Modeling of Strata Gas Liberation into the Mine Drifts with Time-Dependent Ventilation

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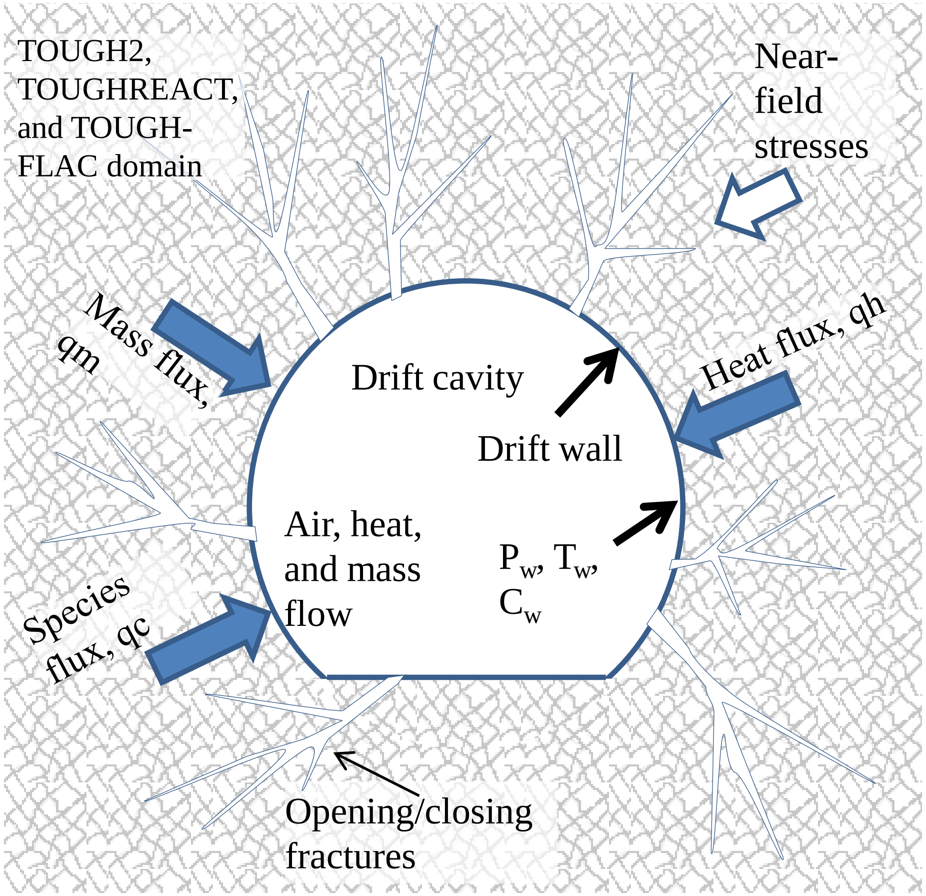
Outline

- Introduction
- Coupled transient transport processes
- Response changes in ventilation to flow control in a large-scale mine
- Response to barometric pressure variation
- Conclusions

Introduction

Coupled transient transport processes

- Assume that the air flow is modified according to VOD control: P, Qa change
- Fan start, stop, or partial change of RPM: P, Qa change
- Air regulator adjustment: P, Qa change
- ΔQa modifies concentration
- ΔP modifies qm, qc, and qh

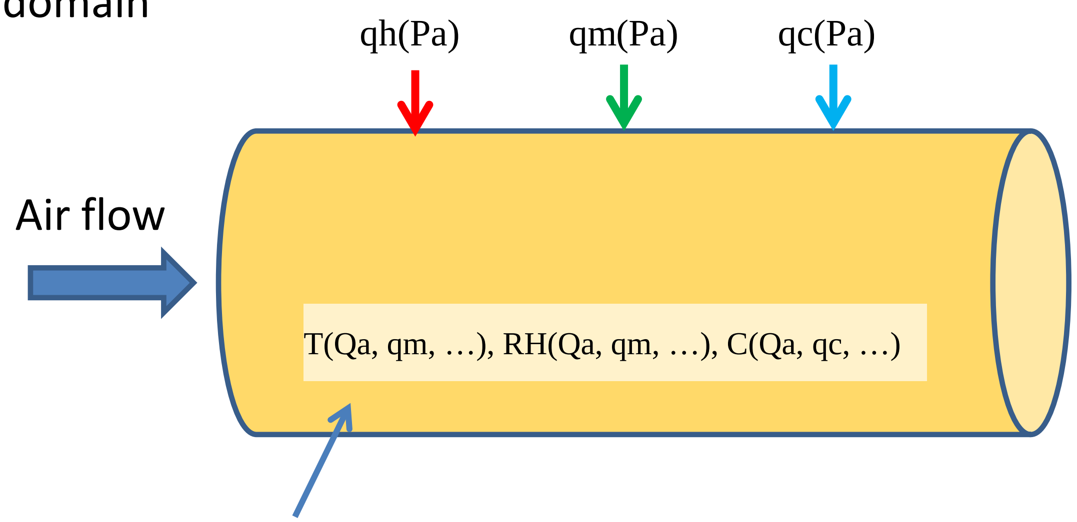


Introduction

Coupled transient transport processes

TOUGH2, **NUFT** for heat and moisture
TOUGHREACT for heat, moisture and chemical reaction
TOUGH-FLAC for heat, moisture and mechanical (stress) interaction

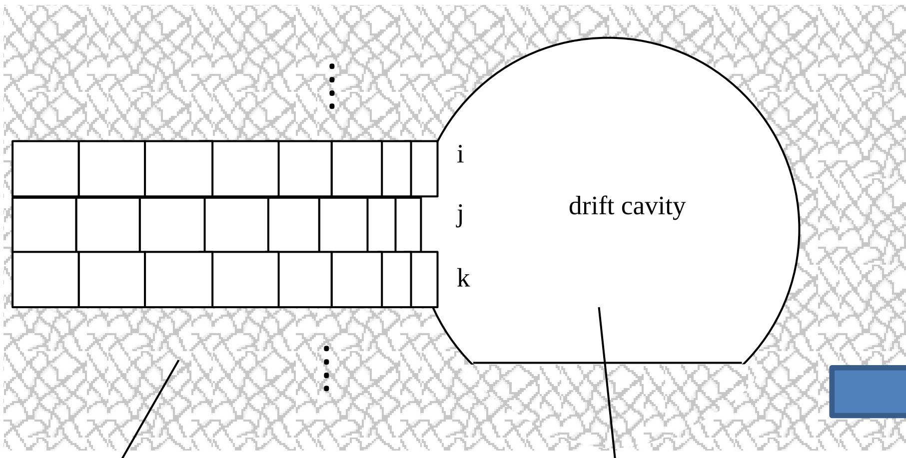
PMC domain → Rock strata flows and transport model:



CFD domain: Fine-scale
Integrated-parameter MULTIFLUX
or a simple flow and transport numerical model

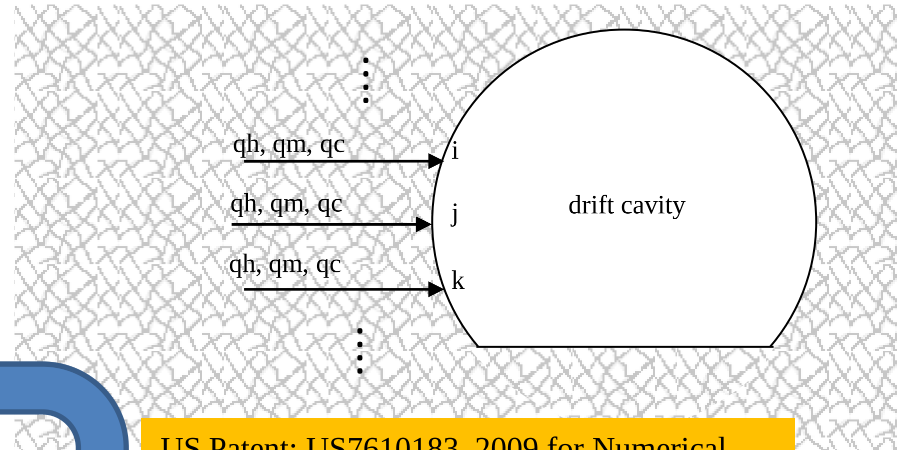
Introduction

Coupled transient transport processes



Time dependent 2-D or 3-D sub-models domains for poro-elastic conduction-advection (TOUGH2, TOUGHREACT, or TOUGH-FLAC)

Time-dependent MULTIFLUX Convection-advection-flow and heat transport CFD model in the drift cavity



US Patent: US7610183, 2009 for Numerical Transport Code Funcionalization in MULTIFLUX

$[\mathbf{qh}]=[[\mathbf{ht}]](\mathbf{T_w}-\mathbf{T_0})+[[\mathbf{hp}]](\mathbf{P_w}-\mathbf{P_0})+[[\mathbf{hc}]](\mathbf{C_w}-\mathbf{P_0})$

$[\mathbf{qm}]=[[\mathbf{mt}]](\mathbf{T_w}-\mathbf{T_0})+[[\mathbf{mp}]](\mathbf{P_w}-\mathbf{P_0})+[[mc]](C_w-P_0)$

