INL/CON-22-70182-Revision-0

Coupled Multiphysics Seismic Analysis of and MSR core

November 2022

Chandrakanth Bolisetti, Guillaume Louis Giudicelli, Abdalla Abou Jaoude, Mauricio Eduardo Tano Retamales, Paolo Balestra, Som LakshmiNarasimha Dhulipala

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Idaho National Laboratory

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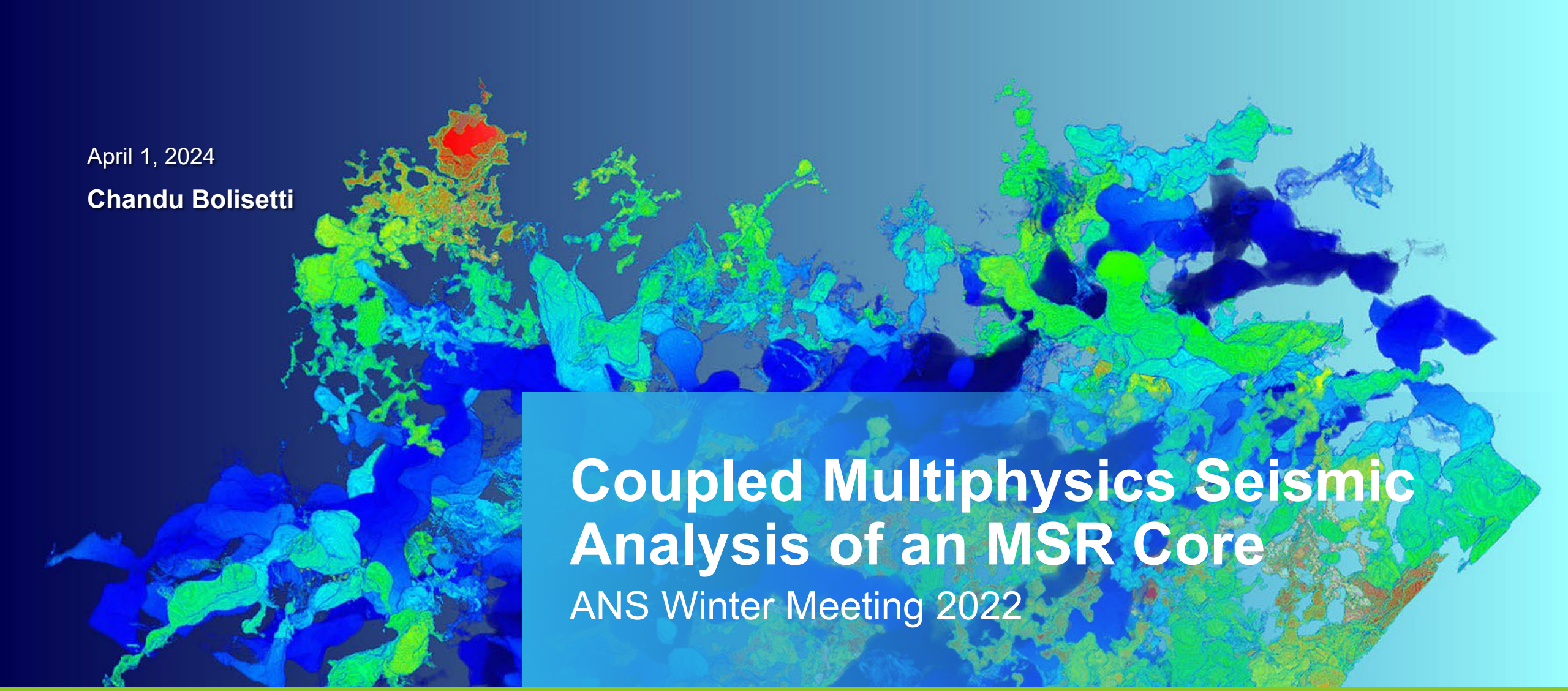

April 1, 2024

Chandu Bolisetti

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ANS Winter Meeting 2022

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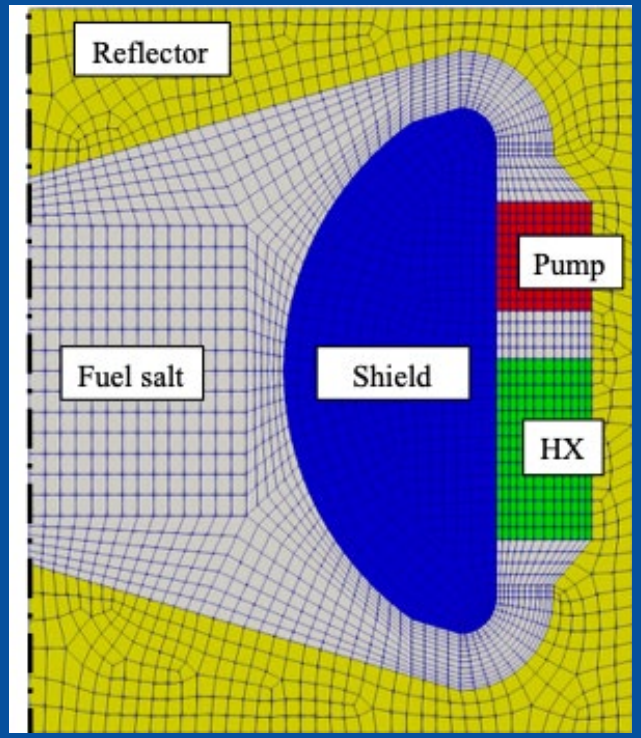
Introduction

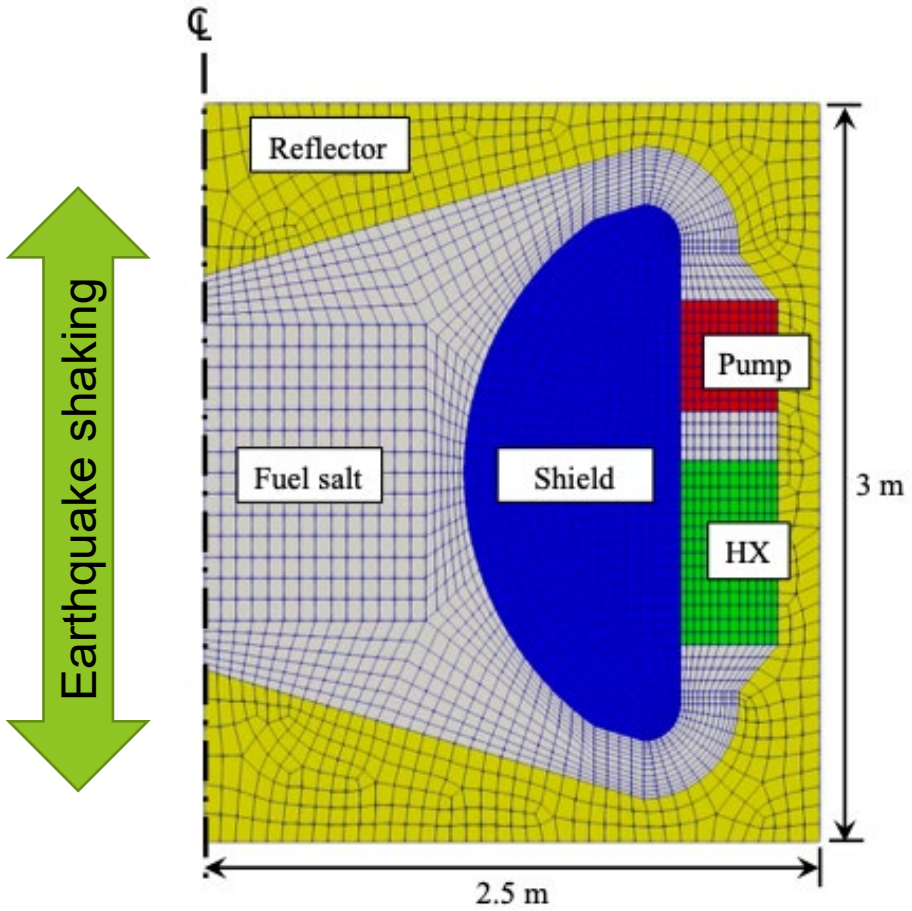
- Goals
  - Enable simulation of MSRs subjected to earthquakes using MOOSE-based Multiphysics software tools
  - Investigate the effect of earthquakes on MSRs
  - Determine the level of Multiphysics coupling needed to calculate the earthquake response
- Funding
  - INL Seed LDRD



