Control of Linepack in Natural Gas System: Balancing Limited Resources Under Uncertainty

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May 17, 2023

PSIG Pipeline Simulation Interest Group

Project Goals

- Operations-aware modeling and simulation of reduced model of Israel's NG network
  - Flux control at inlets
  - Realistic initial and boundary conditions
  - Assessing robustness under uncertain PV generation
  - Assessing robustness under an "insult" to the system

Agenda

- Introduction to Israel gas system
- Effective gas flow equations
- Staggered-grid method
- Scenario descriptions
- Results
- Discussion

Israel Natural Gas

- Starting ~2010, large natural gas (NG) reserves were discovered off the coast of Israel
- These supplies transitioned Israel from an energy importer to an exporter of NG, and set NG as main fuel for electricity production.
- Following the global agreement at the Paris Climate Accords in 2015, Israel plans to convert remaining coal-fired plants to NG.

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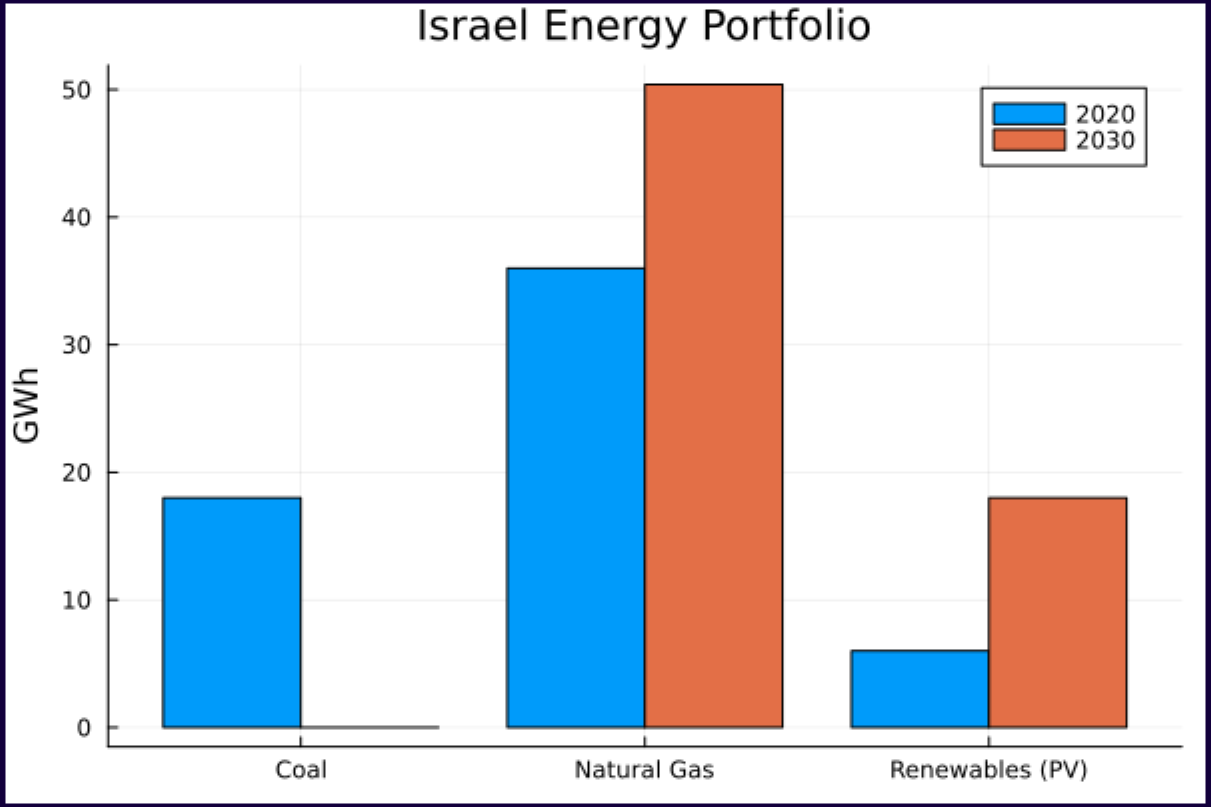
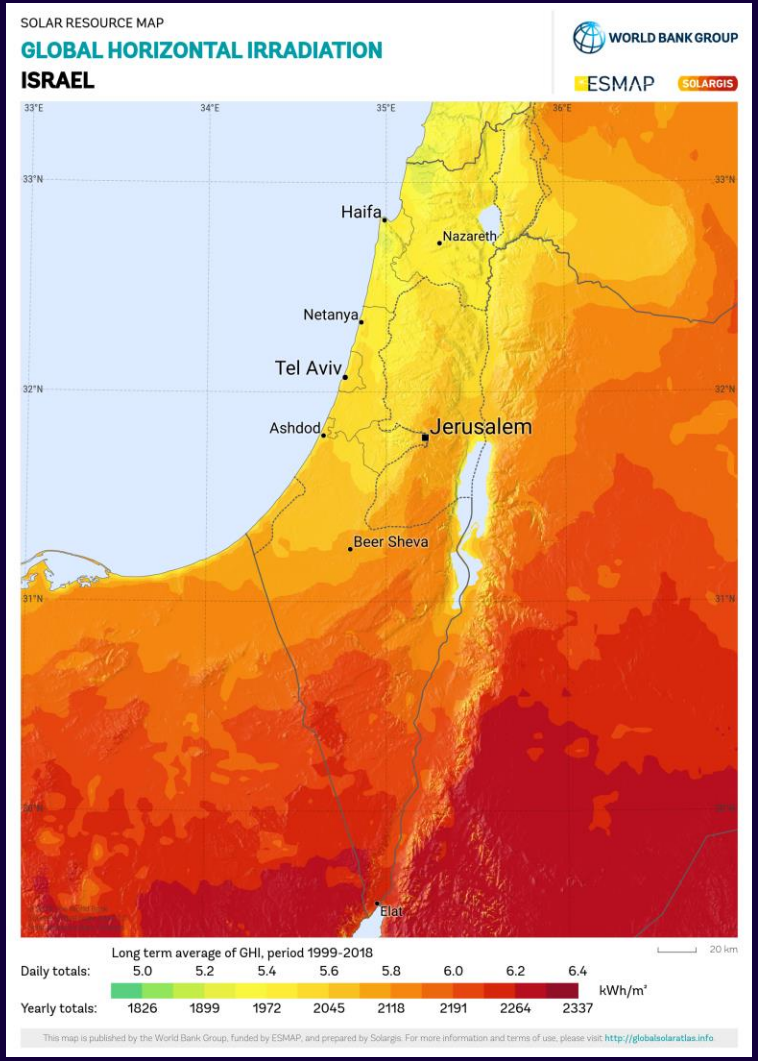
Israel Natural Gas