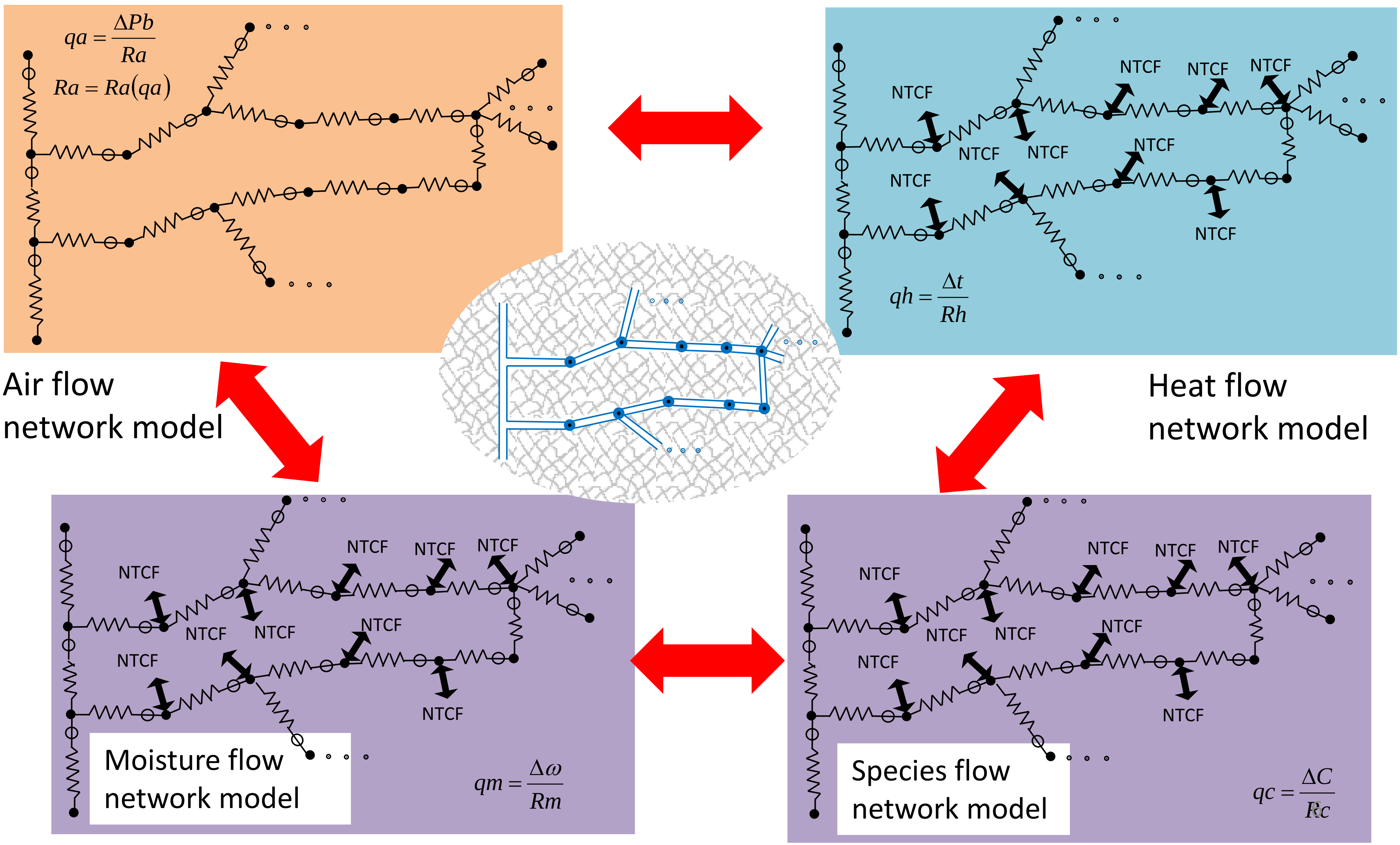
$[\mathbf{qc}]=[[\mathbf{ct}]](\mathbf{T_w}-\mathbf{T_0})+[[\mathbf{cp}]](\mathbf{P_w}-\mathbf{P_0})+[[\mathbf{cc}]](\mathbf{C_w}-\mathbf{P_0})$

Where,

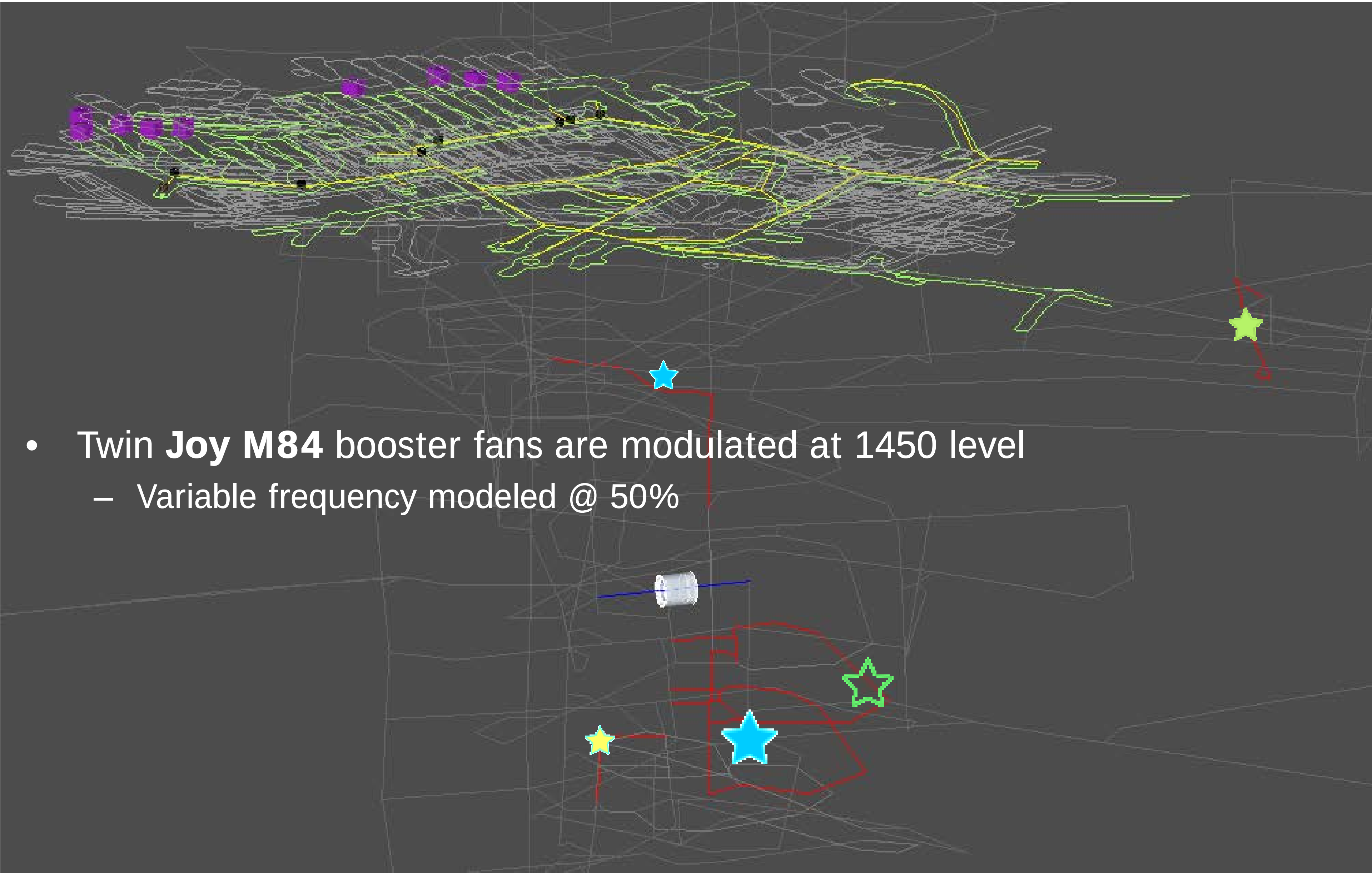
[[**ht**]], [[**hp**]], [[**hc**]], [[**ht**]], [[**mp**]], [[**mc**]], [[**ct**]], [[**cp**]], and [[**cc**]] are system-response NTCF matrices for time-dependent flux exchanges with the rockmass

Introduction

Coupled transient transport processes in MULTIFLUX



Real Mine Example
Change in Airflow Directions due to Fan RPM Modulation

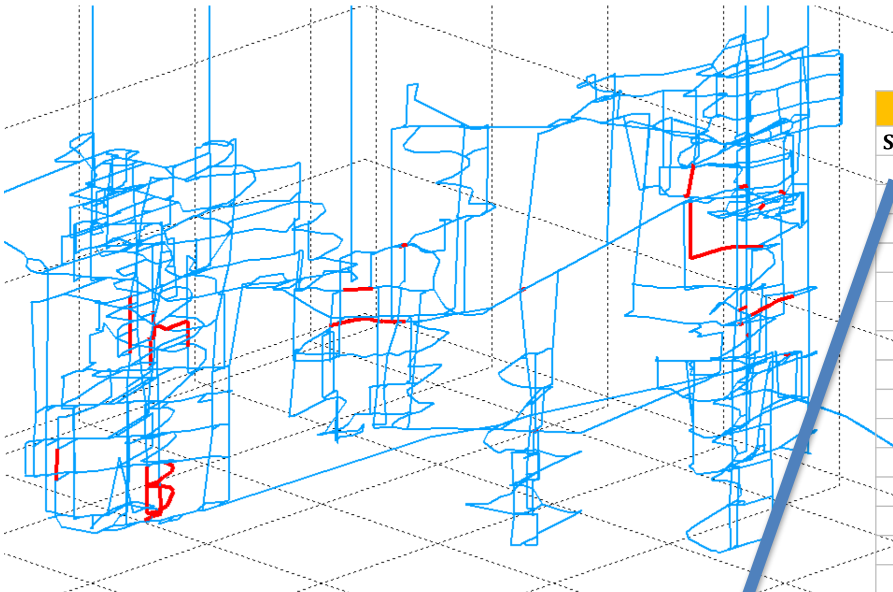


- Twin **Joy M84** booster fans are modulated at 1450 level
  - Variable frequency modeled @ 50%

Change in Airway Velocities Due to Fan RPM Modulation

A twin ***Joy M84*** booster fans is modulated at 1450 level

Variable frequency control modeled at 50% pressure



Airways where the flow direction reversed

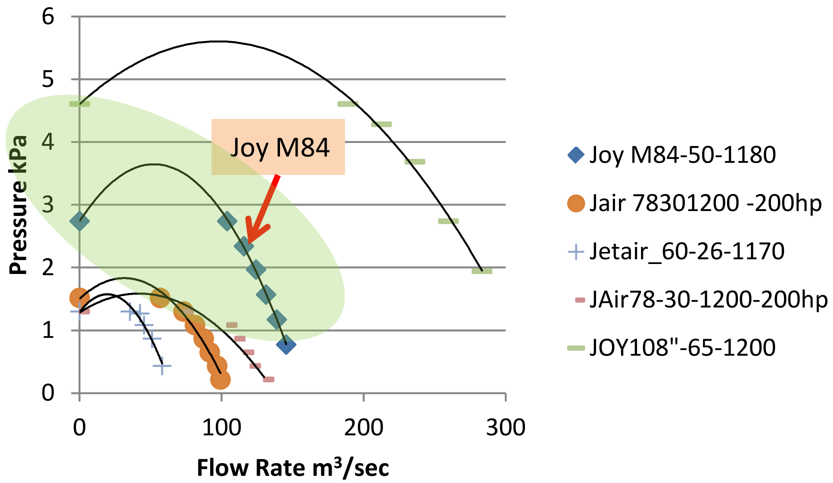
Start	End	$Q_{previous}$ (kg/s)	Q_{new} (kg/s)
280	286	26.41	-0.21
1012	1015	5.33	-5.05
399	1492	3.50	-1.29