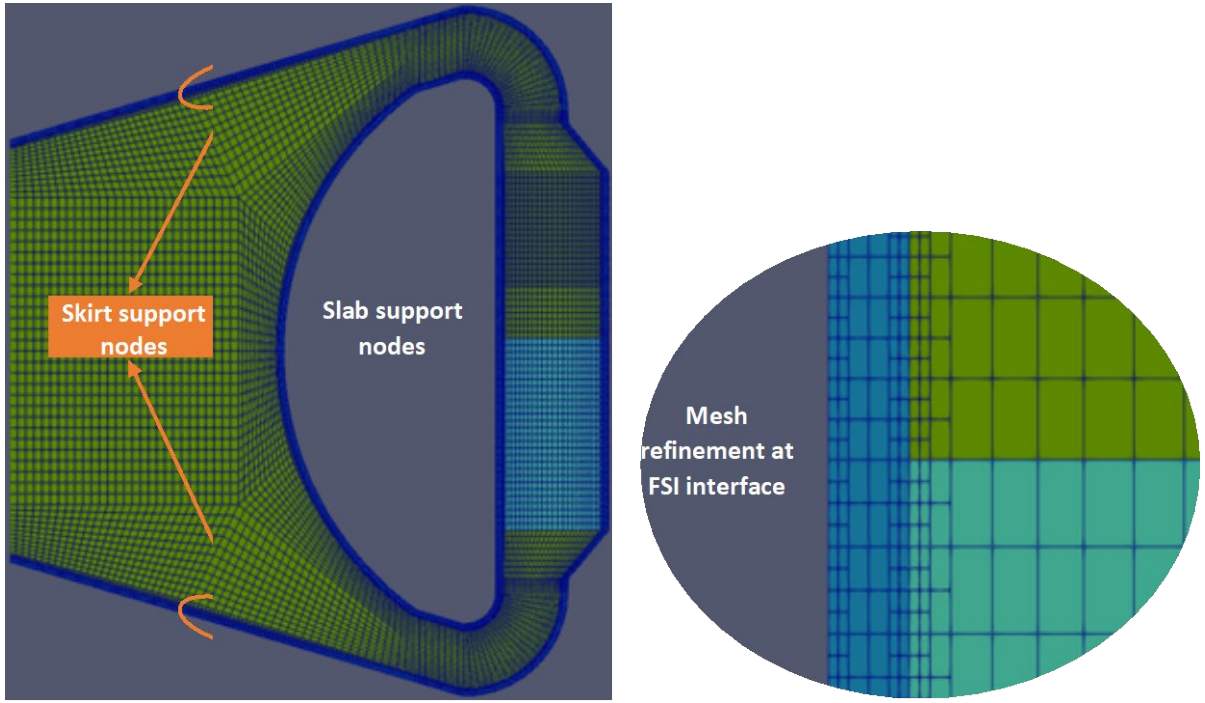
Software and modeling

- NEAMS codes
  - Griffin – Neutronics
  - Pronghorn – thermal hydraulics
- Others
  - MASTODON – seismic analysis
- MSR model
  - SAMOFAR molten salt fast reactor
  - Model borrowed from the Virtual Test Bed (VTB)
  - Seismic multi-physics models may be added to VTB
- TH formulations explored
  - Incompressible (state of practice)
  - Weakly-compressible
  - Weakly-compressible accounting for bubble compressibility
- MASTODON formulation
  - Acoustic wave propagation in the fluid
  - ‘Monolithic’ fluid-structure interaction

MSFR model

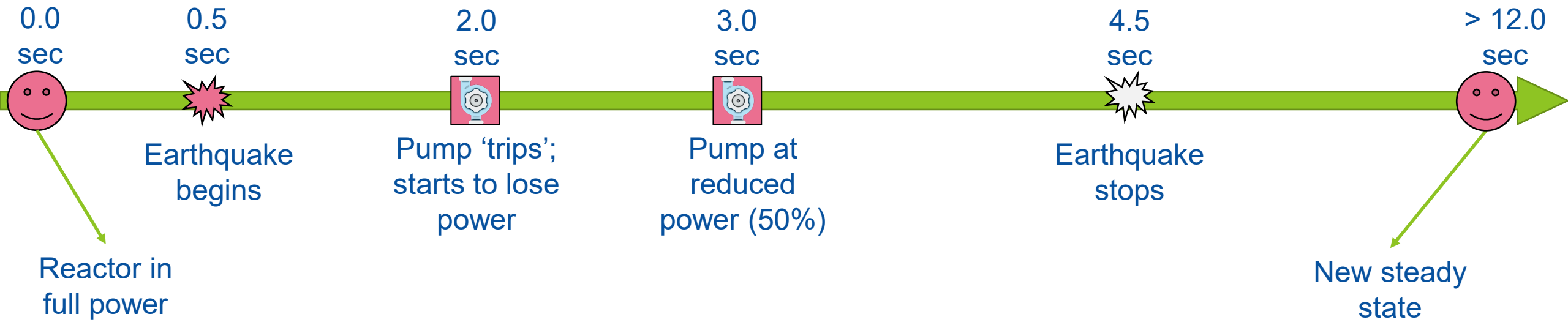


Griffin and Pronghorn models



MASTODON model (simple mechanical design with RV thickness and structural supports developed for this project)