- Simultaneously, Israel is committed to increasing renewables (mainly PV), with the goal of 30% production by 2030





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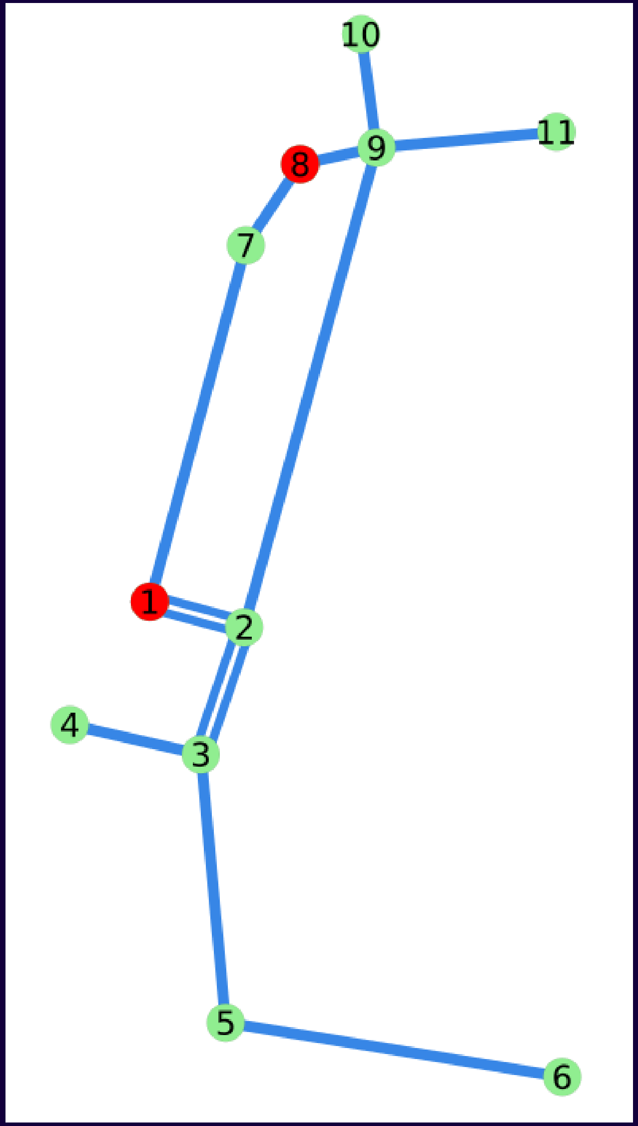
Reduced Model of Israel Natural Gas



Effective Gas Flow Equations

Under reasonable assumptions, the system of PDEs governing gas flow is

$$\partial_t \rho + \partial_x \phi = 0$$
$$\partial_t \phi + \partial_x p = -\beta \frac{\phi|\phi|}{\rho}$$

Supplemented with initial

$$\rho(x,0) = \rho_0(x)$$
$$\phi(x,0) = \phi_0(x)$$

And boundary conditions at each node

$$\rho_i(t) \text{ or } \phi_i(t)$$

And an equation of state relating pressure and density – we use CNGA

$$p(\rho) = Z(p,T)RT\rho$$

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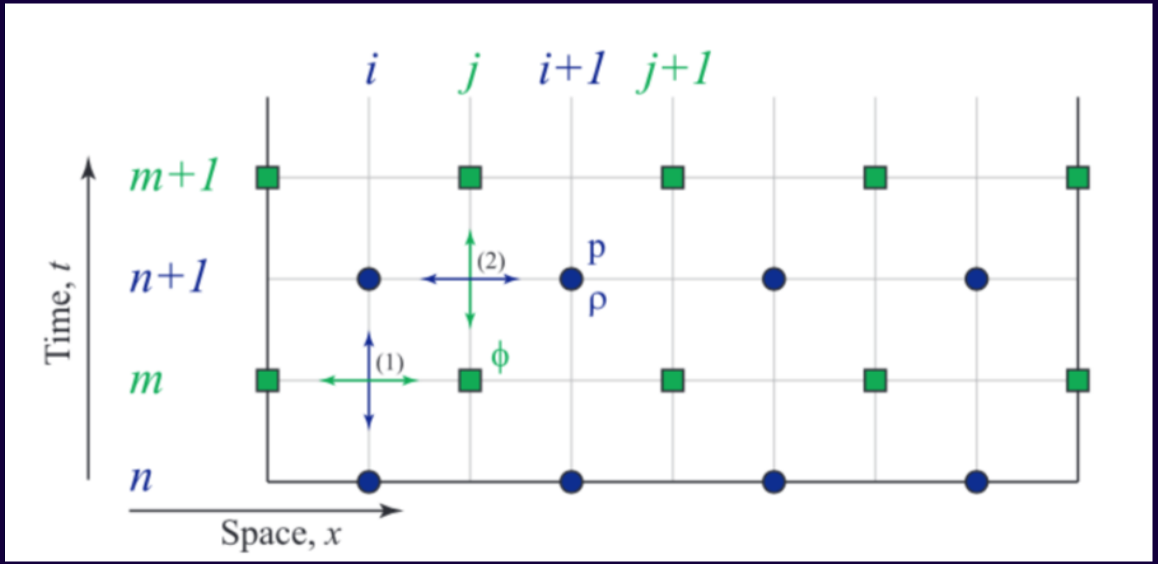
Staggered-Grid Method