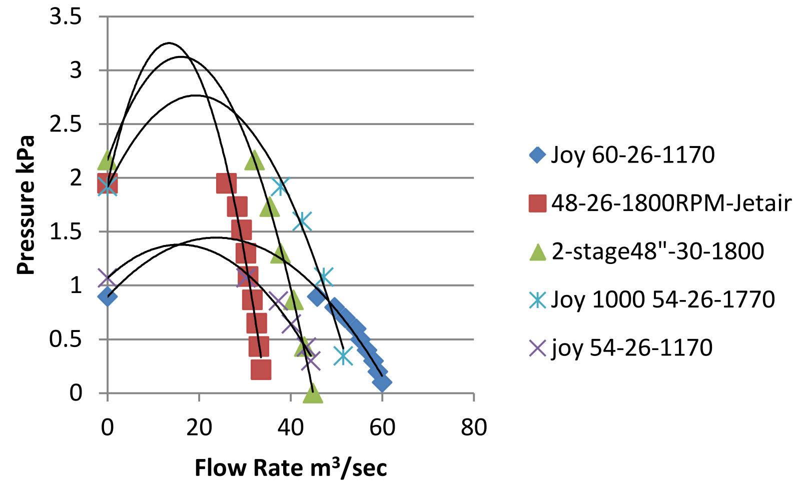
- ❖ Negative sign in the change means change in air flow direction

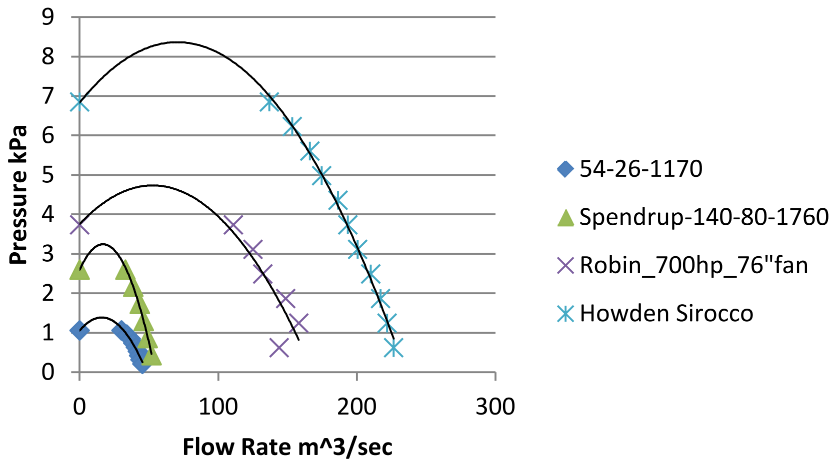
Dominantly Affected Airways - Percentage Change in Airflow Rate

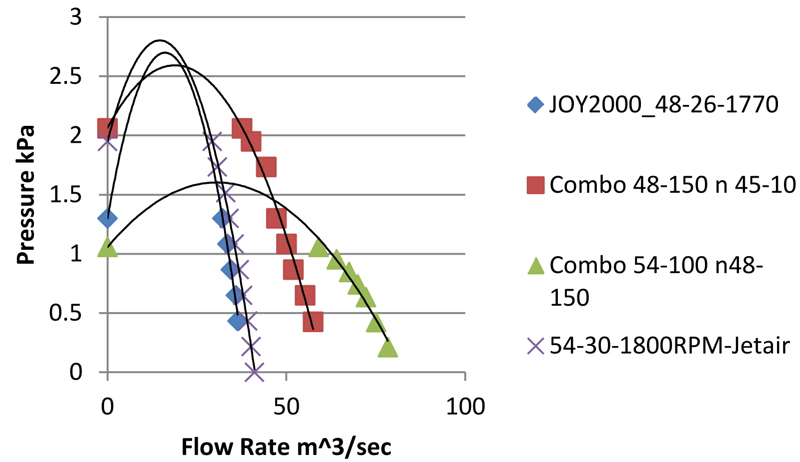
Start	End	ΔQ_{ab}	% Δ	Previous	New		Start	End	ΔQ_{ab}	% Δ	Previous	New
280	286	-26.622	-101%	26.412	-0.20943		475	478	-6.721	-192%	3.4943	-3.2267
286	296	-26.622	-101%	26.412	-0.20943		1062	1061	-3.9417	-129%	3.0483	-0.89347
411	410	-33.943	-157%	21.575	-12.368		1061	1056	-3.9167	-130%	3.0056	-0.91109
418	411	-33.943	-157%	21.575	-12.368		1056	1057	-3.9167	-130%	3.0056	-0.91109
410	412	-33.943	-157%	21.575	-12.368		1421	1455	-12.983	-592%	2.1931	-10.789
412	415	-33.943	-157%	21.575	-12.368		1342	1209	-11.912	-819%	1.454	-10.458
415	417	-33.943	-157%	21.575	-12.368		1902	1867	-0.22717	-122%	0.18642	-0.04075
1270	1258	-23.28	-147%	15.831	-7.4483		1043	1042	-3.0427	-1676%	0.18154	-2.8611
1280	1270	-23.28	-147%	15.831	-7.4483		1044	1043	-3.0427	-1676%	0.18154	-2.8611
1286	1280	-23.28	-147%	15.831	-7.4483		1046	1044	-3.0427	-1676%	0.18154	-2.8611
1287	1286	-23.28	-147%	15.831	-7.4483		1047	1045	-3.0427	-1676%	0.18154	-2.8611
1288	1287	-23.28	-147%	15.831	-7.4483		1045	1046	-3.0427	-1676%	0.18154	-2.8611
1289	1288	-23.28	-147%	15.831	-7.4483		1051	1047	-3.0427	-1676%	0.18154	-2.8611
1291	1289	-23.28	-147%	15.831	-7.4483		1057	1051	-3.0427	-1676%	0.18154	-2.8611
1197	1196	-23.263	-147%	15.793	-7.4704		658	757	-0.17297	-114%	0.1514	-0.02156
1198	1197	-23.263	-147%	15.793	-7.4704		429	425	0.32736	157%	-0.20841	0.11896
1201	1198	-23.263	-147%	15.793	-7.4704		1342	1244	11.912	819%	-1.454	10.458
1206	1201	-23.263	-147%	15.793	-7.4704		400	398	4.6321	218%	-2.1234	2.5087
1208	1206	-23.263	-147%	15.793	-7.4704		324	226	6.0118	175%	-3.4439	2.5678
1248	1208	-23.263	-147%	15.793	-7.4704		226	227	6.0118	175%	-3.4439	2.5678
1196	1291	-23.263	-147%	15.793	-7.4704		329	323	6.0118	175%	-3.4439	2.5678
811	808	-29.569	-207%	14.304	-15.265		325	324	6.0118	175%	-3.4439	2.5678
989	988	-12.632	-138%	9.1362	-3.4963		323	325	6.0118	175%	-3.4439	2.5678
991	989	-12.632	-138%	9.1362	-3.4963		332	329	6.0118	175%	-3.4439	2.5678
1462	1502	-10.644	-174%	6.1307	-4.5137		336	332	6.0118	175%	-3.4439	2.5678
1012	1015	-10.377	-195%	5.3298	-5.0474		1462	1458	10.644	174%	-6.1307	4.5137
399	1492	-4.7941	-137%	3.5036	-1.2906		305	277	15.675	179%	-8.7679	6.9068