Earthquake scenario timeline

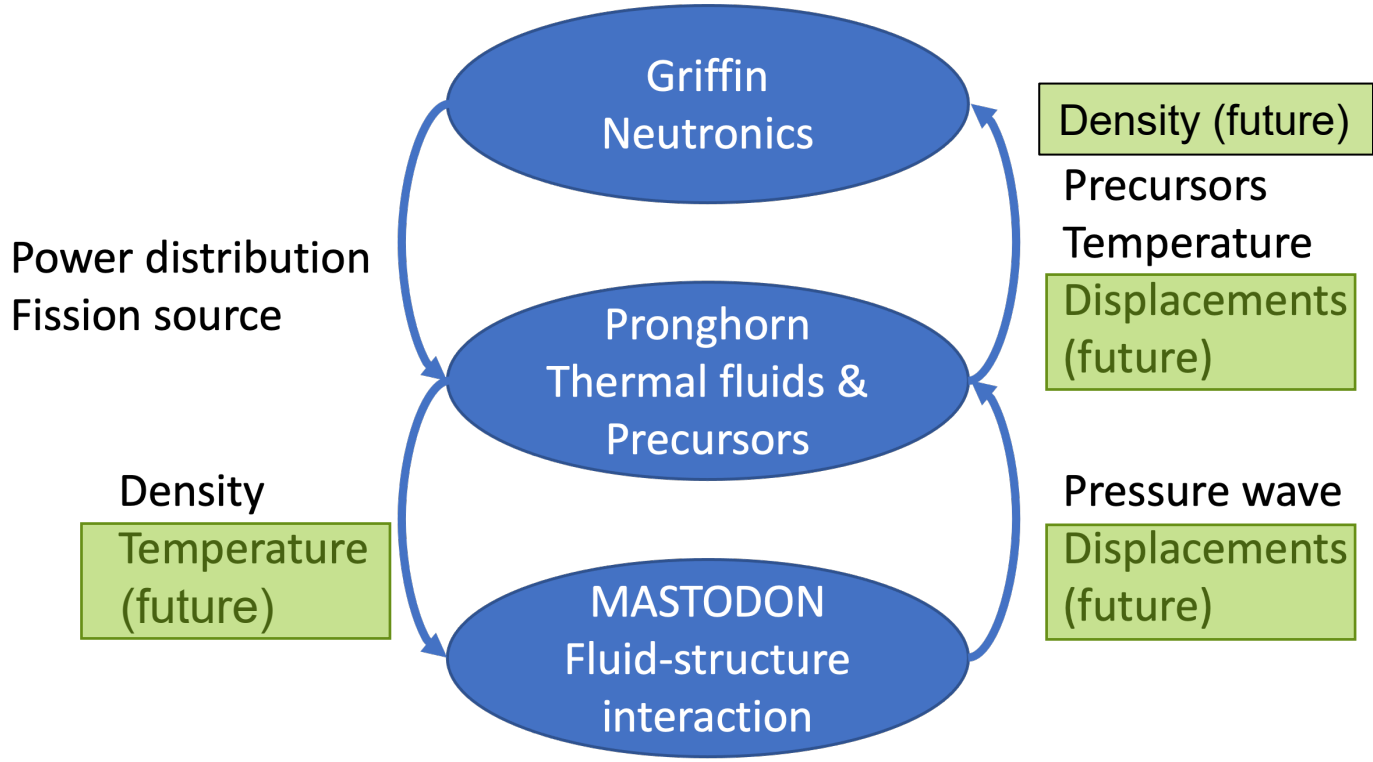


Quantities of interest (QoI)

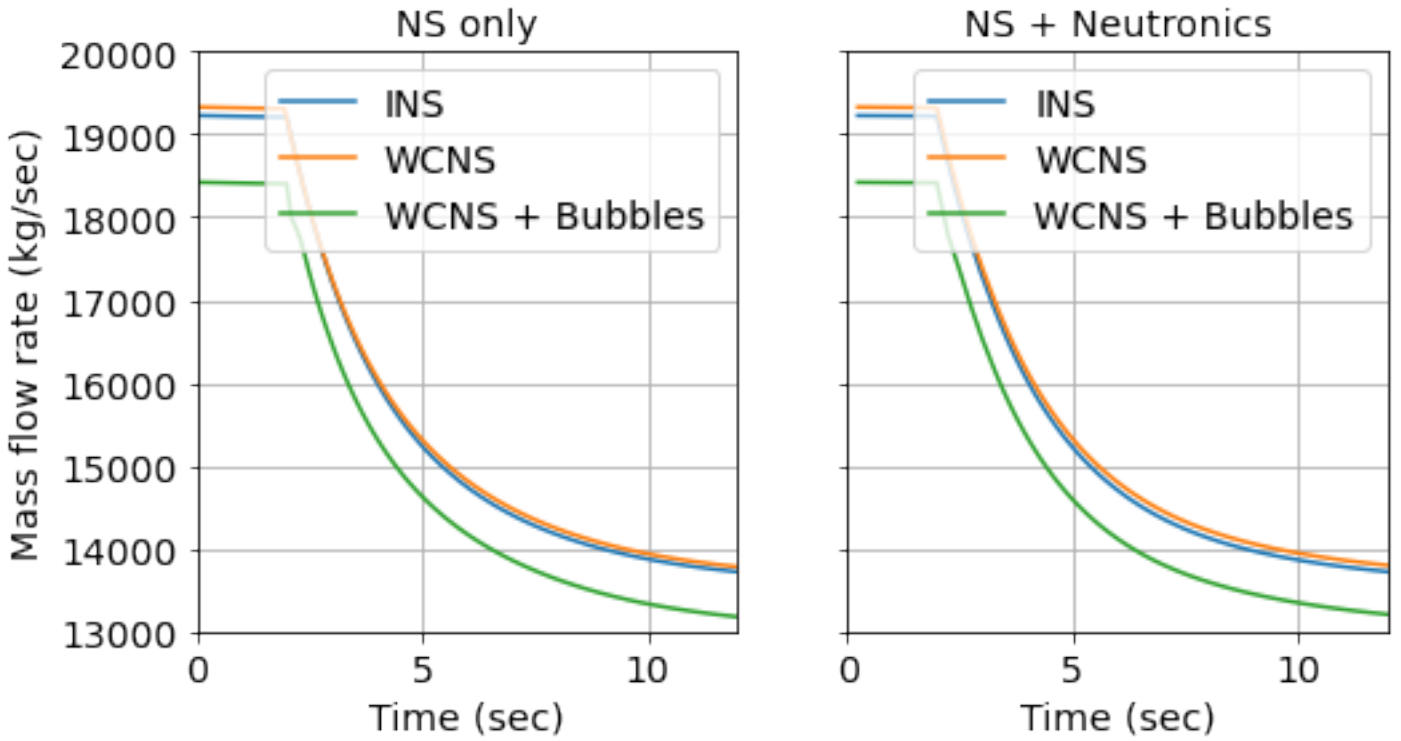
- Reactor power
- Mass flow rate across heat exchanger (HX)
- Maximum Von Mises stress in the reactor vessel (RV)

Multi-physics coupling in MOOSE

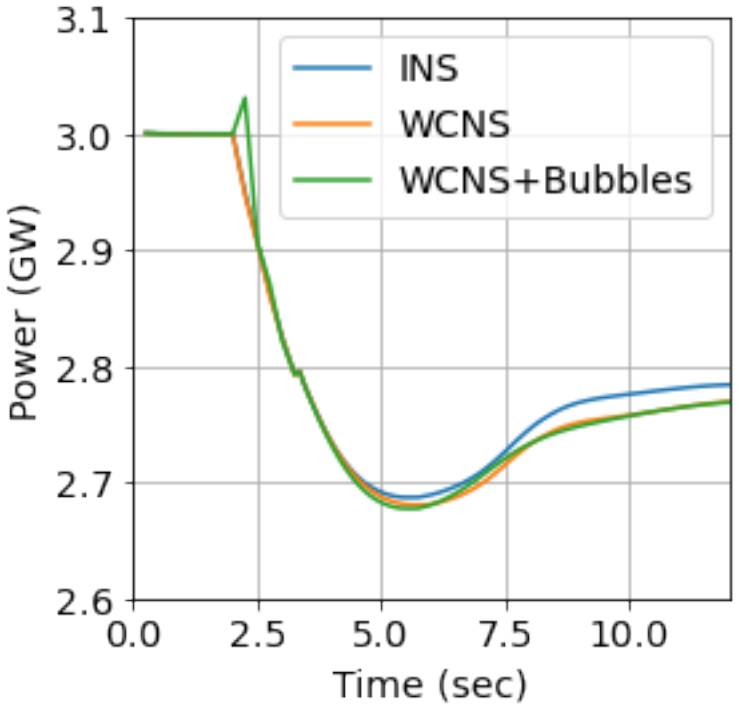
- Uses the MOOSE multi-app system
  - System to couple individual systems that solve different physics
  - In this case, Griffin, Pronghorn, and MASTODON
- Incremental levels of seismic coupling
  - Level 0 – no seismic coupling
  - Level 1 – one-way coupling
  - Level 2 – two-way coupling