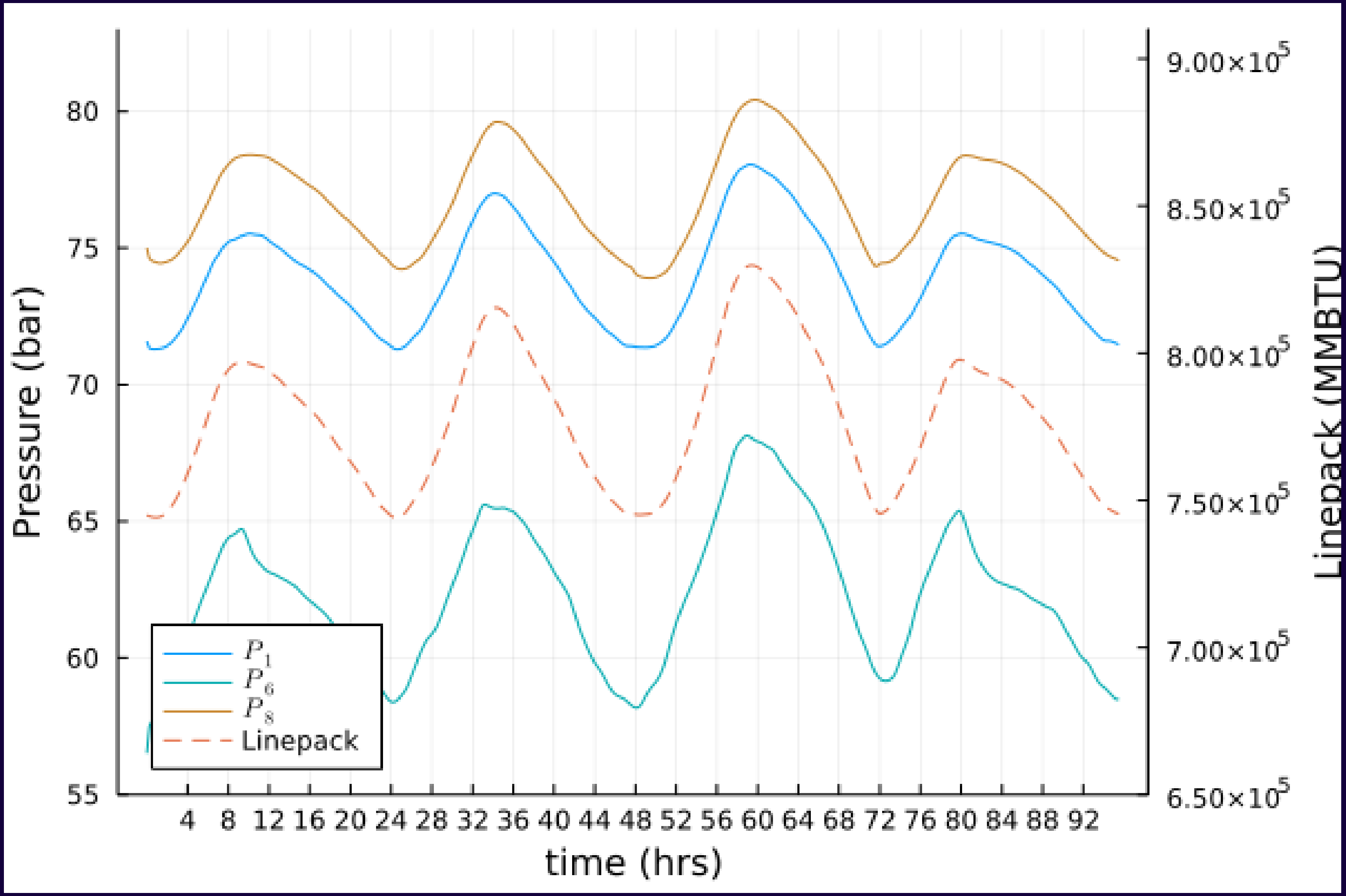
Gyrya, Vitaliy, and Anatoly Zlotnik. "An explicit staggered-grid method for numerical simulation of large-scale natural gas pipeline networks." *Applied Mathematical Modelling* 65 (2019): 34-51.

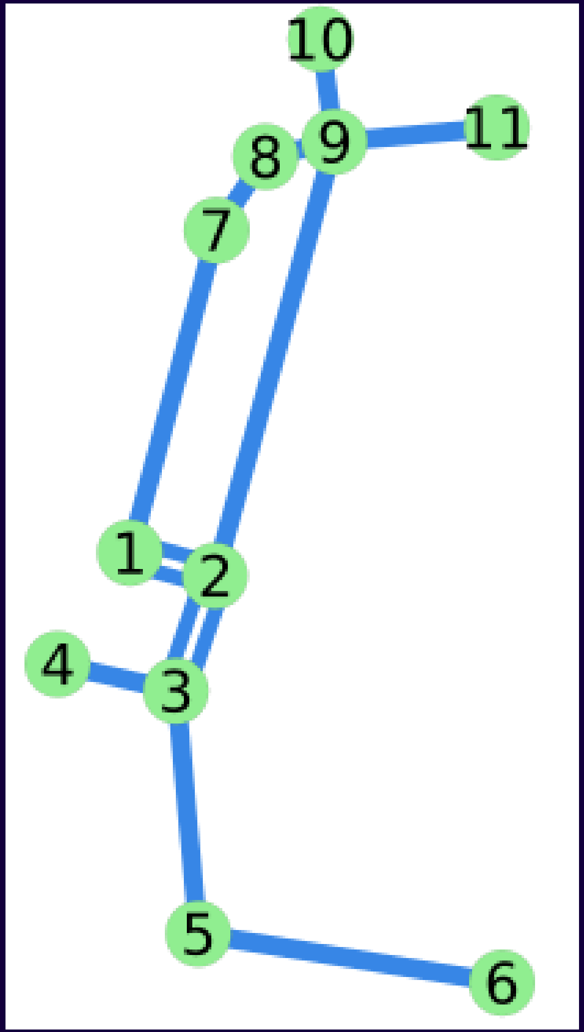
- Explicit, 2nd order, centered finite difference method
- Solves conservation of mass and momentum on staggered grids
- Conserves mass to numerical precision
- Stable given condition is satisfied
  - $\sqrt{p'(\rho)}\,\frac{\Delta t}{\Delta x} \leq 1$