Change in Pressure Due to Fan RPM Modulation





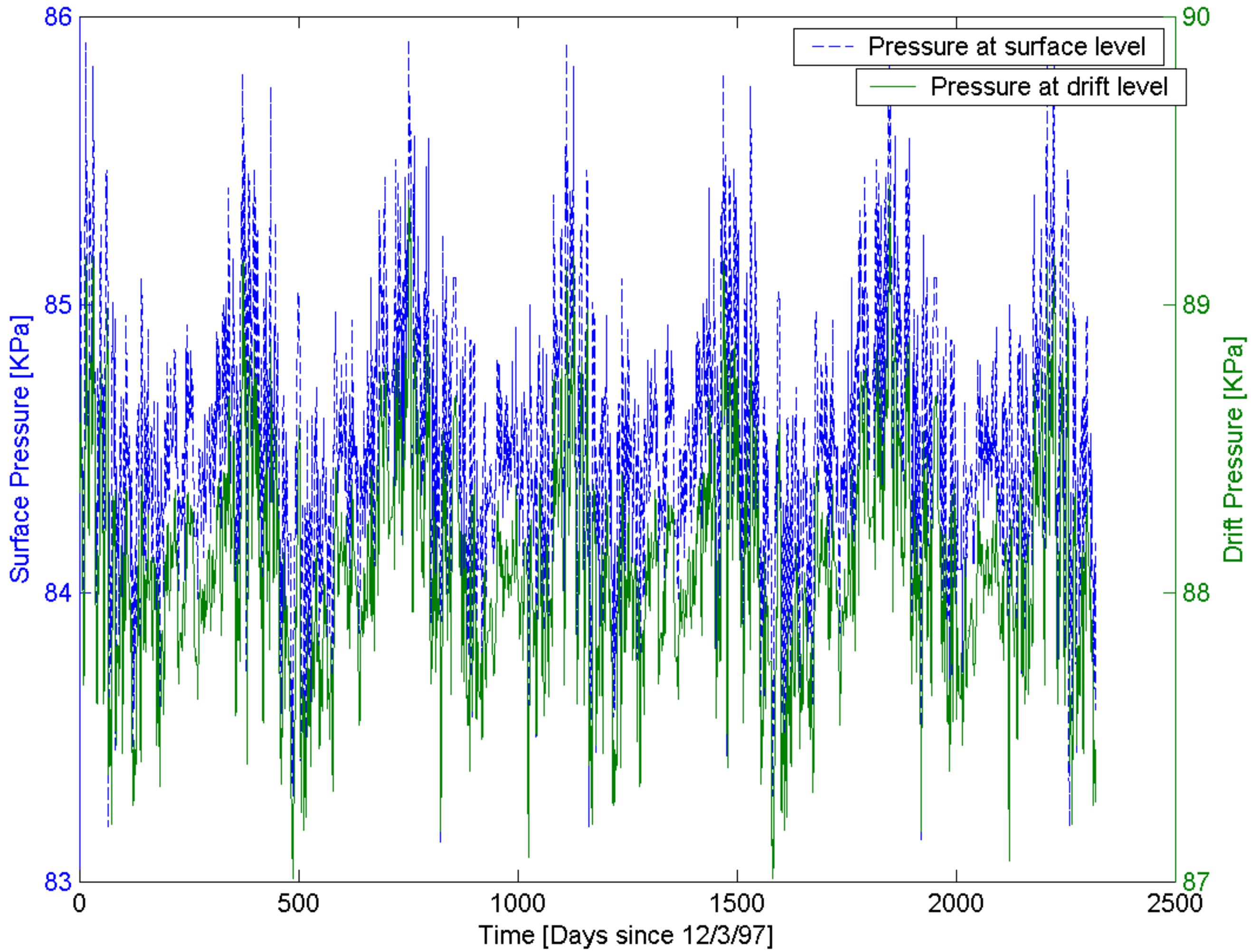




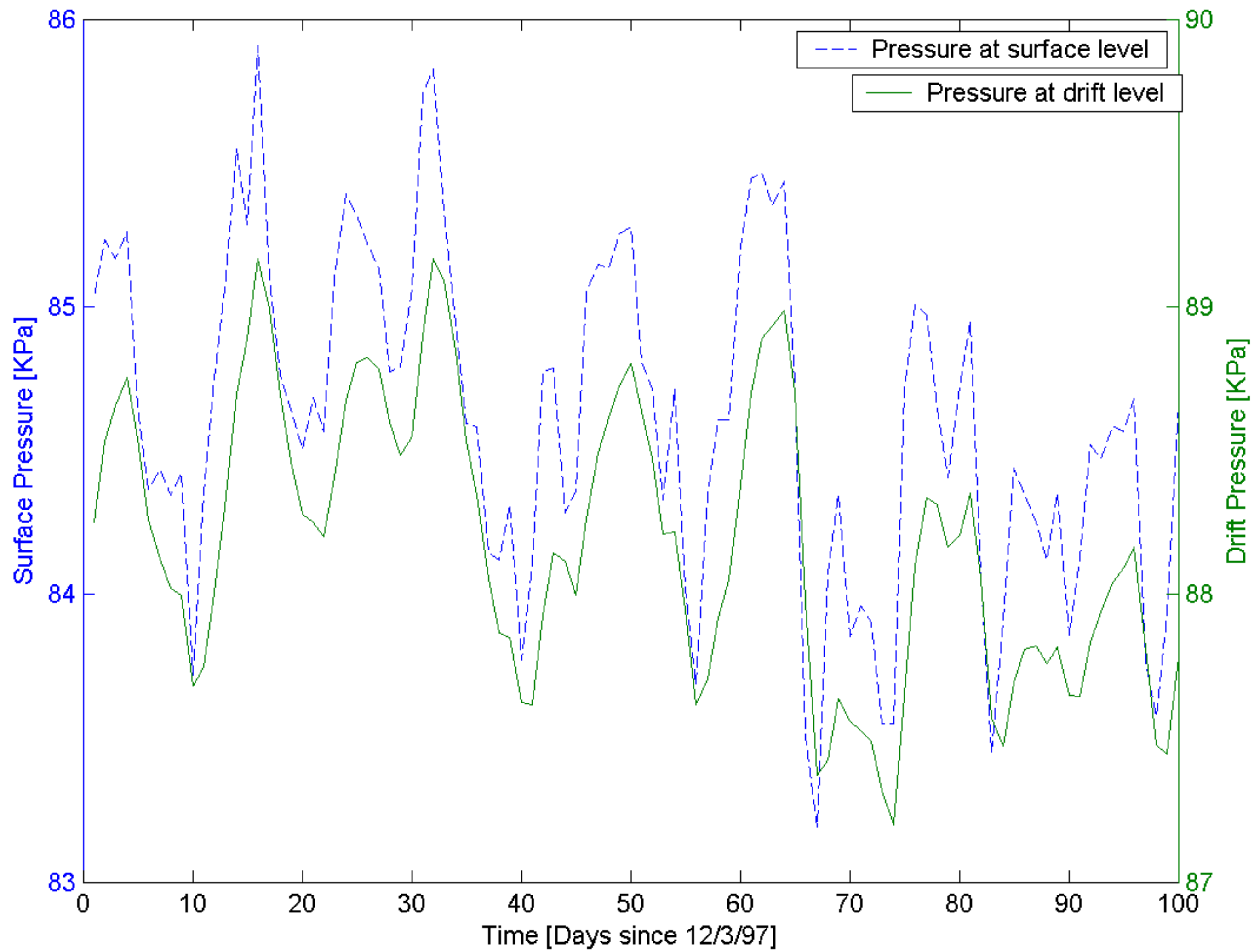
Change of Dynamic Variations

- Air pressure variations:
  - Atmospheric pressure (Pb) variation
  - VOD-related pressure changes caused by variable fan operation
  - Dynamic airway resistance changes, e.g., door opening or closing
  - Blasting operation, underground or surface
  - Fire/explosion in a different section of the mine
- Flow rate (Qa) variations:
  - VOD-related pressure difference changes caused by variable fan operations (booster or main)
  - Dynamic airway resistance changes, e.g., door opening or closing.

Typical Barometric Pressure, Pb, Variation in Nevada



Typical Barometric Pressure, Pb, variation in Nevada



Summary of changes

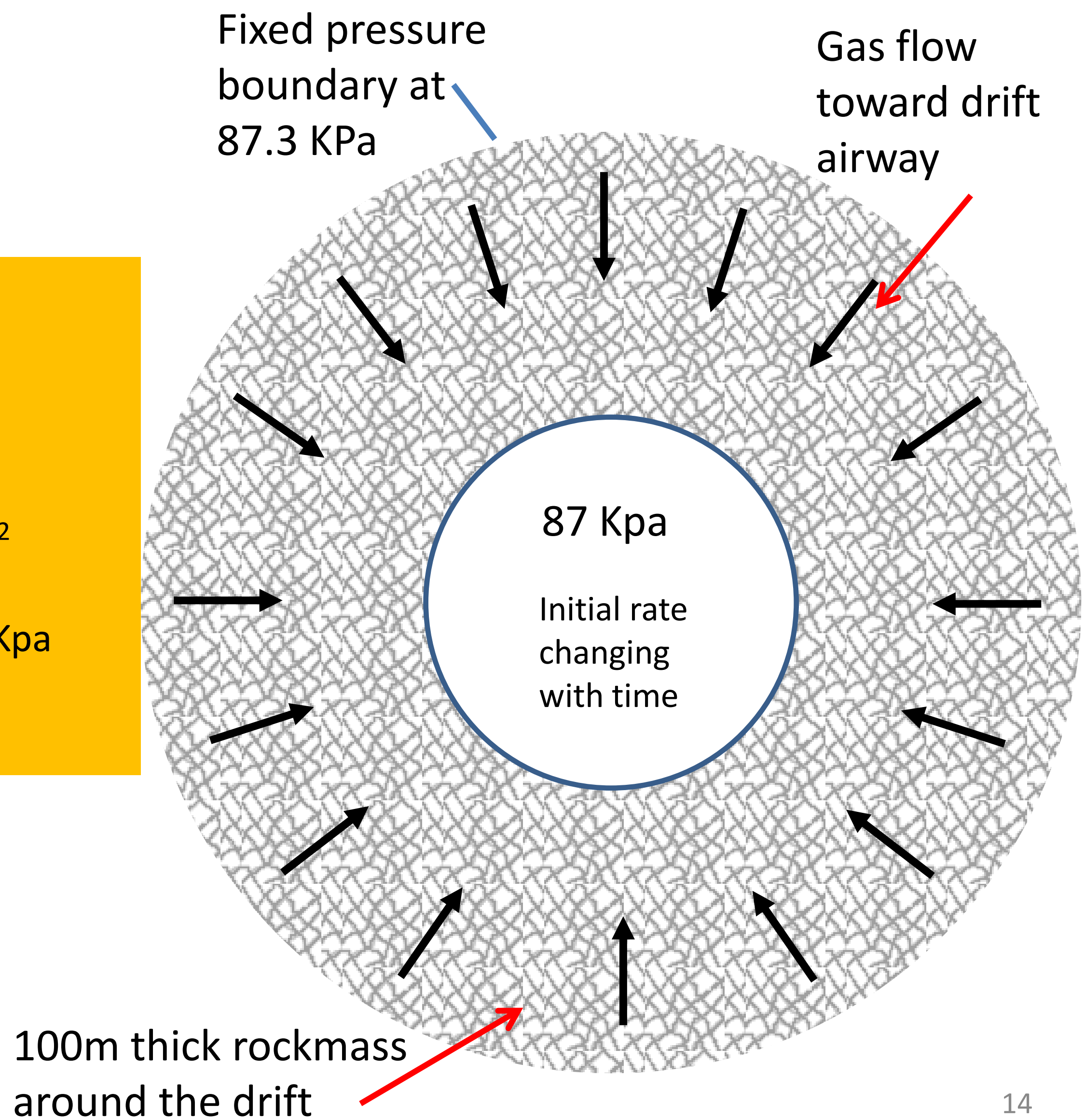
	Pressure, Pb	Air flow (related to $\Delta P = Pb_{in} - Pb_{out}$)
1	Pb ↑	Qa ↓
2	Pb ↑	Qa ↑
3	Pb ↓	Qa ↑
4	Pb ↓	Qa ↓