Level 0: No seismic coupling

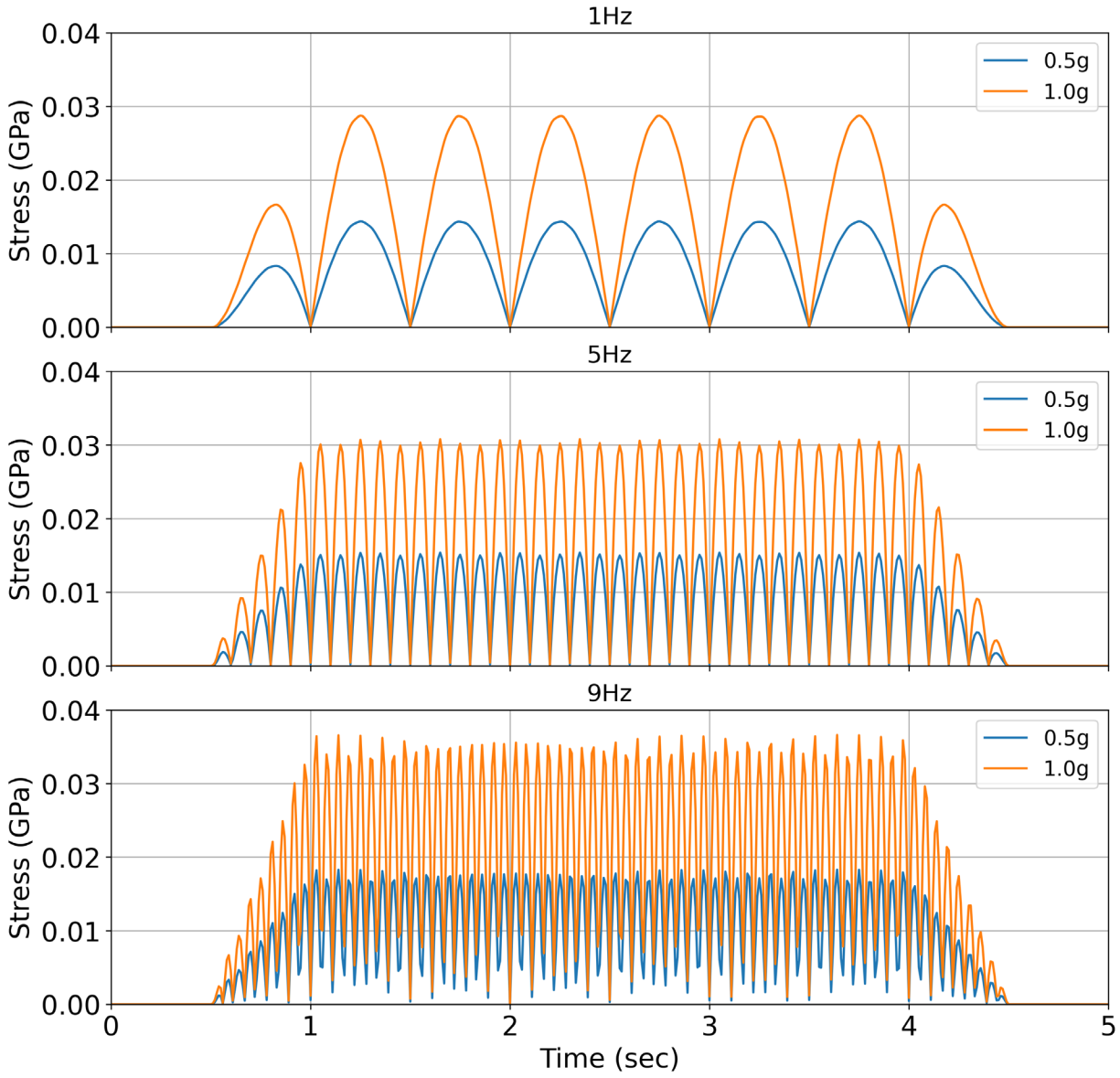


Mass flow rate across the heat exchanger



Power

Level 0: No seismic coupling



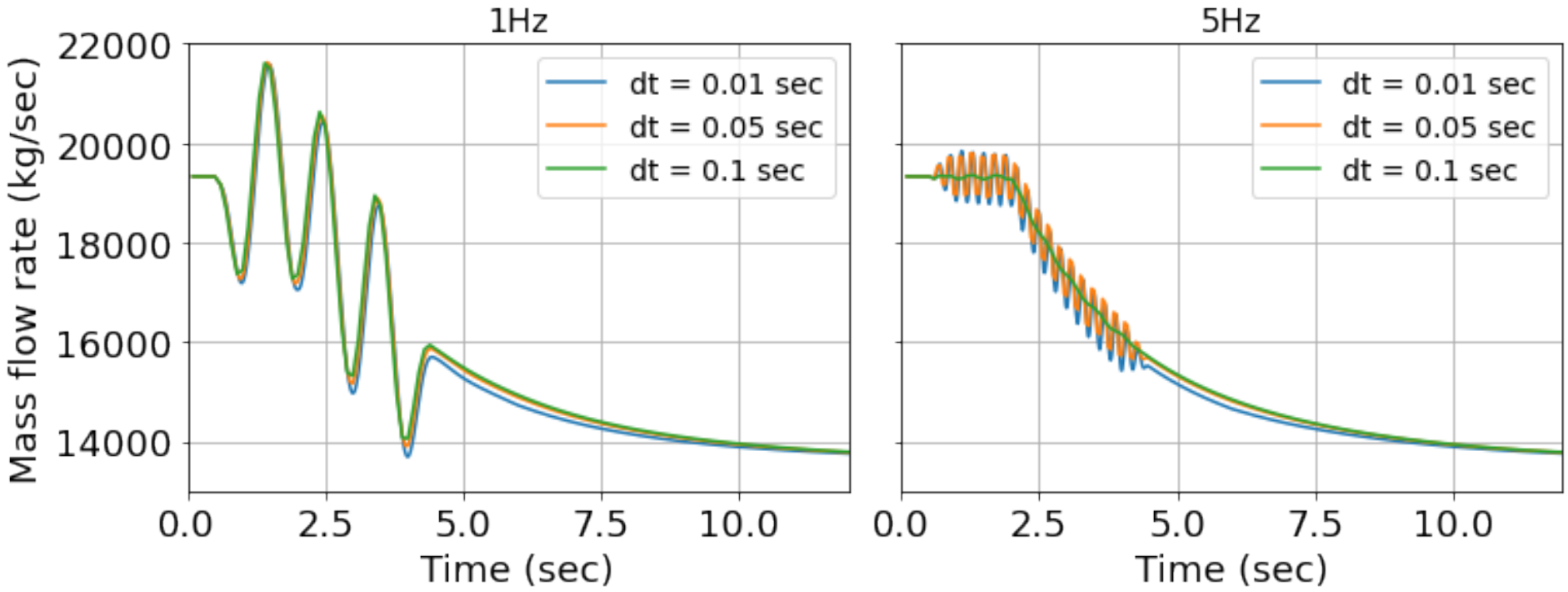
Shaking characteristics

- Simple sinusoidal shaking
- 0.5g, 1.0g
- 1 Hz, 5 Hz, and 9 Hz

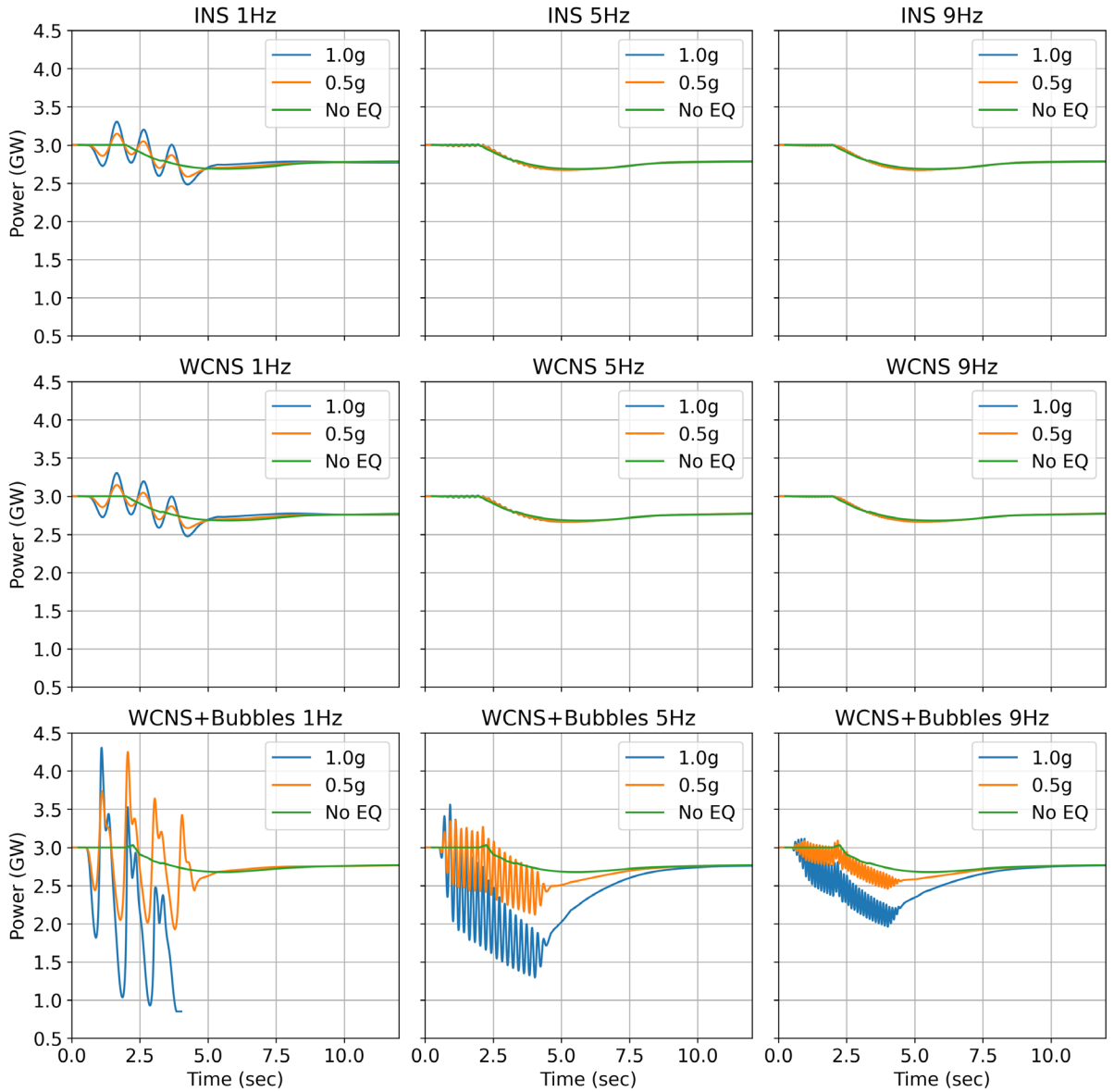
Maximum Von Mises stress in the RV

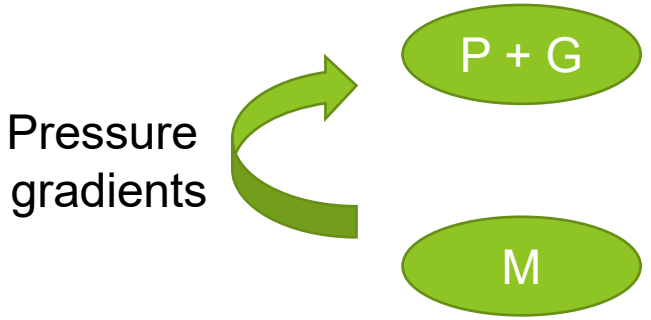