Scenarios

Scenario #	Description	Features
1	A reference week in August	Pressure variation in flow-control regime
2	Scenario #1 with empirical noise added to demand curves, supplies unchanged	Linepack and pressure drift when using flow control and uncertain demand
3	Scenario #2 with insult at node 1	Introduce the notion of survival time, and set baseline without any controls.
4	Scenario #3 with insult time change to trough of linepack timeseries.	Illustrate that survival times change with timing of insult.
5	Scenario #4 with step-wise supply increase from node # 8.	Survival times lengthen, but become less certain.
6	Scenario #5 with step-wise curtailing of demand.	No low pressure crossings are found. The high pressure at node # 8 shows need for finer control.

Results: Scenario 1





Nominal week in August

Uncertainty

Moderate uncertainty at demand nodes represented via substitution of stochastic process for boundary condition

$$d_i(t) \to X_i(t)$$

where

$$dX_i(t) = \alpha\big(d_i(t) - X_i(t)\big) + \gamma dW$$

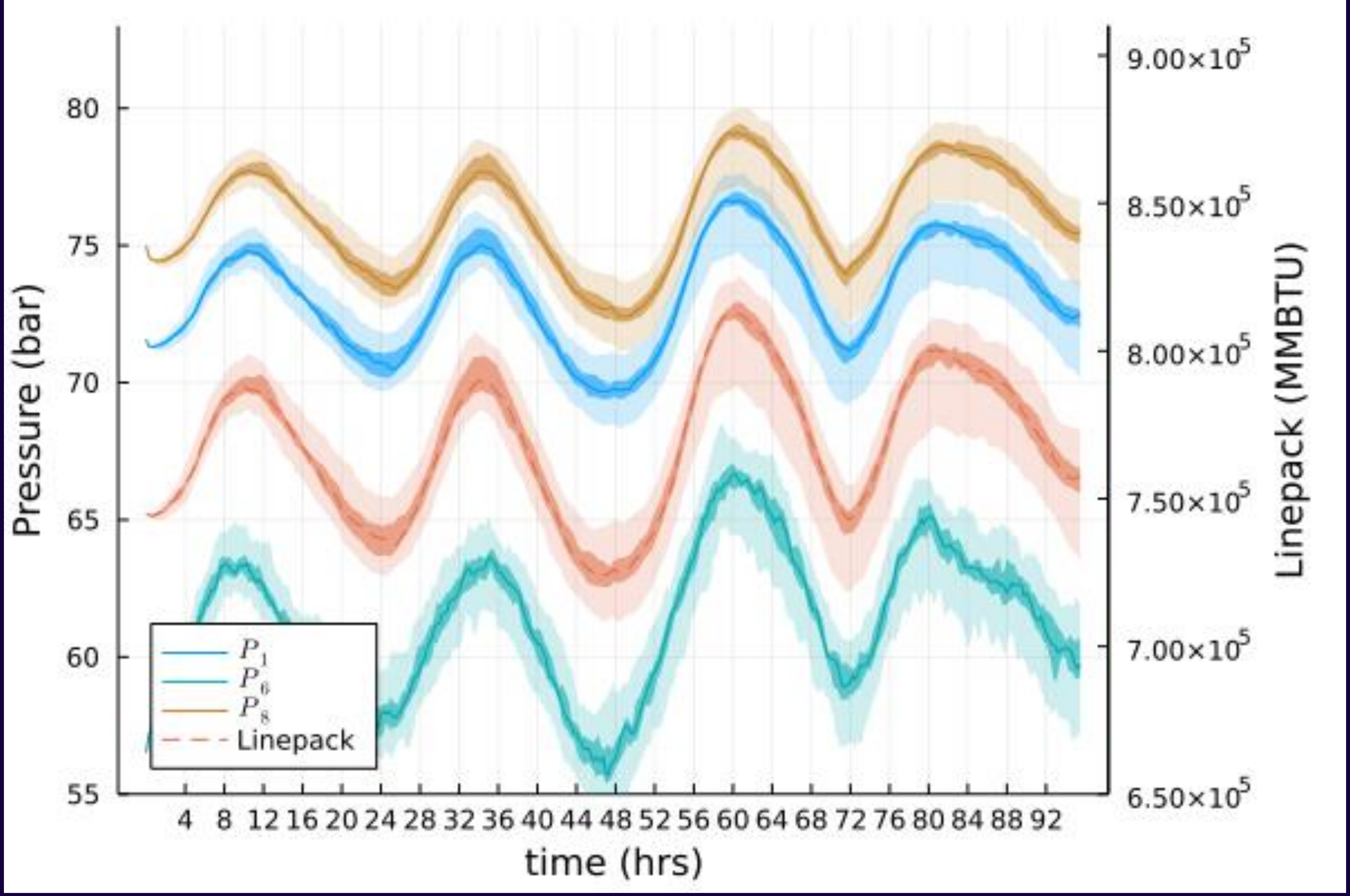
Is an Ornstein-Uhlenbeck process

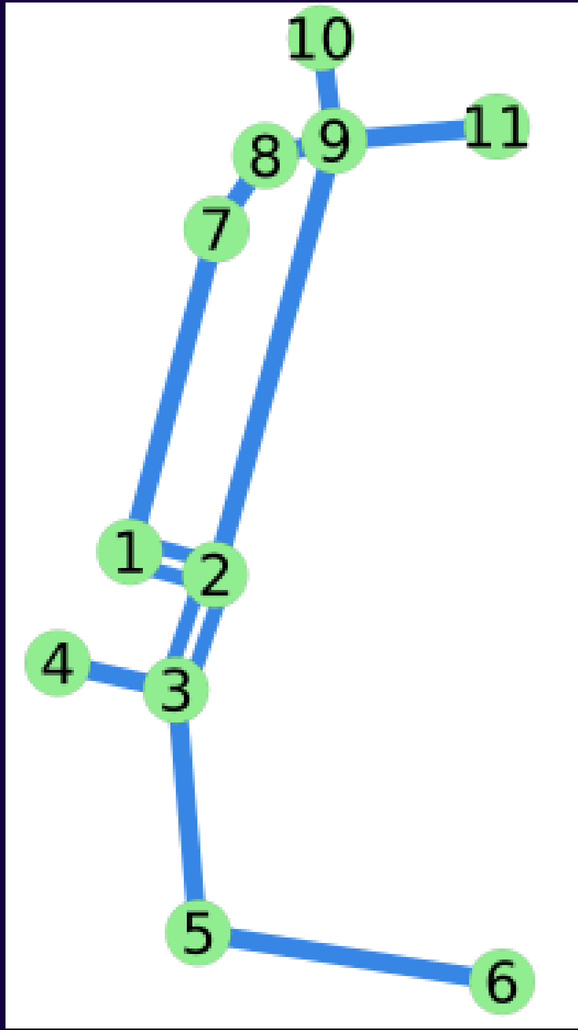
- $E[X_i(t)] = d_i(t)$
- $Var\big(X_i(t)\big) = \frac{\gamma}{2\alpha}(1 - e^{2\alpha t})$
- The parameters were tuned heuristically to ensure the mean was respected, and the variance approaches

$$Var\big(X_i(t)\big) \approx 0.01\mu_i^2$$

with μ_i being the mean withdrawal of node i.

Results: Scenario 2





Distributions of linepack and pressures for random perturbations added to August week

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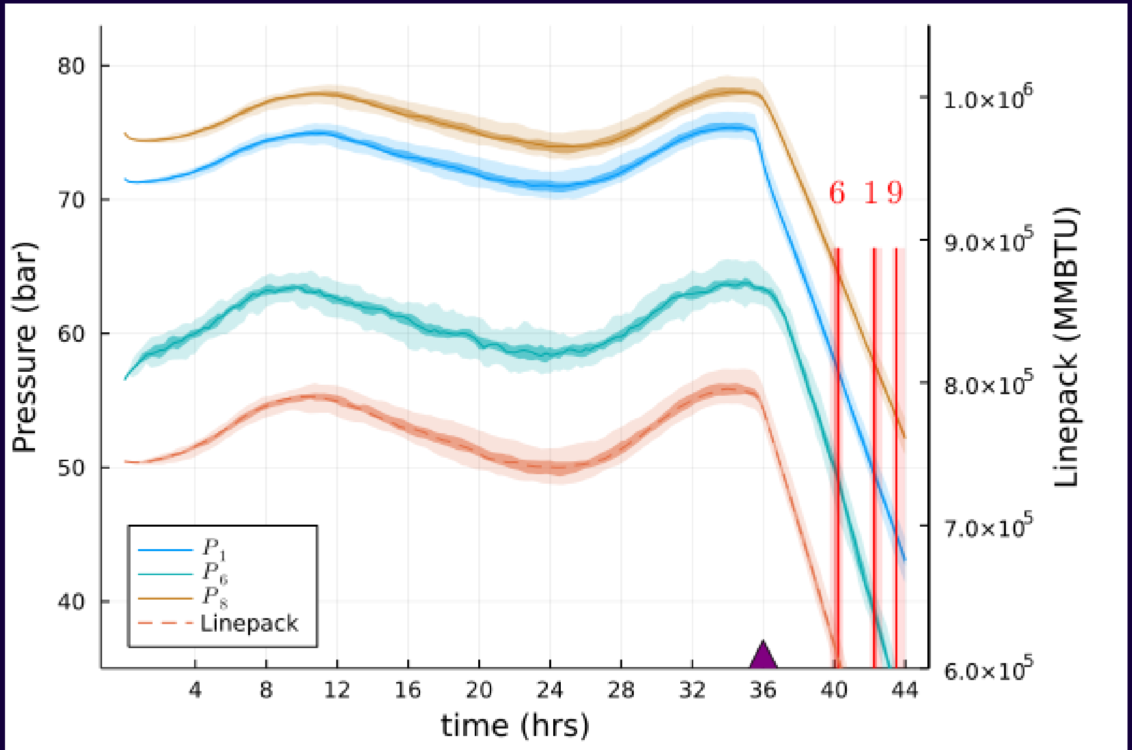
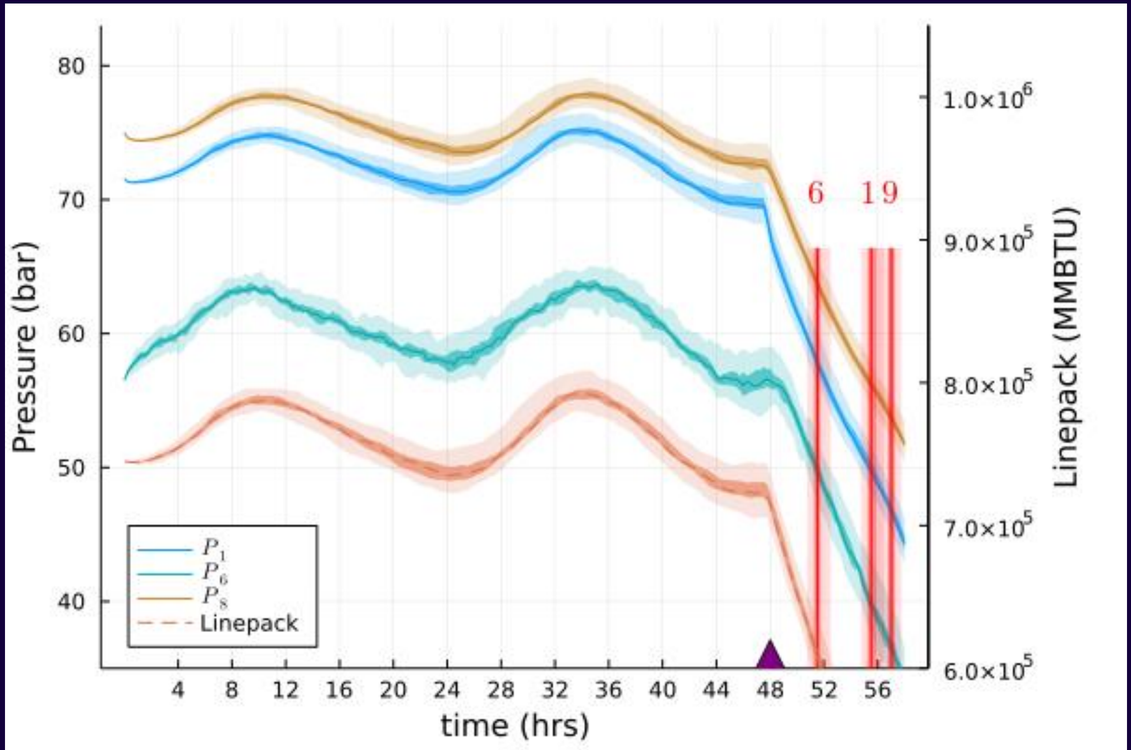
Results: Scenario 3 & 4

