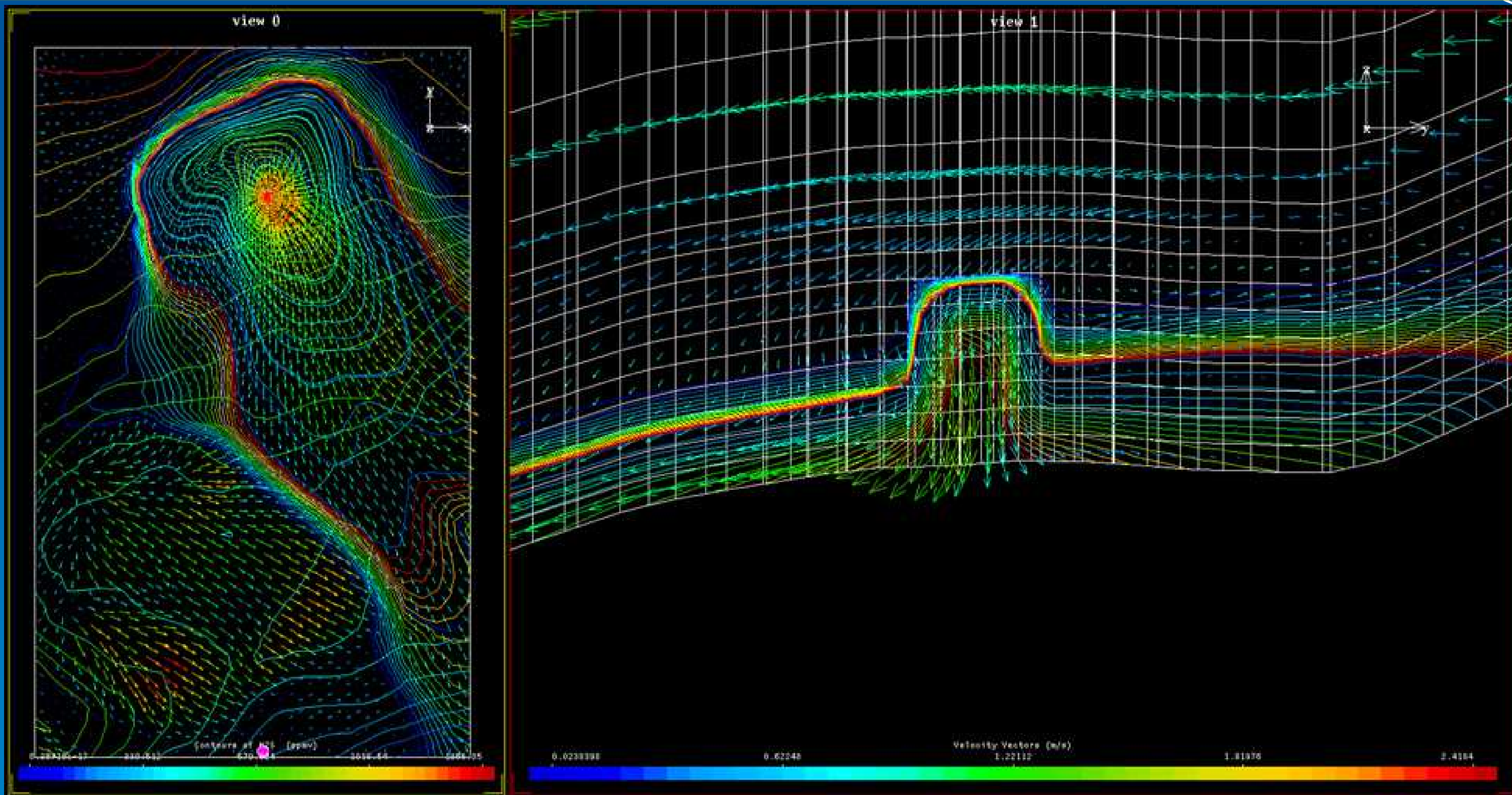
Blowout Parameterization – Larger Source

Minor effects on far field plume (left)

Source size affects peak near-field concentrations (right)