Level 1 coupling: MASTODON to Pronghorn

Sensitivity to dt



Level 1 coupling: MASTODON to Pronghorn + Griffin

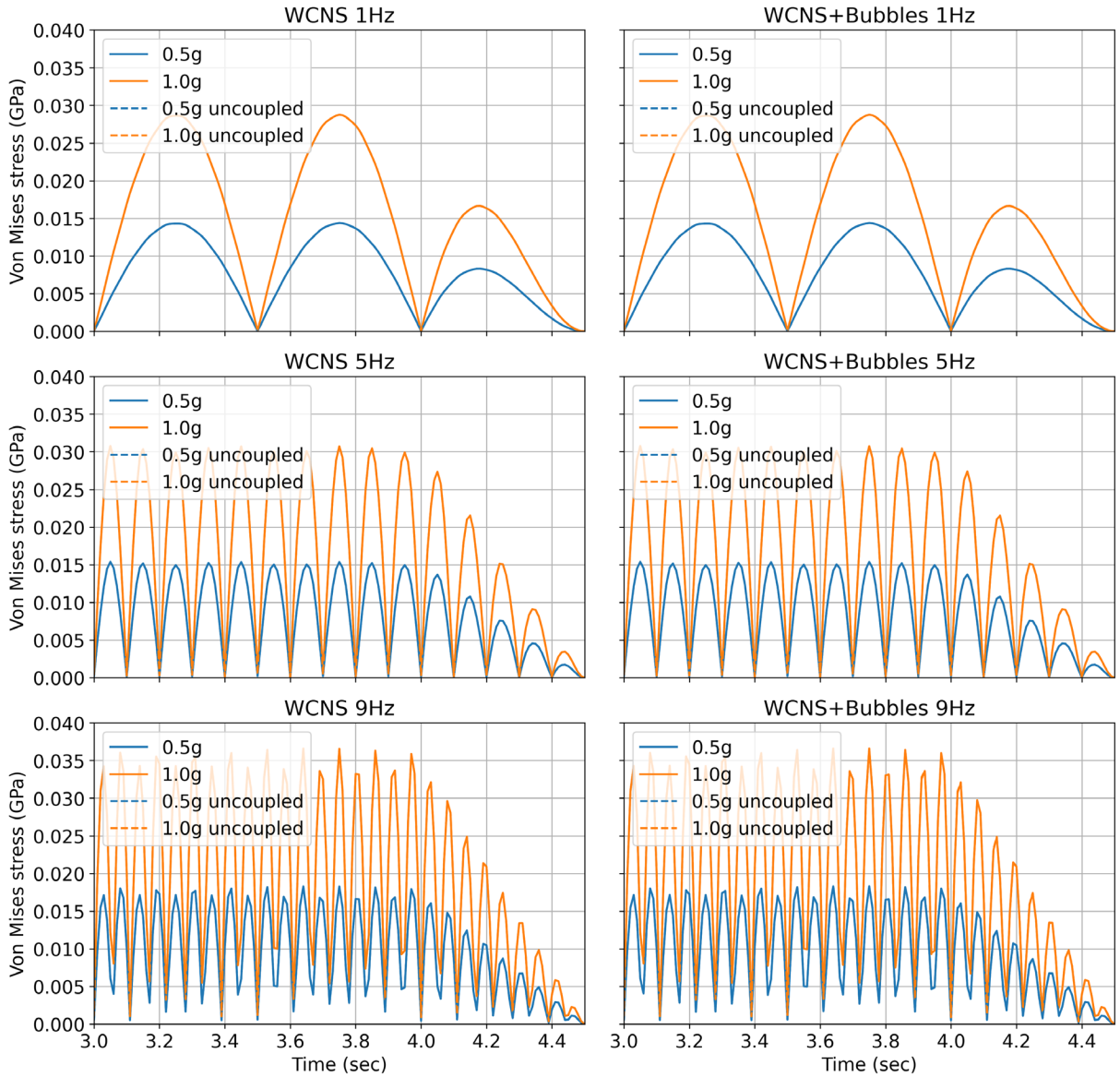


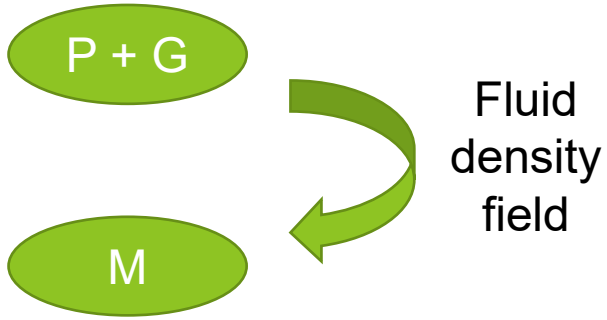


Notable observations

- Sensitivity to lower frequency shaking
- Bubbles formulation is highly sensitive to EQ
- Power gradually decreases during the earthquake
- Steady state is unaffected