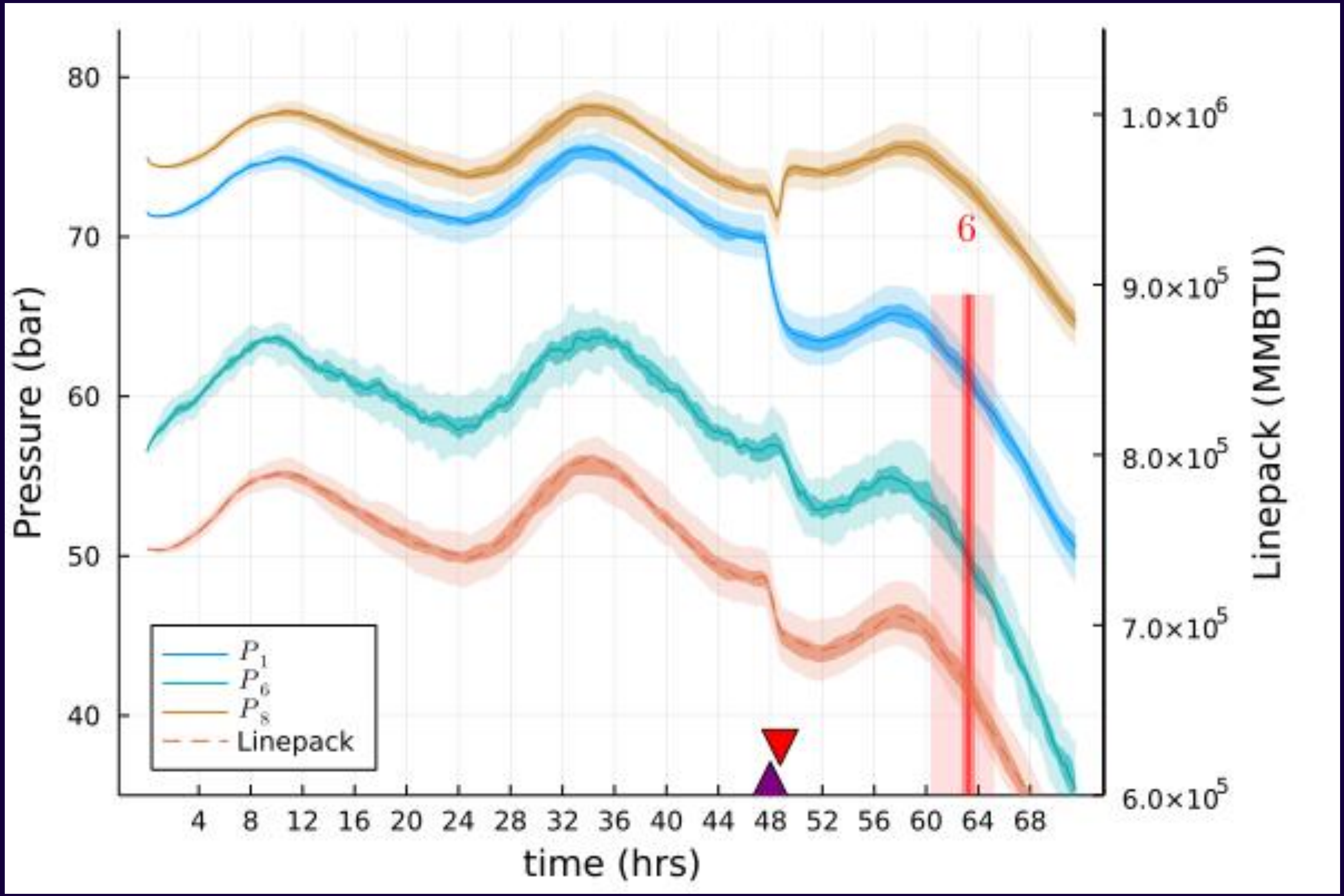


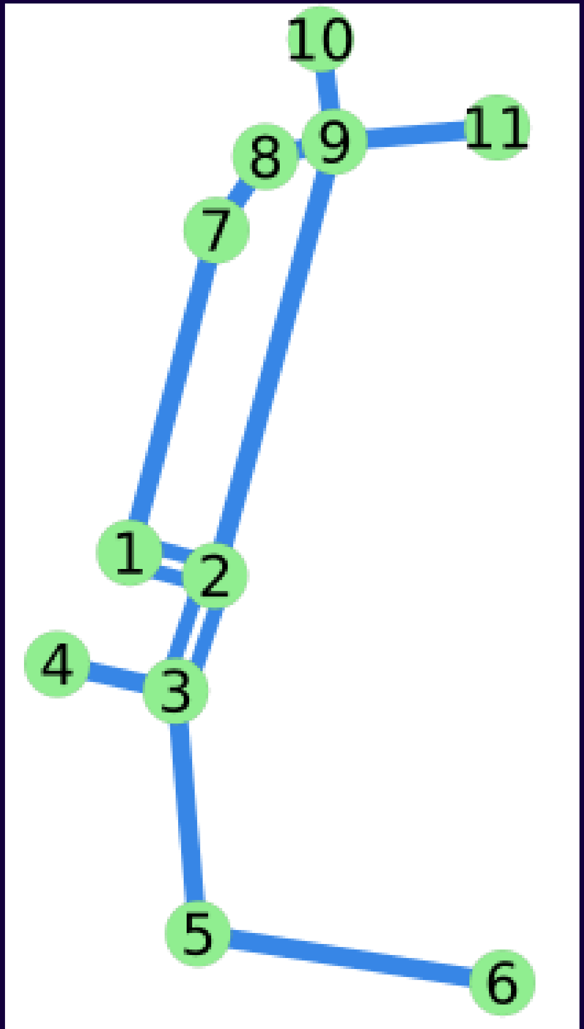


Linepack and pressures responding to loss of supply at node 1. (Left) shows the insult at a peak of intraday linepack, and (right) shows the same insult at the trough.

$\tau = 4.13 \pm 0.38$ hrs $\tau = 3.58 \pm 0.89$ hrs