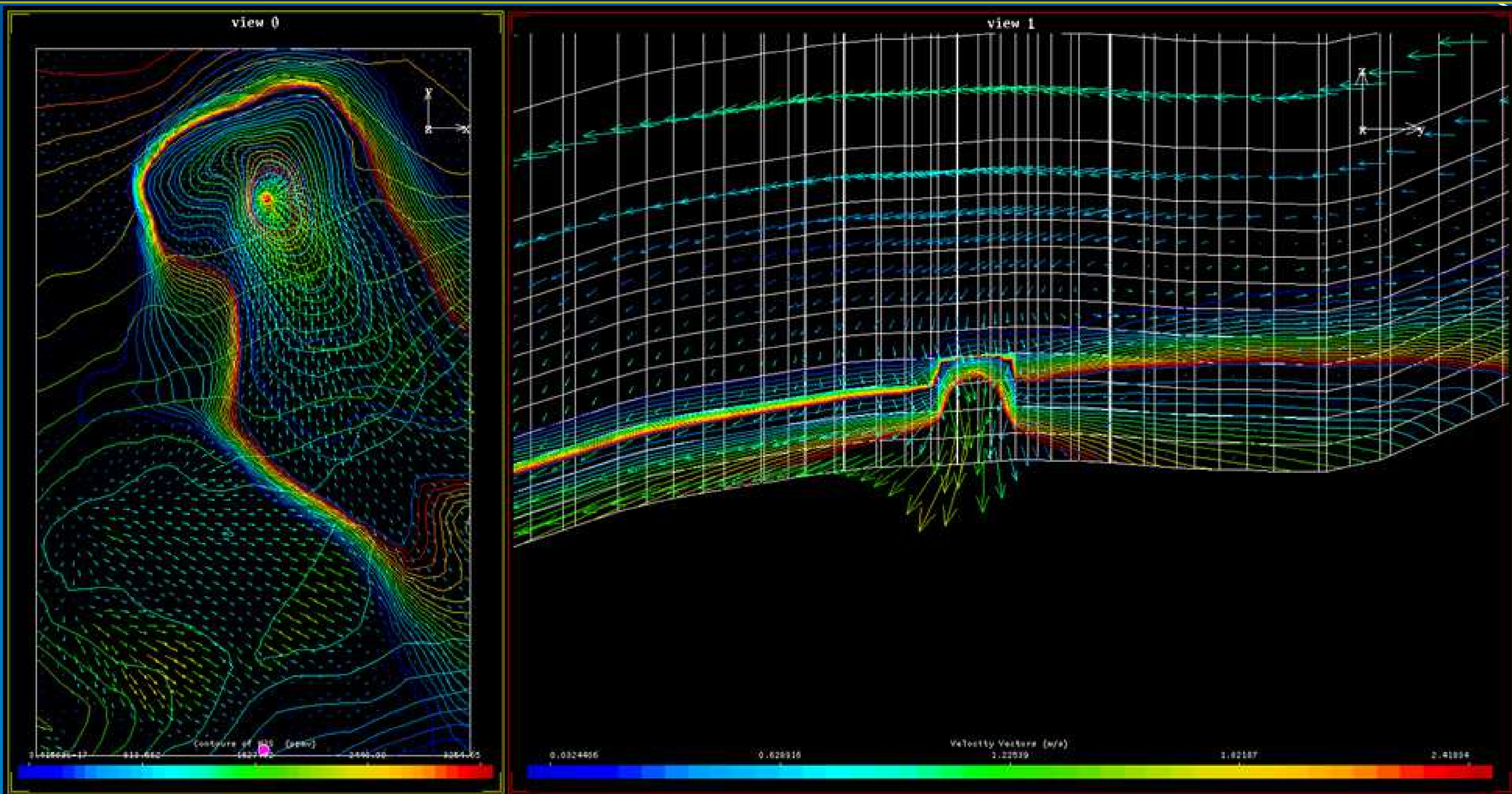


(10 m)^3 source, peak ground-level [H_2S] = 1,360 ppm

Blowout Parameterization – Smaller Source

Minor effects on far field plume (left)

Source size affects peak near-field concentrations (right)



(2.5 m)^3 source, peak ground-level [H_2S] = 3,250 ppm

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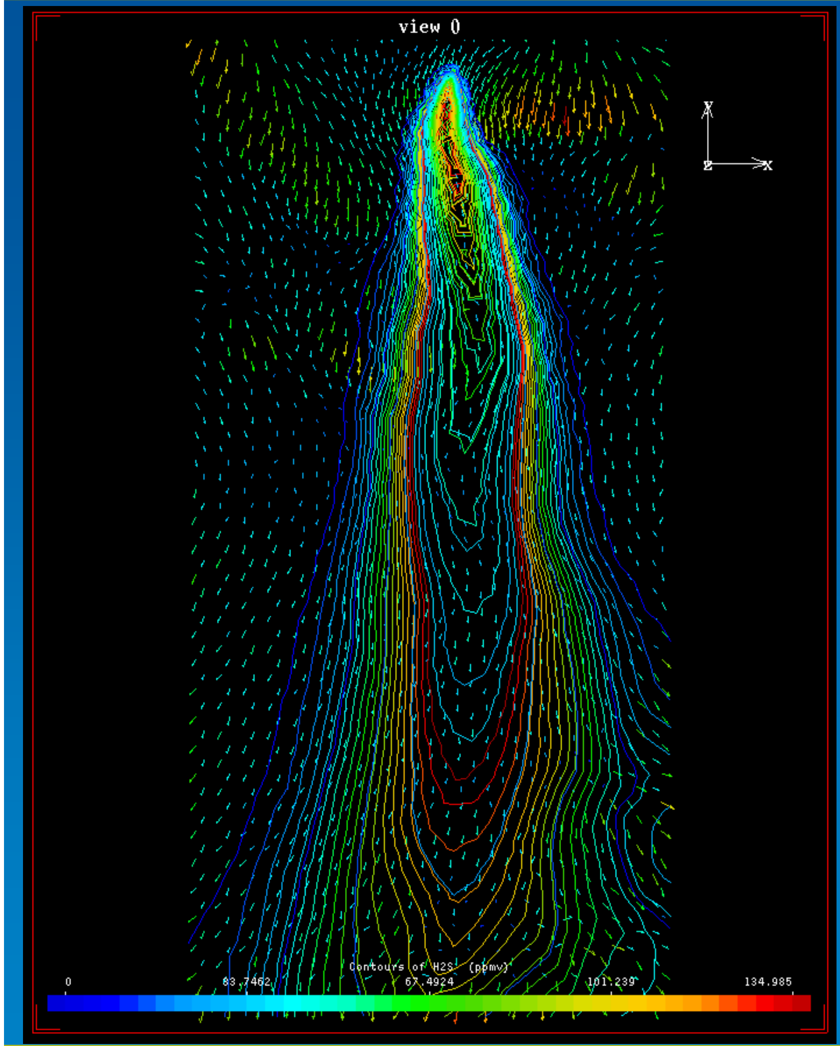
Effects of Terrain