Criticality	
Pb ↓ More gas inflow from strata or gob	Qa ↓ Less gas dilution by air flow

Example Application

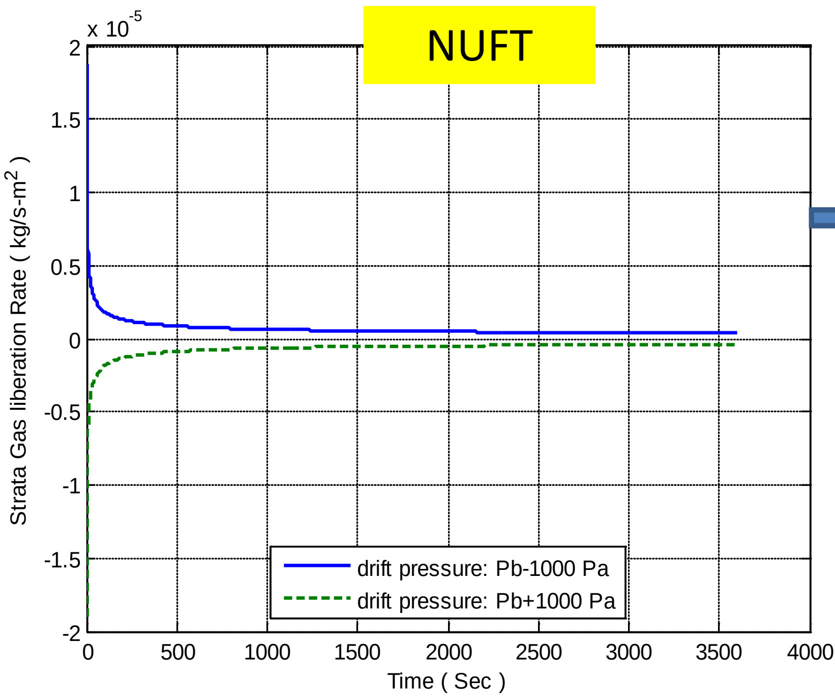
Model input

- Flow cross section, A: $23m^2$
- Flow wetted perimeter, Per: 19m
- Rockmass porosity: 15%
- Rockmass liquid saturation: 0
- Rockmass permeability: $2.4x10^{-12}\ m^2$ (~2.4 Darcy)
- Far-field barometric pressure: 87.3 Kpa
- In-drift barometric pressure: 87 KPa



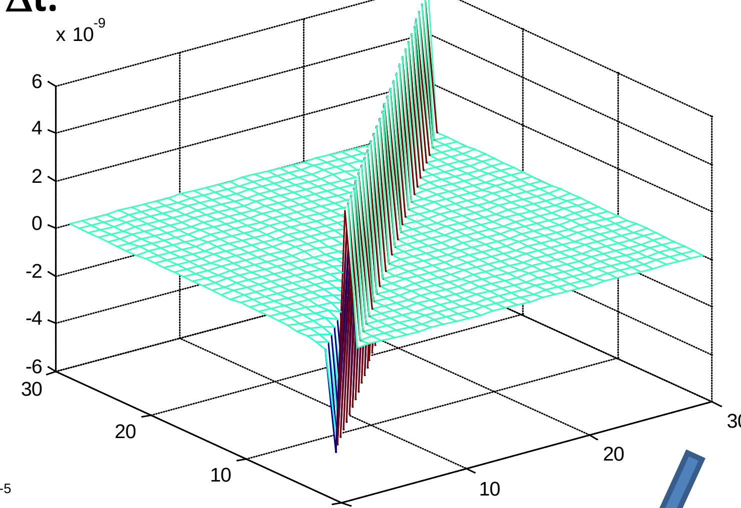
NTCF model Preparation

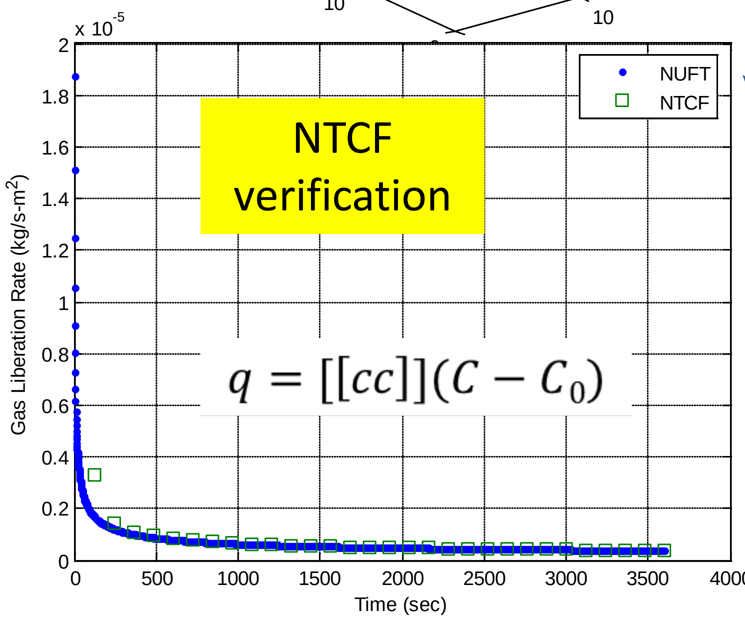
NTCF code was used with a cylindrical mesh around the opening. A 1-hr transient model was prepared in 2-min Δt.