Results: Scenario 5

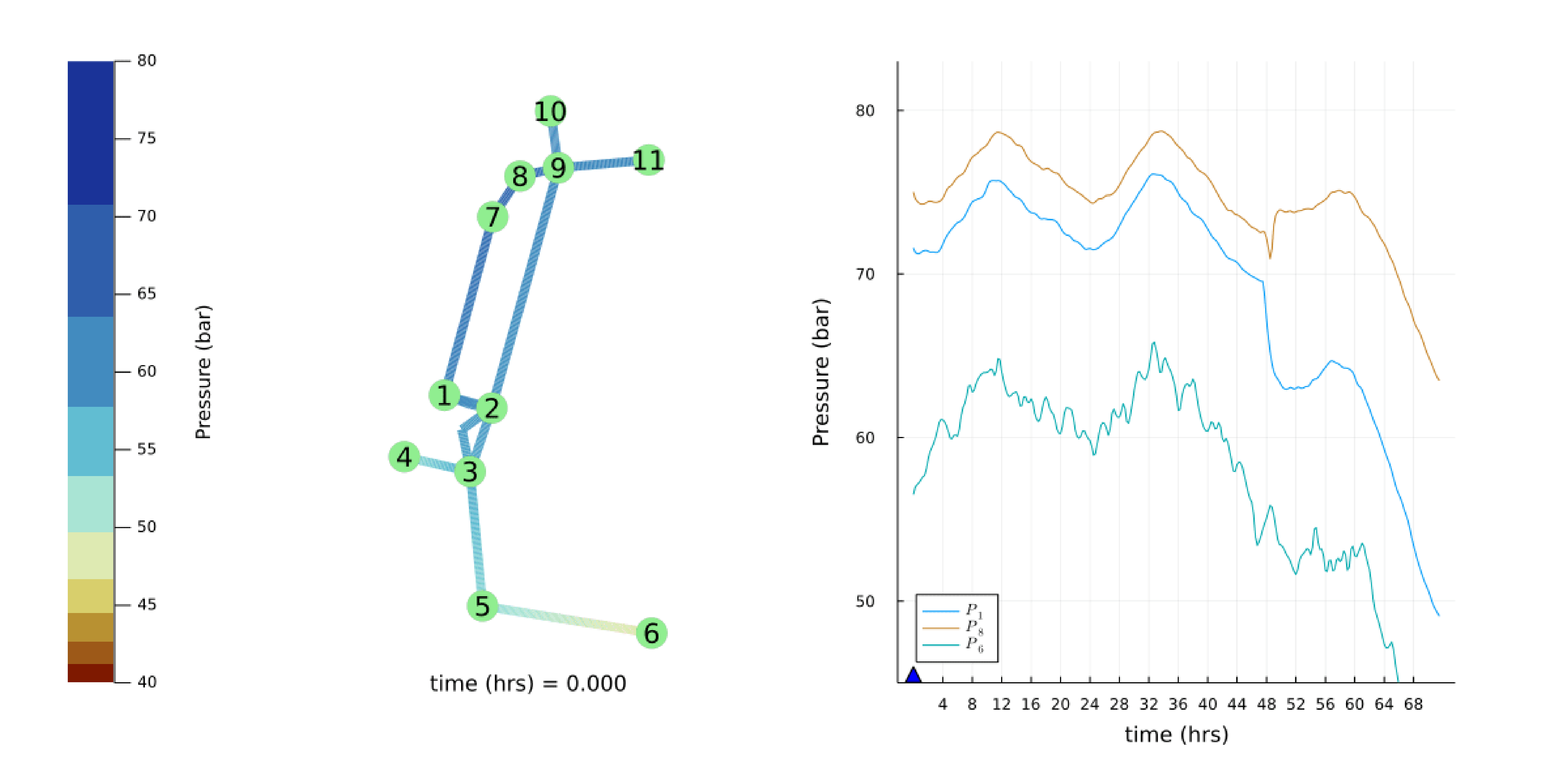




Insult at hour 48, implementing a max-flow control on the remaining supply at node 8

$\tau = 14.17 \pm 4.07$

Results: Scenario 5



Insult at hour 48, implementing a max-flow control on the remaining supply at node 8