Level 1 coupling: Pronghorn + Griffin to MASTODON

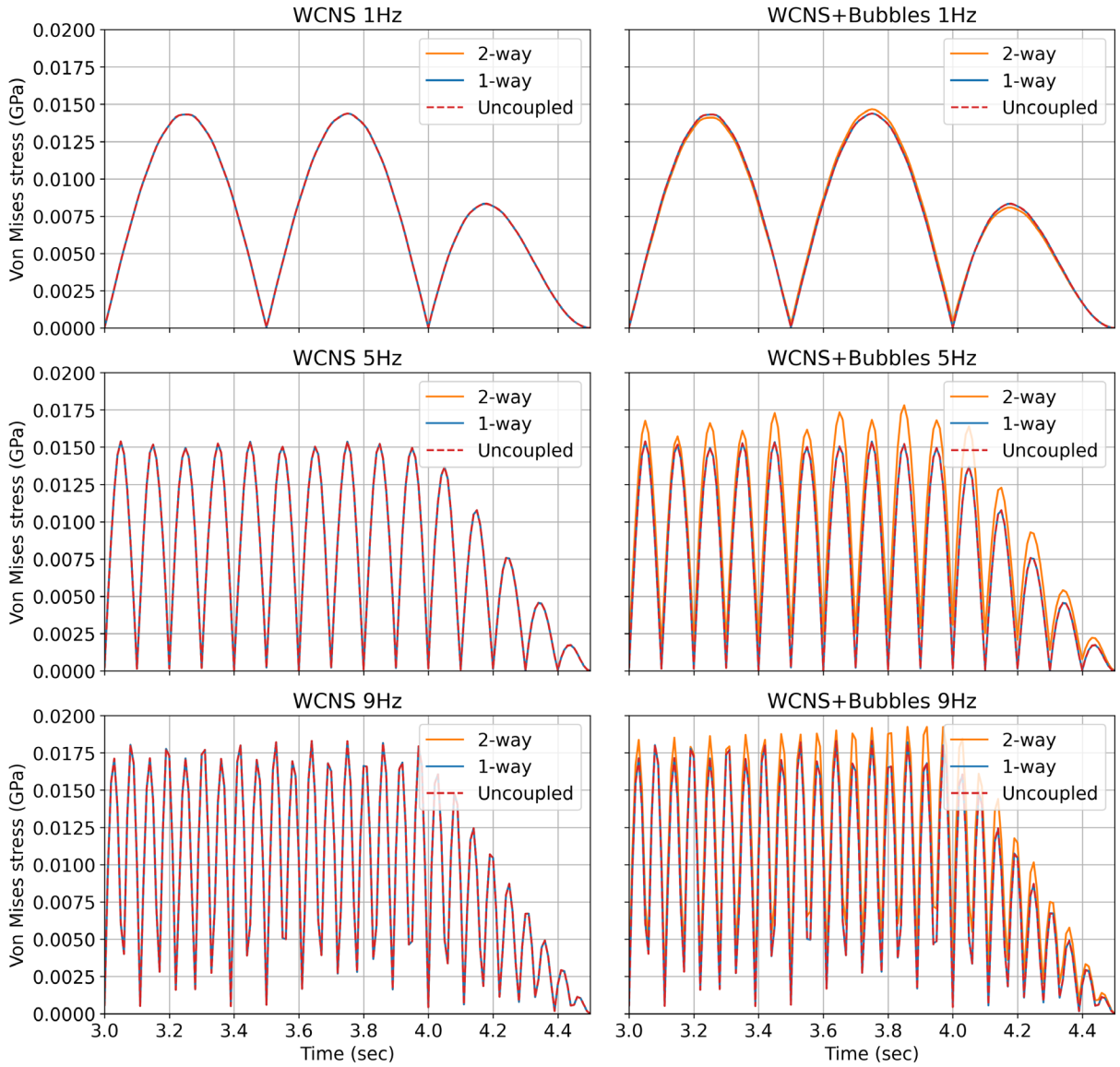




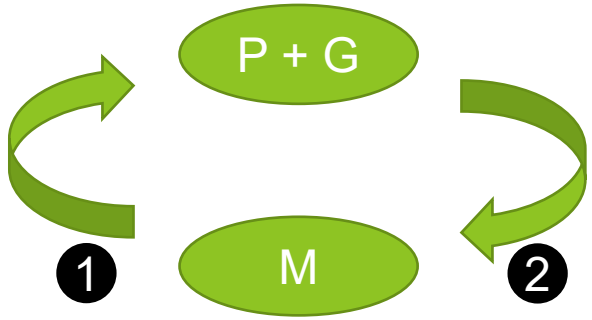
Notable observations

- MASTODON results are unaffected when density distribution due to TH and neutronics is changed
- Therefore, coupling in this direction may not be significant

Level 2 manual coupling: M to P+G to M



Pressure gradients (one transfer)