1000 Pa or -1000 Pa step change in drift air pressure

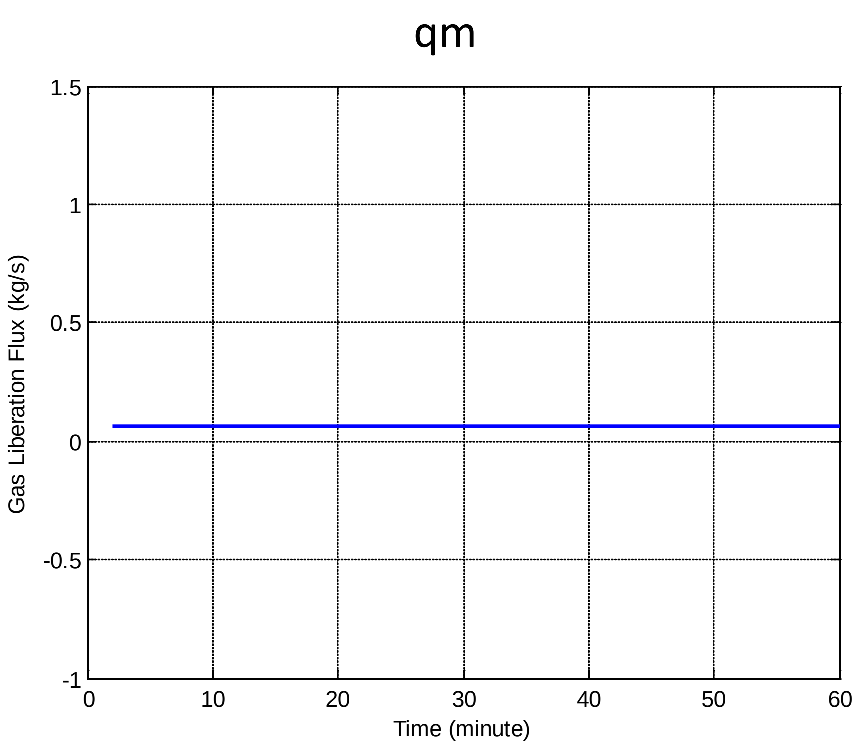
NTCF matrix, [[CC (NxN)]] where N=30

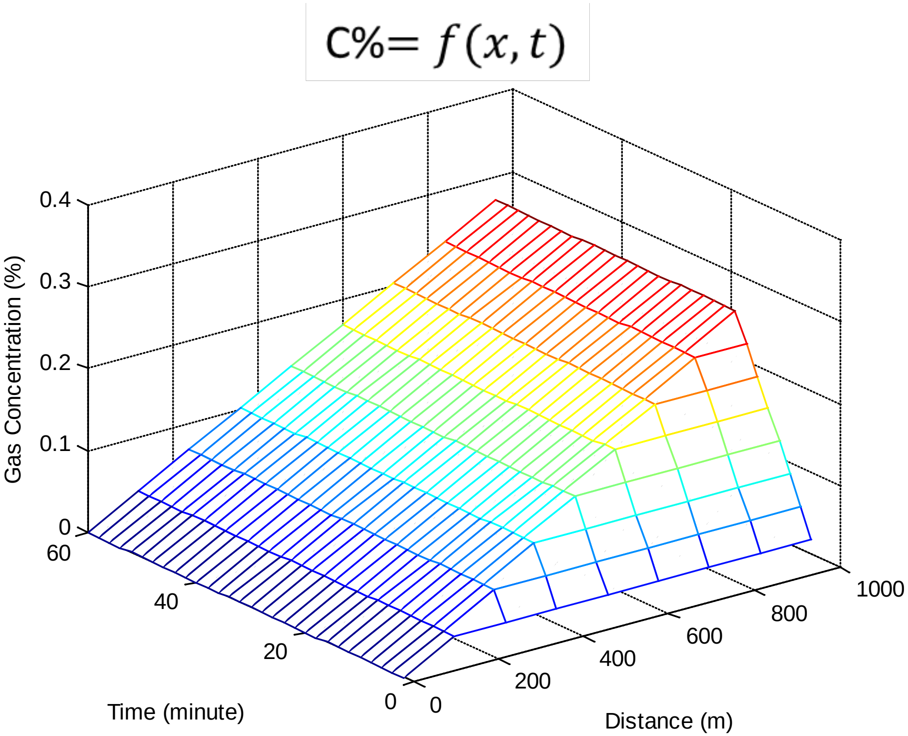




Gas Liberation and Concentration Example

Darcy, background gas flow



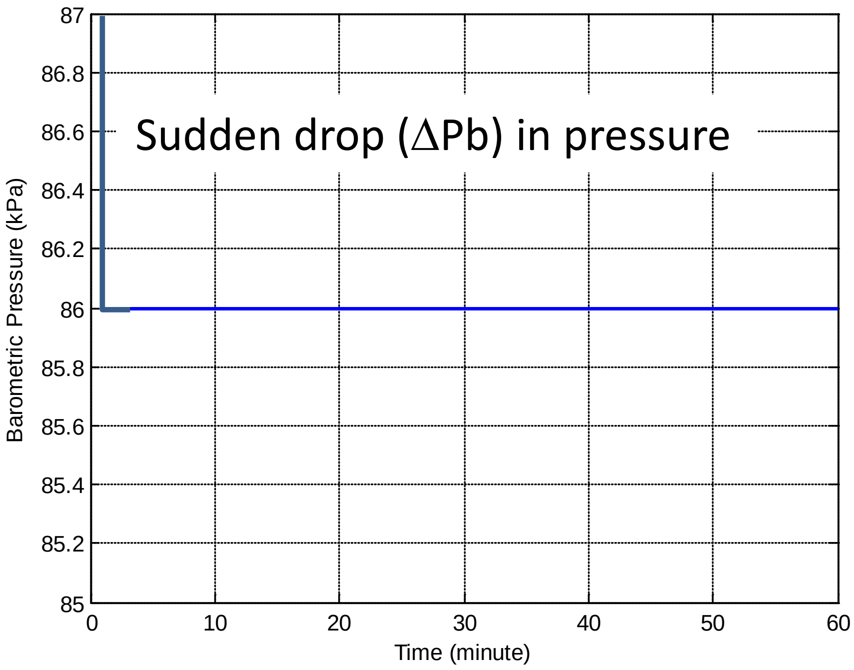


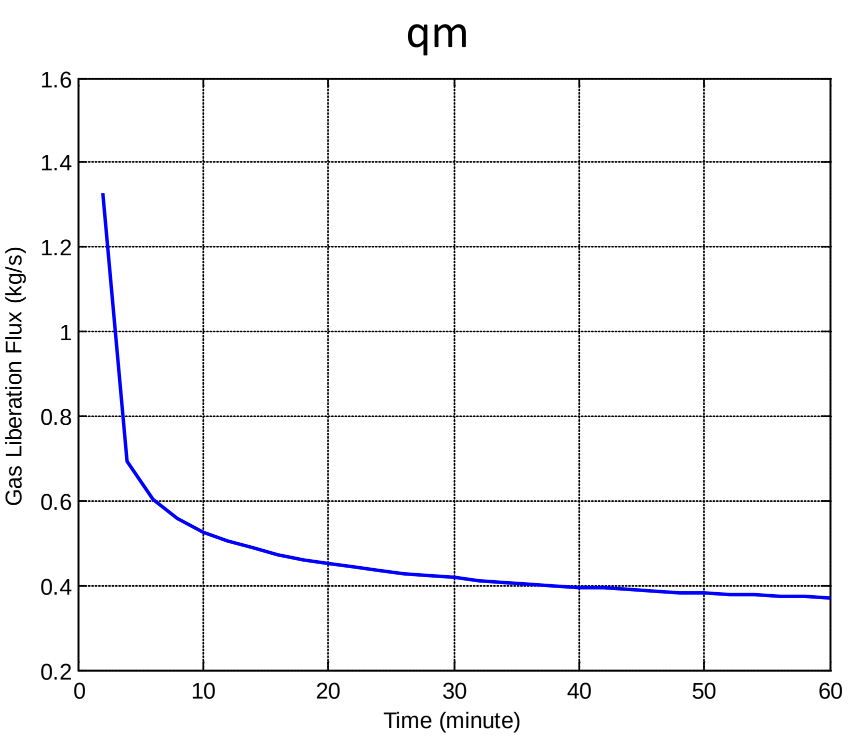
Gas concentration variation in time at 1000m distance. Steady state gas flow

Gas concentration variation in time and space due to 87kPa in-drift air pressure. V= 1 m/s

Gas Liberation and Concentration Example

1000 Pa in-drift pressure change

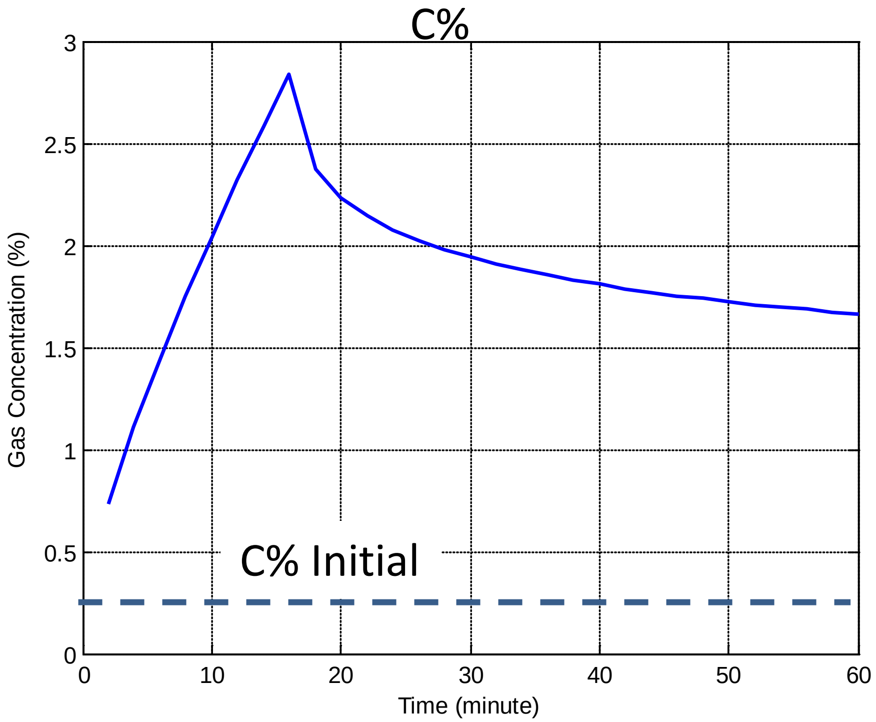




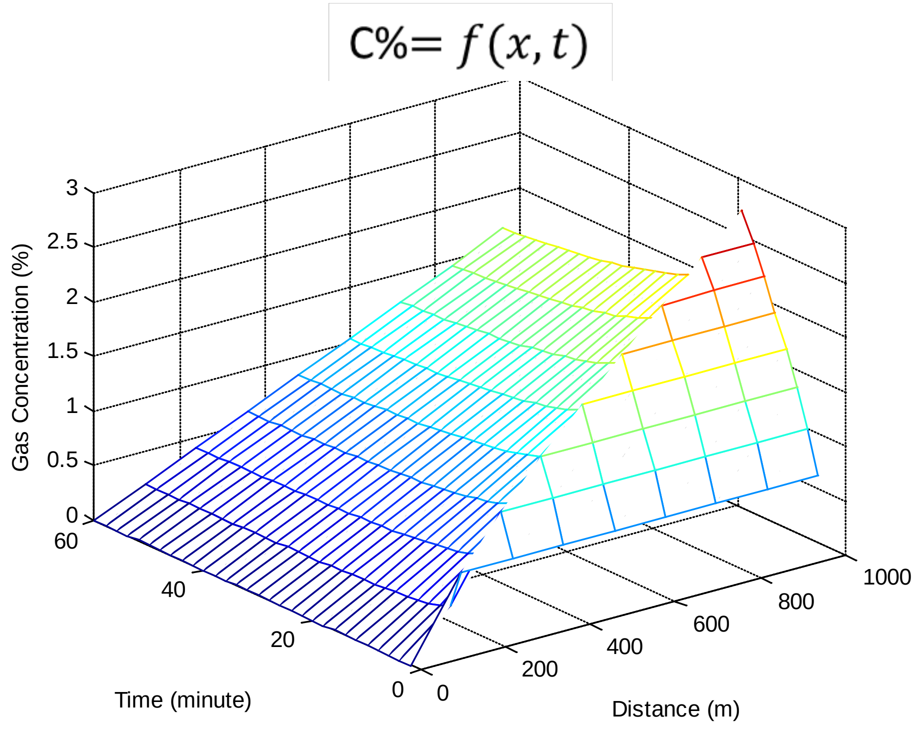
Gas concentration variation in time for Darcy flow condition
1000m drift section, 86 kPa in-drift air pressure.

Gas Liberation and Concentration Example

1000 Pa in-drift pressure change



Gas concentration variation in time at 1000m distance. V=1 m/s

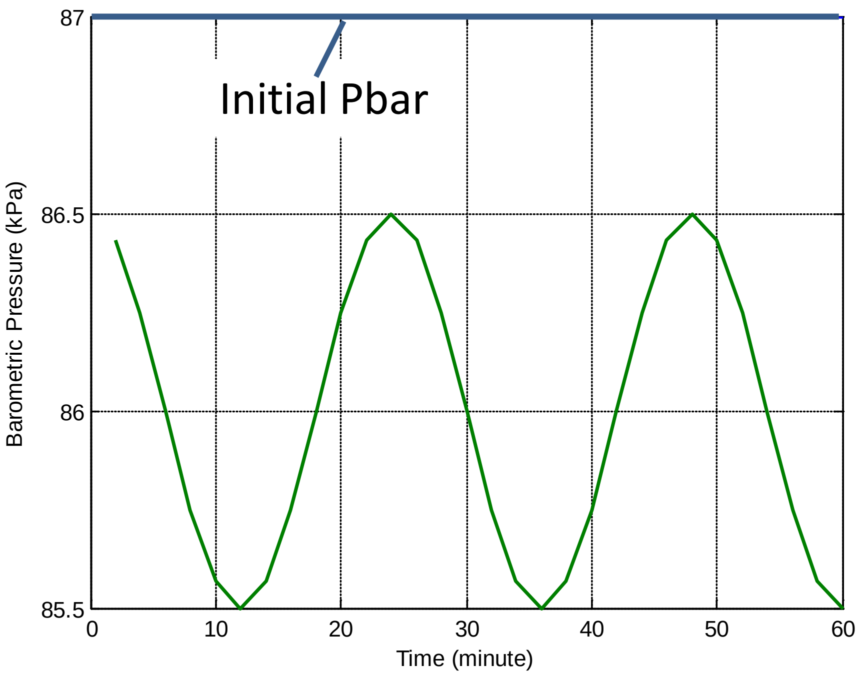


Gas concentration variation in time and space due to 86kPa in-drift air pressure.