$$\tau = 14.17 \pm 4.07$$

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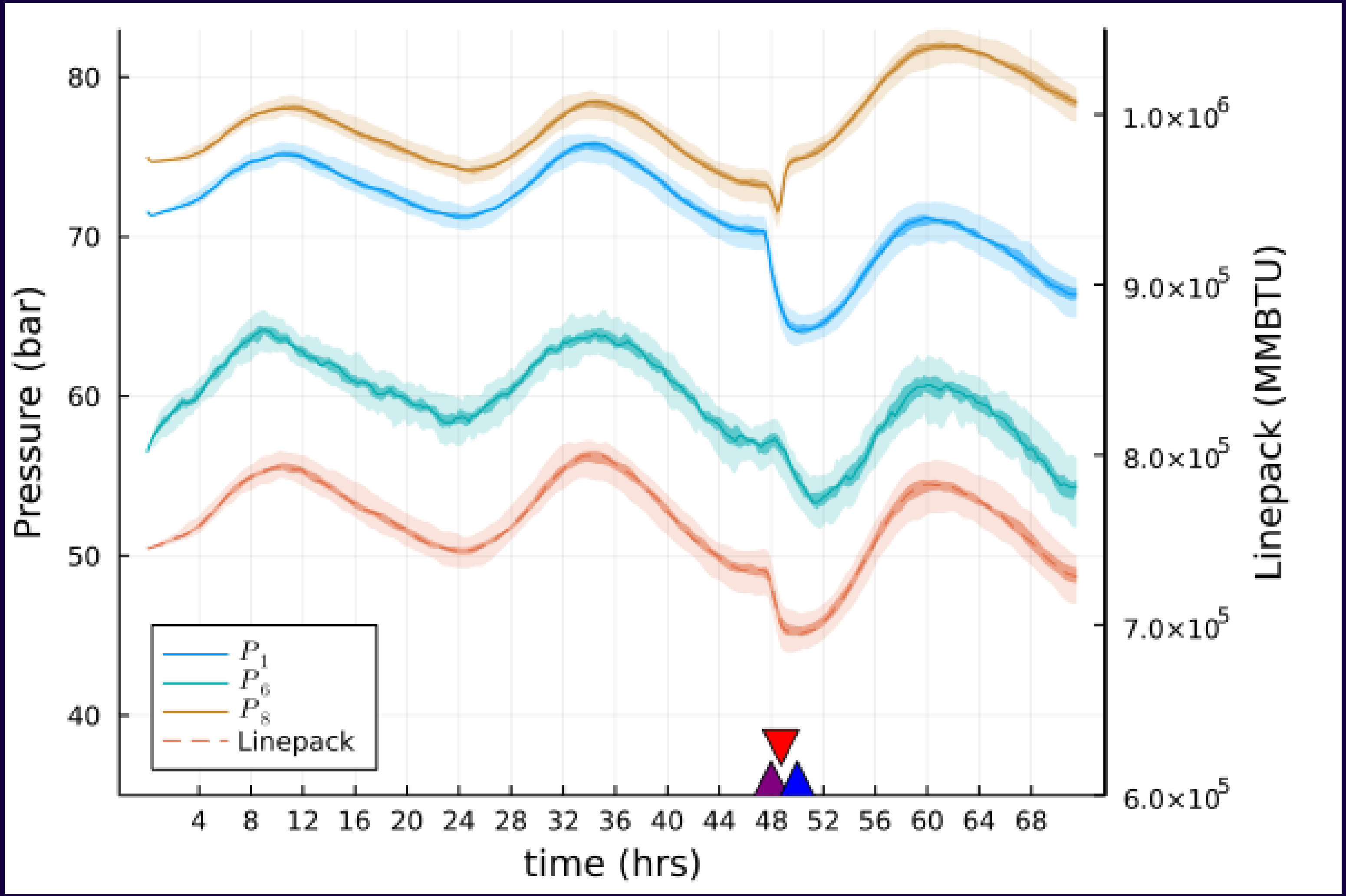
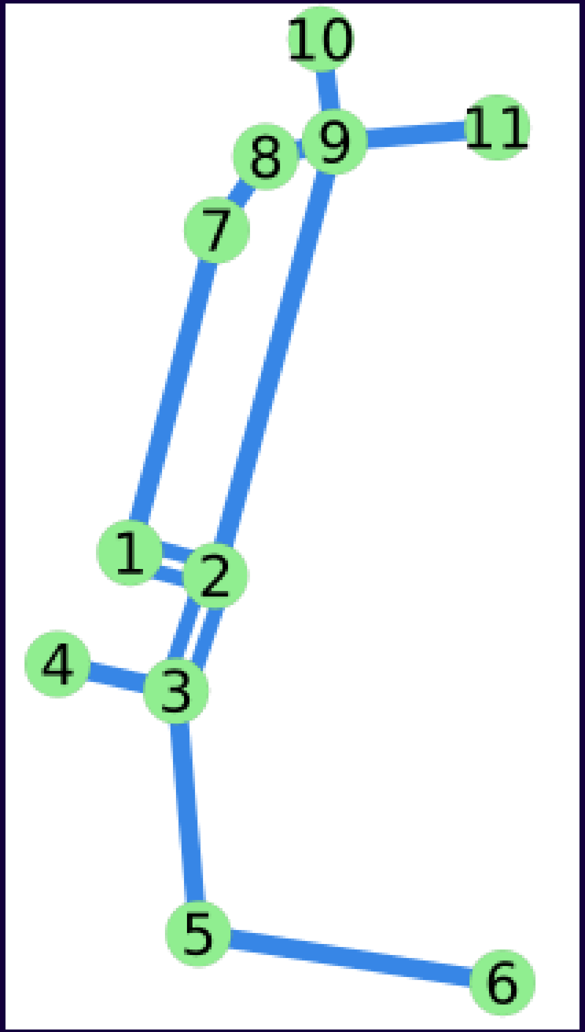
Results: Scenario 6





Insult at hour 48, implementing a max flow control at node 8, and curtailing demand at hour 50.

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Discussion & Future Work

- We investigate the spatiotemporal response of a reduced model of Israel's NG network to prescribed insults and human-in-the-loop controls in order to evaluate robustness and suggest control strategies
- Flux BCs leads to pressures dominated by daily demand, increasingly susceptible to pressure drift from stochastic fluctuations in demand.
- We call out the importance of robustness of the network not simply to insults, but to insults at any time - leading to the idea of "system reserve" being time and spatially dependent.
- Future work will improve on modeling to more completely capture uncertainty propagation through the network, and its influence and interaction with control strategies.

References & Acknowledgments

- The authors are grateful for discussions with Anatoly Zlotnik, Vitaliy Gyrya, and Kaarthik Sundar. CH, LP and MC acknowledge support from UArizona, as well as travel grant from NOGA Israel. CH acknowledges support from NSF's Data-Driven Research Training Grant.

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