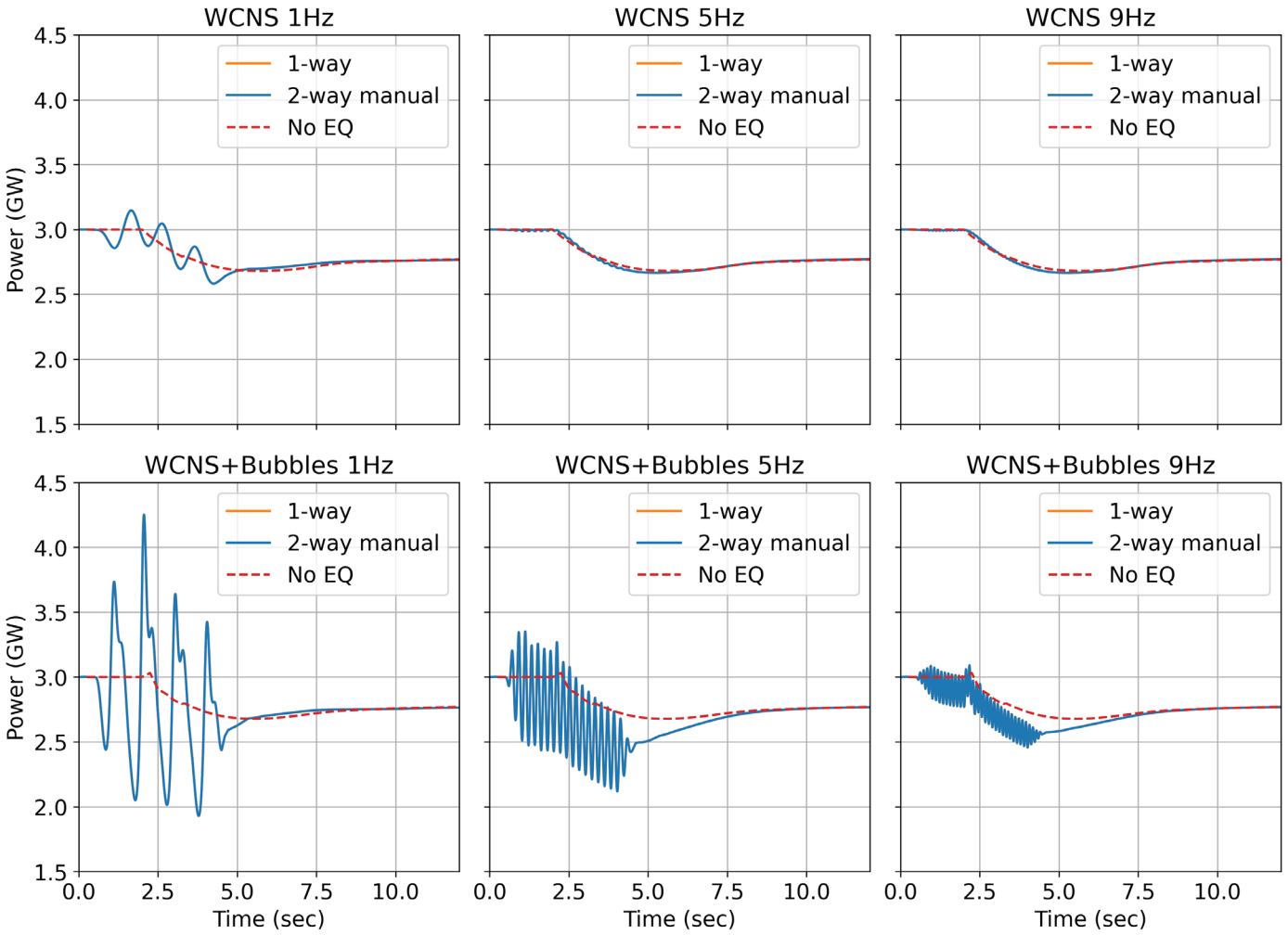


Fluid density field (one transfer)

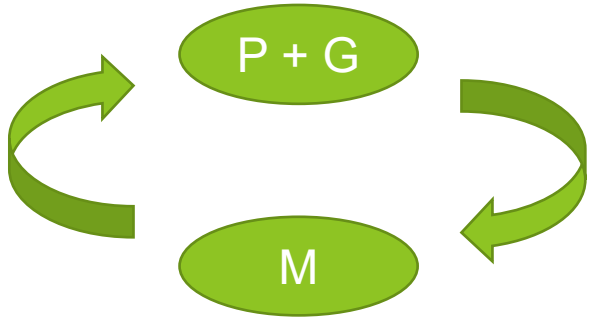
Notable observations

- MASTODON results are now affected by coupling
- Coupling is significant for bubbles formulation but not WCNS

Level 2 manual coupling (M to P+G to M to P+G)