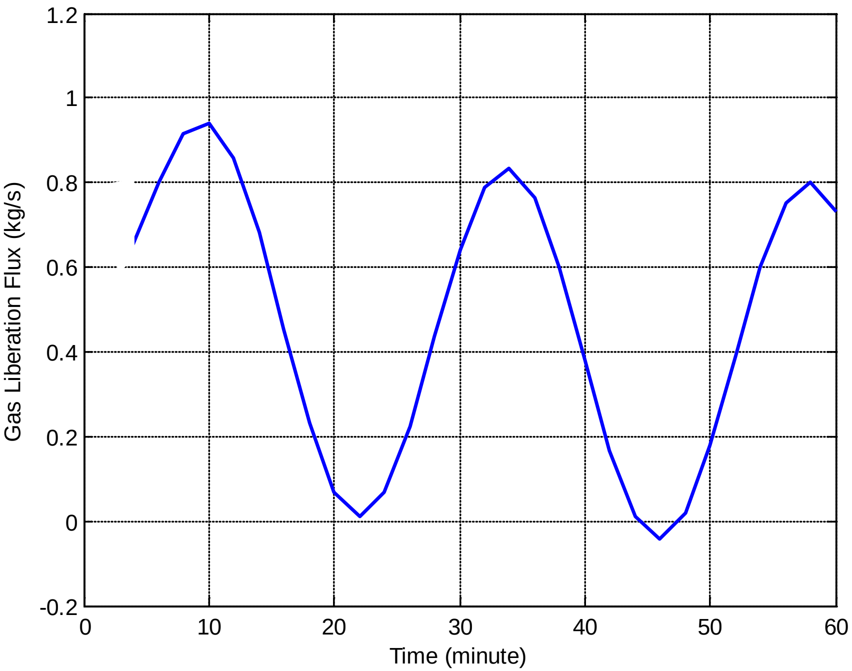
Gas Liberation and Concentration Example

Variable in-drift pressure, and lowered air flow velocity from 5 to 1 m/s

Pb

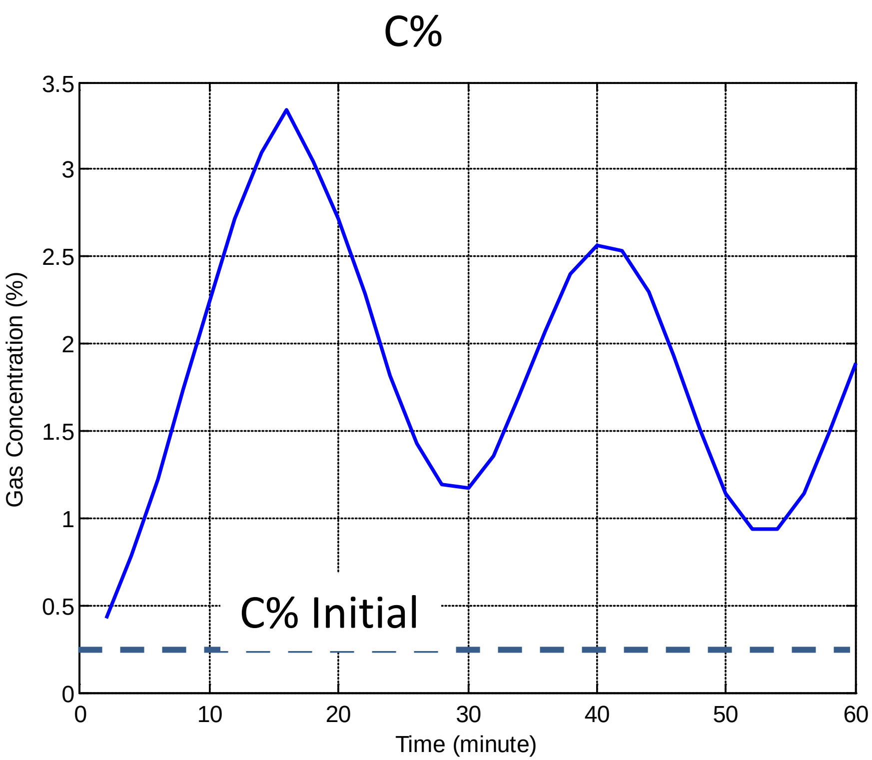


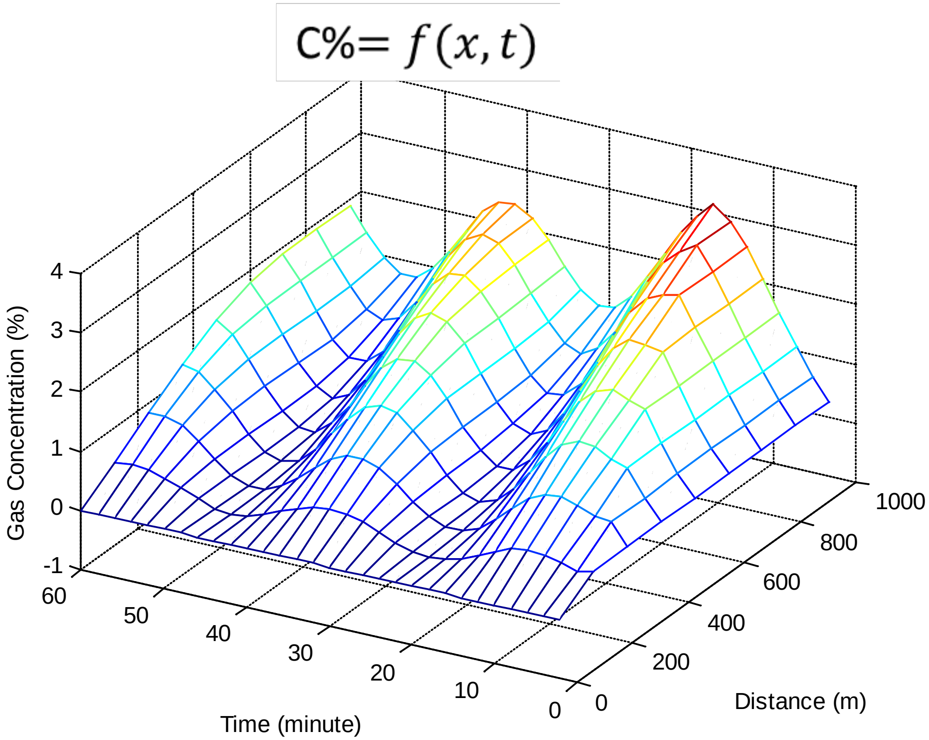
qm



Gas Liberation and Concentration Example

Variable in-drift pressure





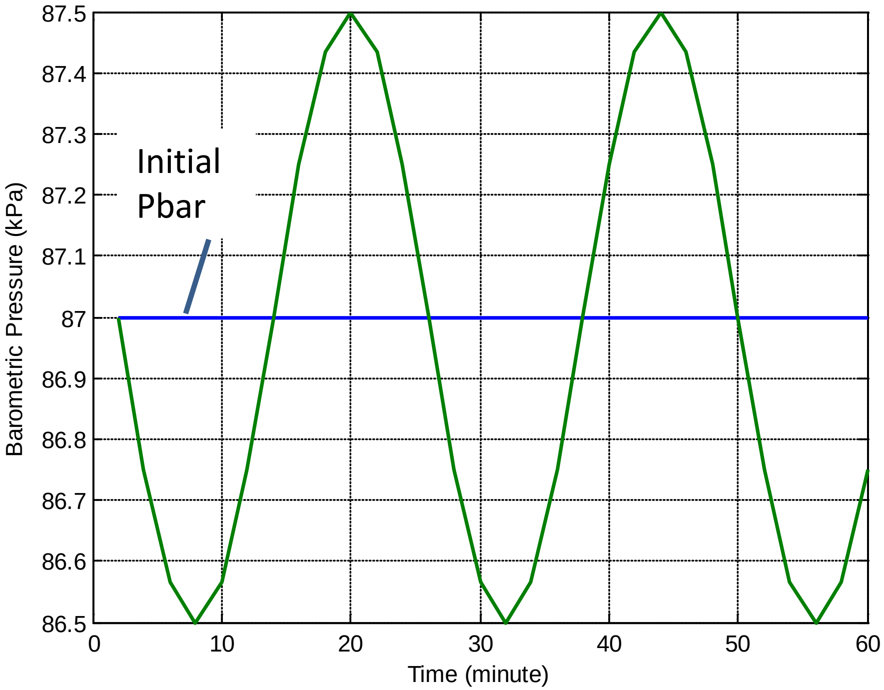
Gas concentration variation in time at 1000m distance. V=1 m/s.

Gas concentration variation in time and space due to variable in-drift air pressure.