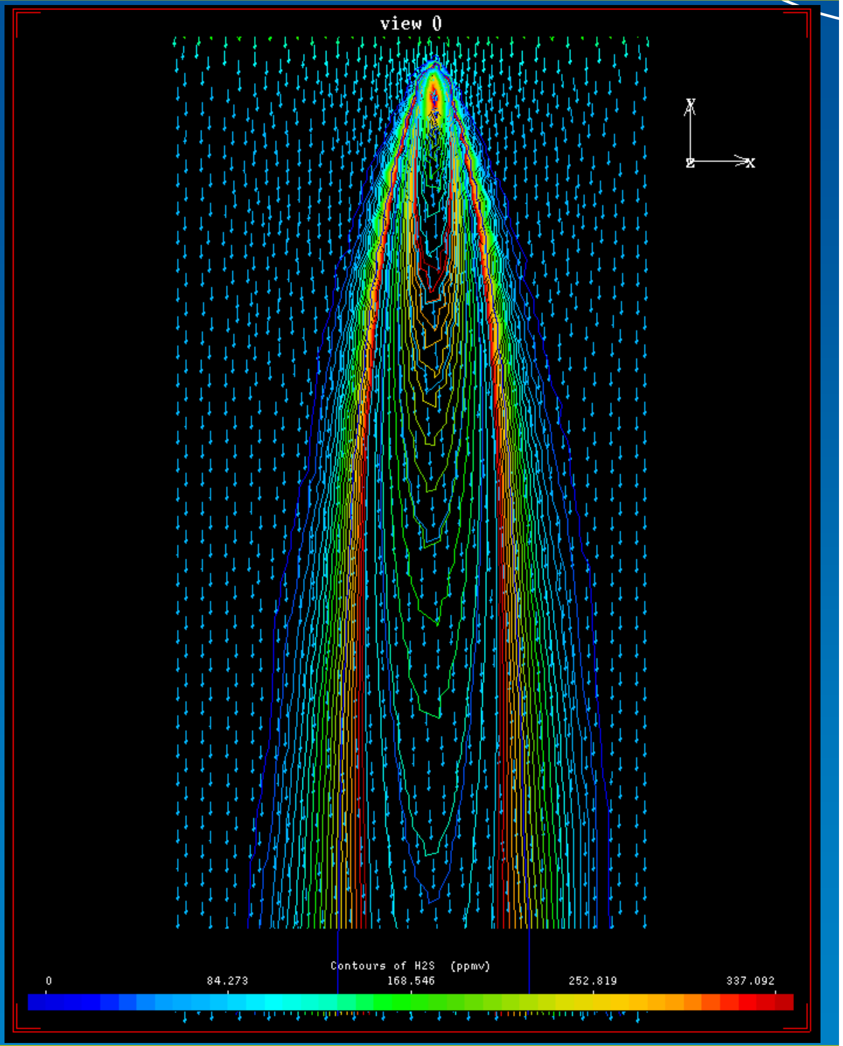
Side-by-side comparison, with (left) and without (right) terrain



Peak Values

135 ppm <= left

337 ppm right =>



Predicted [H_2S] in ppm at 1-hr mark

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Conclusions and Observations

- PANEPR is able simulate plume dispersion to significant distances (several km) in very rough terrain
  - Accounts for highly varying terrain
  - Considers dense gas effects
  - Some evidence of terrain-induced dispersion and gravity channeling effects
- Predictions similar to those of the simple ALOHA model (based on preliminary comparisons)
- Uncertainties to consider
  - Source modeling
  - Grid resolution and boundary condition effects
  - Atmospheric boundary layer characterization

Thanks …

- for your attention – and attending the final session!

Questions or Comments?