Pressure gradients

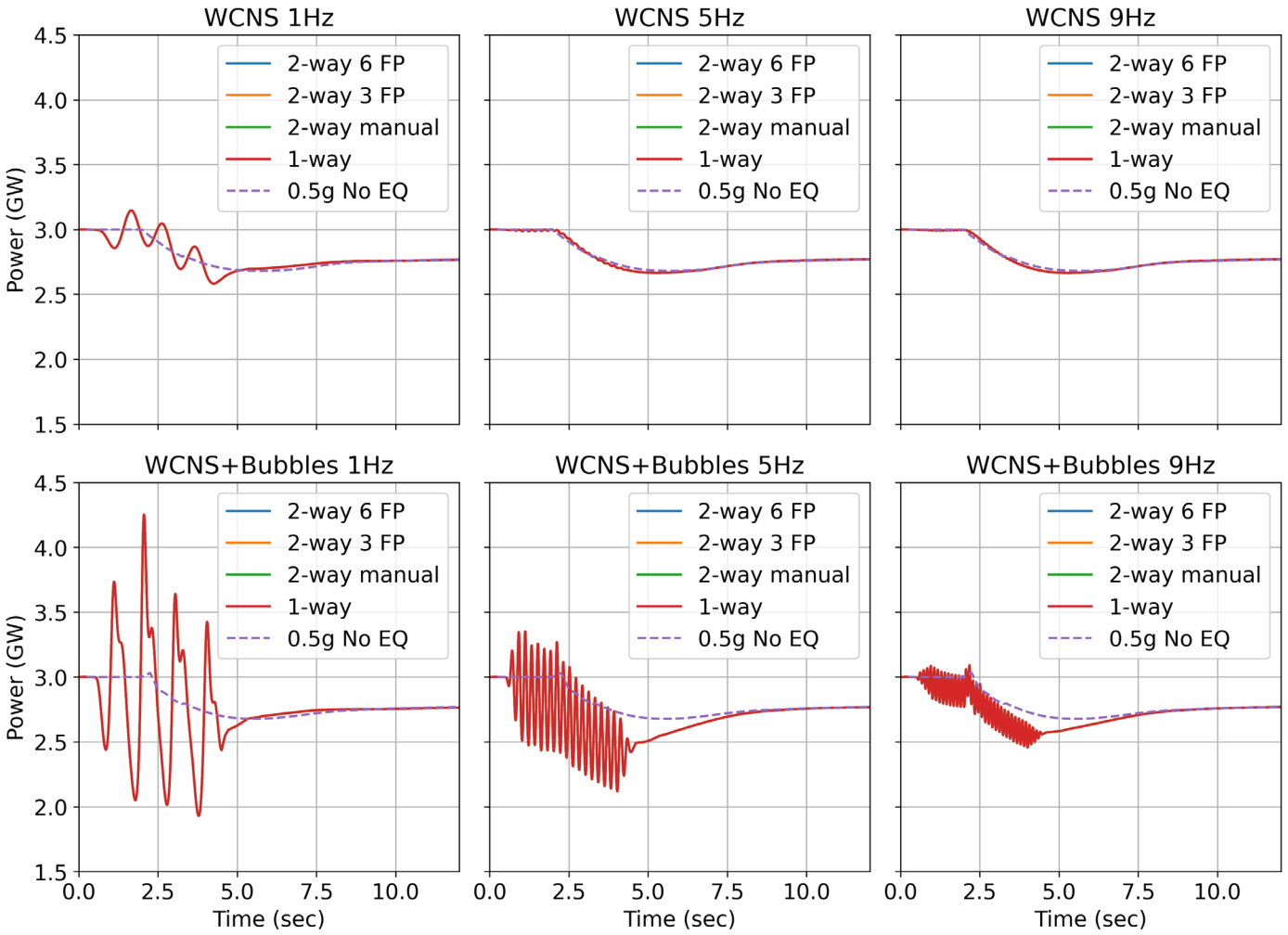


Fluid density field

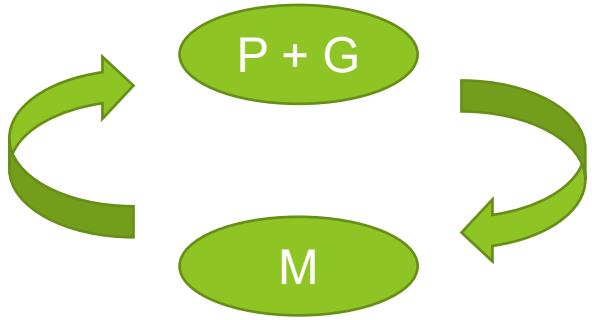
Notable observations

- Results are same as level 1 coupling

Level 2 automatic coupling with Picard iterations



Pressure gradients

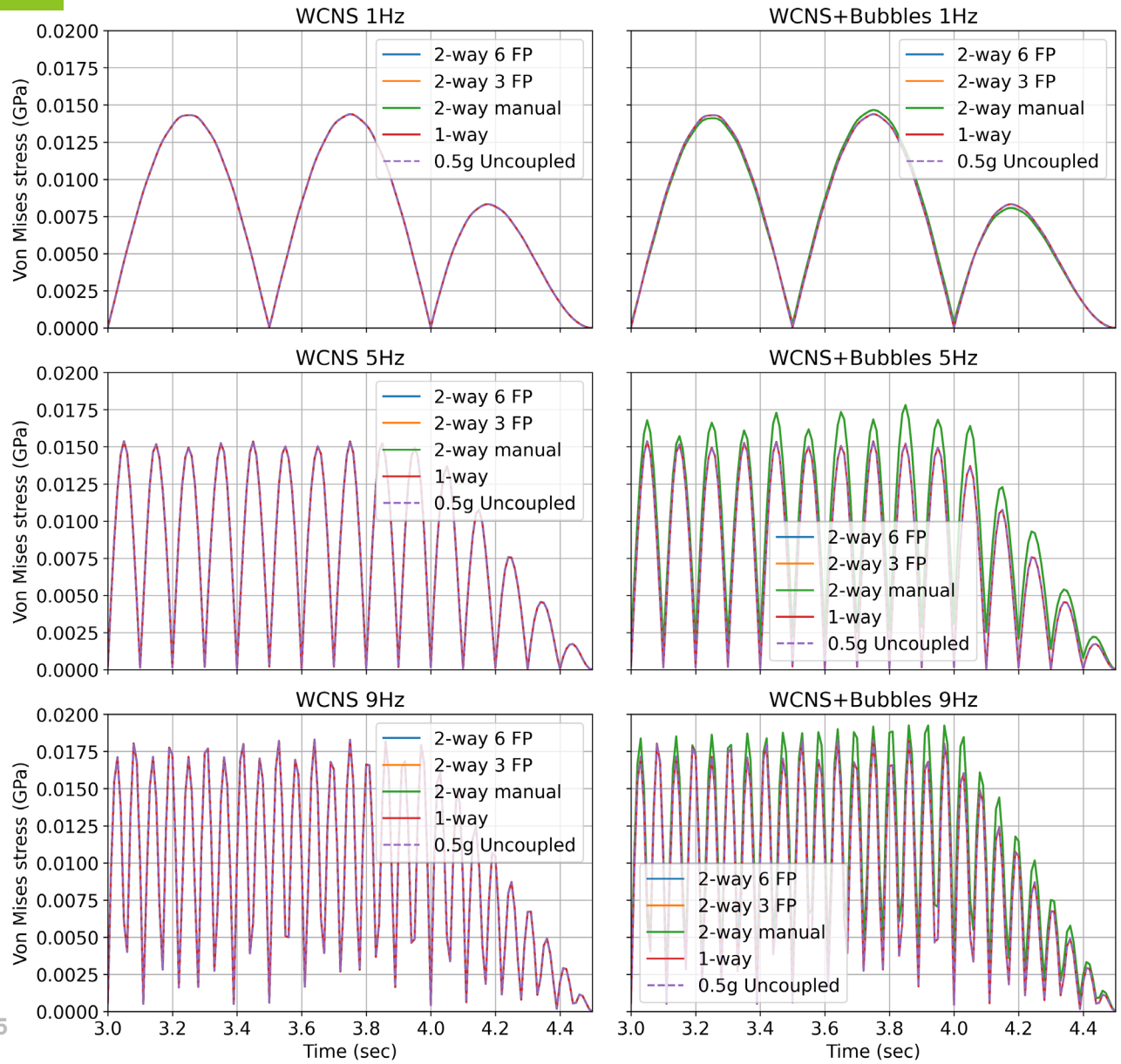


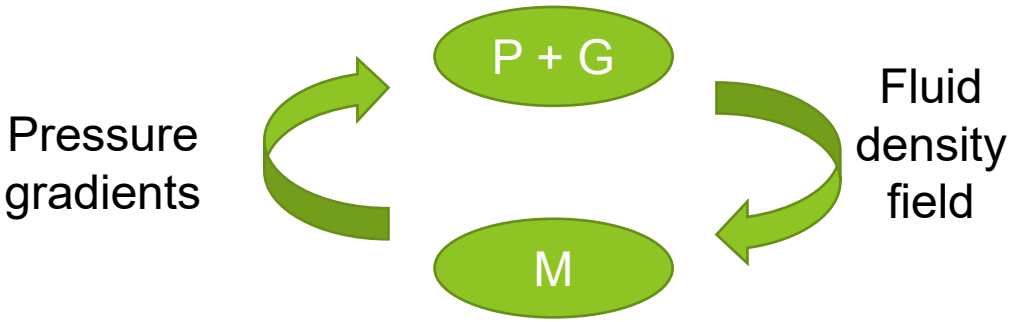
Fluid density field

Notable observations

- Number of fixed-point iterations is not affecting the power
- One transfer from EQ is good enough

Level 2 automatic coupling with Picard iterations





Notable observations

- Number of fixed-point iterations is not affecting the max VM stress
- One loop feedback from EQ back to EQ is good enough

Closing remarks

- Likely that one-way coupling from MASTODON to Pronghorn + Griffin is sufficient
- Important sensitivities discovered
  - Low frequency earthquakes (counter-intuitive from a structural engineering perspective)
  - Bubbles (implications for bubble removal maintenance and for reactivity control mechanisms involving bubble introduction)
  - 2 FPs might be sufficient to capture both (using current formulations)
- Future work
  - Improved bubbles model; sensitivity to pump force and bubble fraction
  - Effect on natural convection (zero pump force)
  - 3D model with horizontal and vertical earthquakes, real earthquakes
  - Full coupling

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