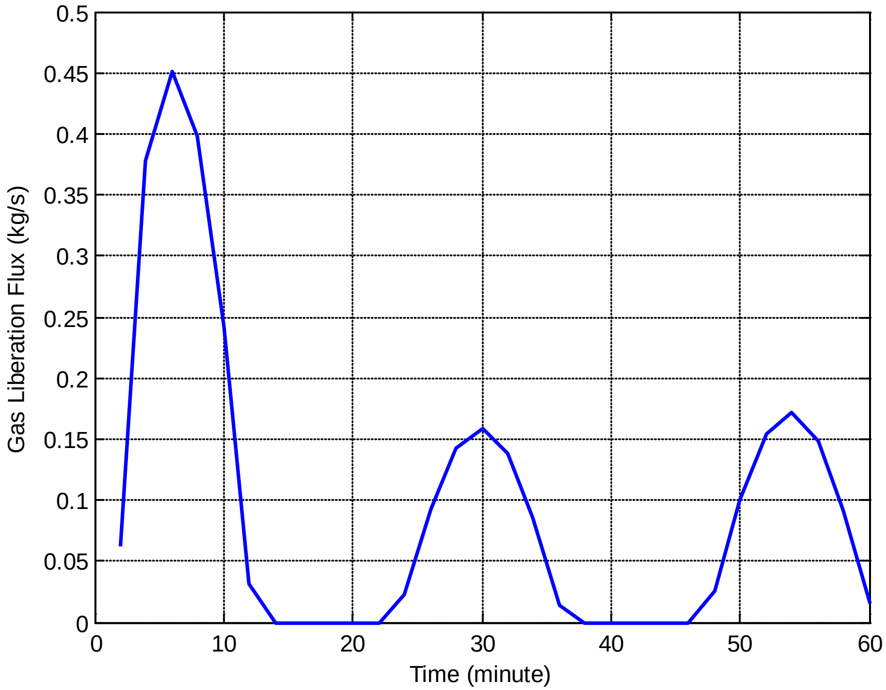
Gas Liberation and Concentration Example

Variable in-drift pressure

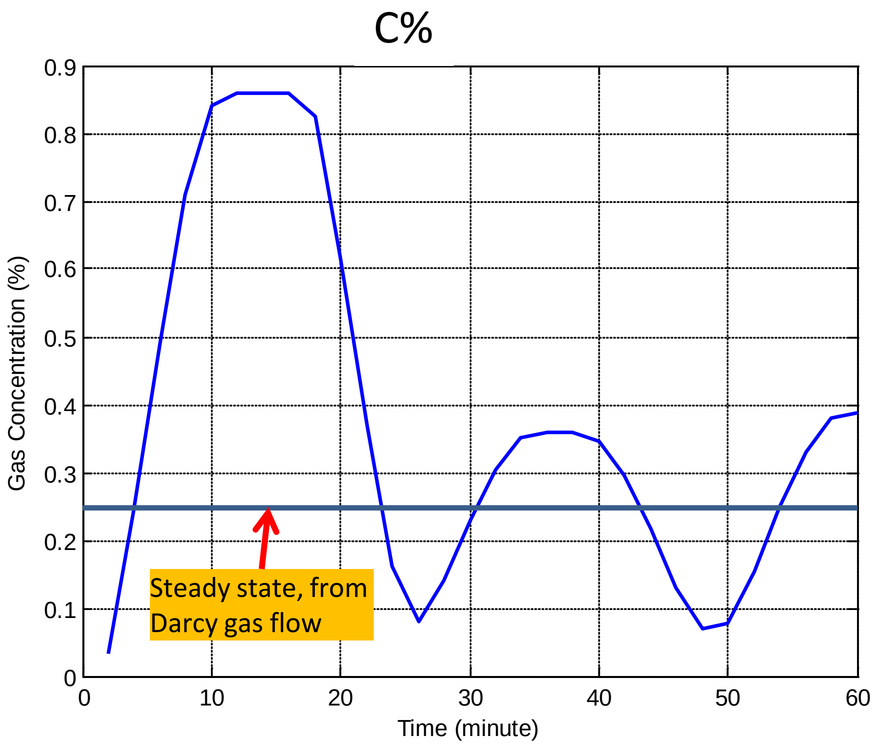
Pb

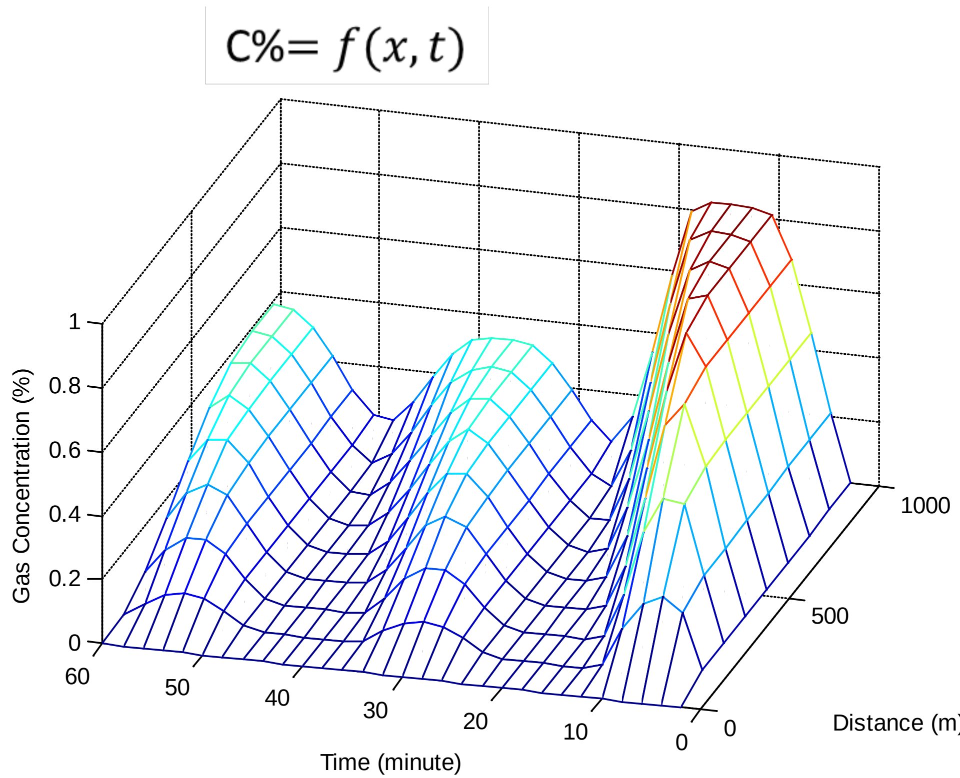


qm



Gas liberation and concentration example
Variable in-drift pressure





Gas concentration variation in time at 1000m distance. V=1 m/s

- We cannot say with confidence that a time-averaged solution is safely equivalent with the short-time-averaged of a transient

Gas concentration variation in time and space due to variable in-drift air pressure.

Conclusions

- Transient responses are different from steady state analysis
- The average of the output response to changed input is not the same as the output response to average input
- $\overline{\boldsymbol{Out}}(\boldsymbol{input}(\boldsymbol{t})) \neq \boldsymbol{Out}(\overline{\boldsymbol{input}}(\boldsymbol{t}))$ for short time periods

  Beware: We are not safe without transient simulations
- A coupled in-drift and in-strata model is needed to understand the transient responses
- Dynamic changes caused by VOD control changes must be modeled and evaluated for safety
- Sensitivity analyses should be conducted to determine influences of one mine section on other sections
- We have a model, up and running, for simulating transient changes using MULTIFLUX

Acknowledgement

BARRICK

NIOSH National Institute for Occupational Safety and Health

Thank You

Questions?

support

- **30 CFR § 77.201-2**
  Methane accumulations; change in ventilation.

  If, at any time, the air in any structure, enclosure or other facility contains 1.0 volume per centum or more of methane changes or adjustments in the ventilation of such installation shall be made at once so that the air shall contain less than 1.0 volume per centum of methane.

support

- **30 CFR § 75.323**
  Actions for excessive methane.

  (a)*Location of tests.* Tests for methane concentrations under this section shall be made at least 12 inches from the roof, face, ribs, and floor.

  (b)*Working places and intake air courses.*

  (1) When 1.0 percent or more methane is present in a working place or an intake air course, including an air course in which a belt conveyor is located, or in an area where mechanized mining equipment is being installed or removed--

  (i) Except intrinsically safe atmospheric monitoring systems (AMS), electrically powered equipment in the affected area shall be deenergized, and other mechanized equipment shall be shut off;

  (ii) Changes or adjustments shall be made at once to the ventilation system to reduce the concentration of methane to less than 1.0 percent; and

  (iii) No other work shall be permitted in the affected area until the methane concentration is less than 1.0 percent.

  (2) When 1.5 percent or more methane is present in a working place or an intake air course, including an air course in which a belt conveyor is located, or in an area where mechanized mining equipment is being installed or removed--

  (i) Everyone except those persons referred to in §104(c) of the Act shall be withdrawn from the affected area; and

  (ii) Except for intrinsically safe AMS, electrically powered equipment in the affected area shall be disconnected at the power source.

  (c)*Return air split.* (1) When 1.0 percent or more methane is present in a return air split between the last working place on a working section and where that split of air meets another split of air, or the location at which the split is used to ventilate seals or worked-out areas changes or adjustments shall be made at once to the ventilation system to reduce the concentration of methane in the return air to less than 1.0 percent.

support

- **30 CFR § 75.323**
  Actions for excessive methane.

  (2) When 1.5 percent or more methane is present in a return air split between the last working place on a working section and where that split of air meets another split of air, or the location where the split is used to ventilate seals or worked-out areas--

  (i) Everyone except those persons referred to in §104(c) of the Act shall be withdrawn from the affected area;

  (ii) Other than intrinsically safe AMS, equipment in the affected area shall be deenergized, electric power shall be disconnected at the power source, and other mechanized equipment shall be shut off; and
  (iii) No other work shall be permitted in the affected area until the methane concentration in the return air is less than 1.0 percent.

- (d)*Return air split alternative.* (1) The provisions of this paragraph apply if--

  (i) The quantity of air in the split ventilating the active workings is at least 27,000 cubic feet per minute in the last open crosscut or the quantity specified in the approved ventilation plan, whichever is greater;

  (ii) The methane content of the air in the split is continuously monitored during mining operations by an AMS that gives a visual and audible signal on the working section when the methane in the return air reaches 1.5 percent, and the methane content is monitored as specified in §75.351; and

  (iii) Rock dust is continuously applied with a mechanical duster to the return air course during coal production at a location in the air course immediately outby the most inby monitoring point.

  (2) When 1.5 percent or more methane is present in a return air split between a point in the return opposite the section loading point and where that split of air meets another split of air or where the split of air is used to ventilate seals or worked-out areas--

  (i) Changes or adjustments shall be made at once to the ventilation system to reduce the concentration of methane in the return air below 1.5 percent;

  (ii) Everyone except those persons referred to in §104(c) of the Act shall be withdrawn from the affected area;

  (iii) Except for intrinsically safe AMS, equipment in the affected area shall be deenergized, electric power shall be disconnected at the power source, and other mechanized equipment shall be shut off; and

  (iv) No other work shall be permitted in the affected area until the methane concentration in the return air is less than 1.5 percent.

  (e)*Bleeders and other return air courses.* The concentration of methane in a bleeder split of air immediately before the air in the split joins another split of air, or in a return air course other than as described in paragraphs (c) and (d) of this section, shall not exceed 2.0 percent.