

# Collecting Transient Two-phase Flow Data from Periodic Oscillations

Caleb S. Brooks and Taiyang Zhang

Presented at the Multiphase Flow Science Workshop  
August 1<sup>st</sup>, 2023

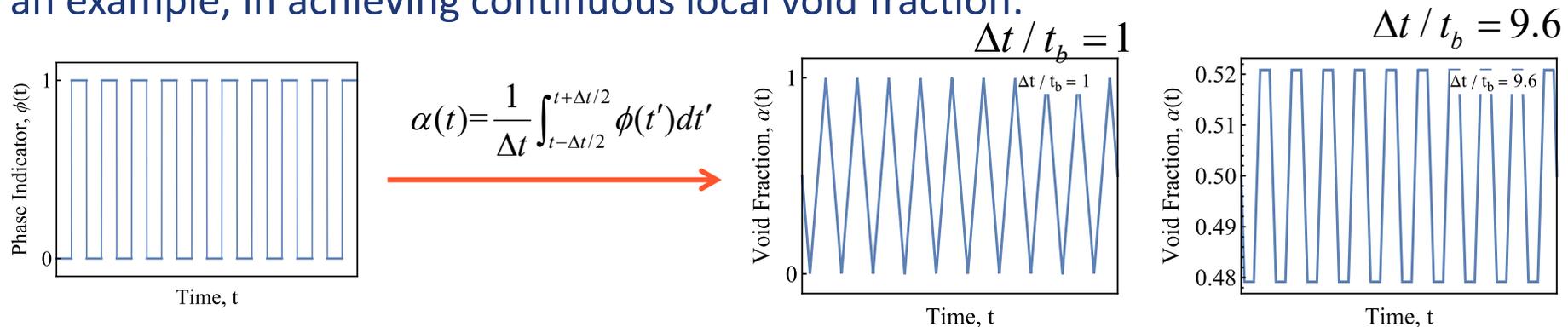


UNIVERSITY OF  
**ILLINOIS**  
URBANA - CHAMPAIGN

# Introduction – Two-phase flow and its statistical description

Two-phase flow is stochastic and complex with small-scale randomness and discontinuity. Its deterministic and continuous description are derived through *averaging which extracts the mean and removes the discontinuity.*

- Theoretically, **this is not a weak assumption.** For a single realization, the time averaging alone only rigorously removes discontinuity when the average window reach infinity.  $\Delta t \rightarrow +\infty$
- As an example, in achieving continuous local void fraction:

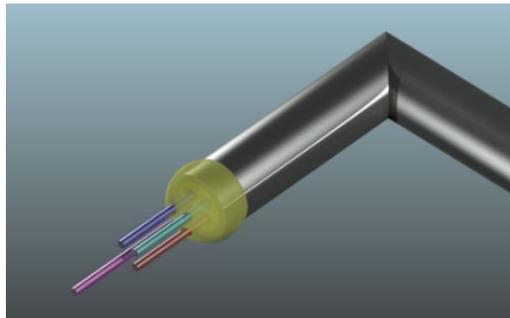


- *The deterministic, continuous, and differentiable description of two-phase flow is based on the requirement of **sampling sufficiency.***

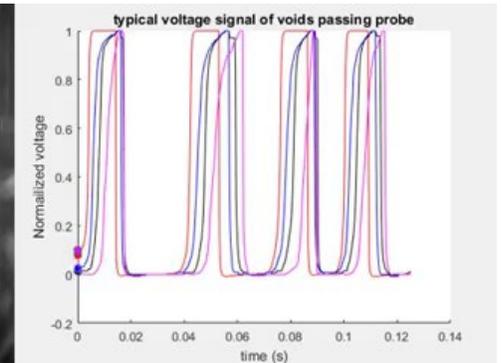
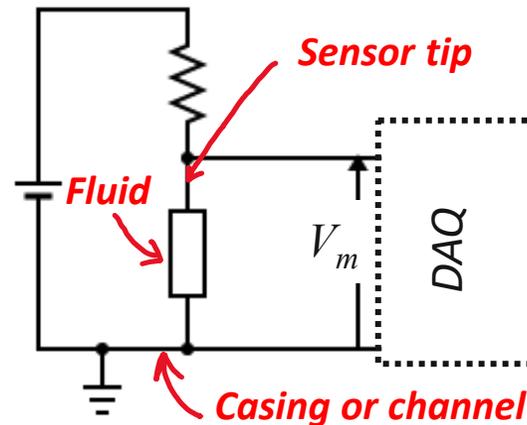
# Introduction – Sampling sufficiency requirements in experiments

*Two-phase measurements* face the similar requirements of *sampling sufficiency*.

- For the current presentation, the conductivity probe is discussed.



Casing size:  $O(1 \text{ mm})$   
Sensor size:  $O(100 \mu\text{m})$

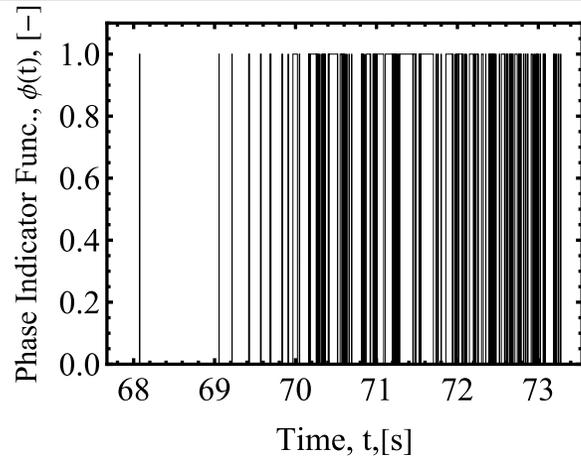
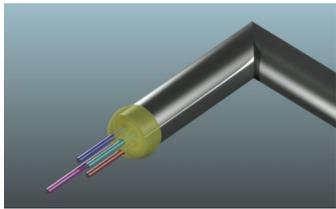


- Reliable measurements of two-phase parameters requires *thousands of bubble counts*. This leads to a typical measurement duration of  *$O(1 \text{ min})$* .

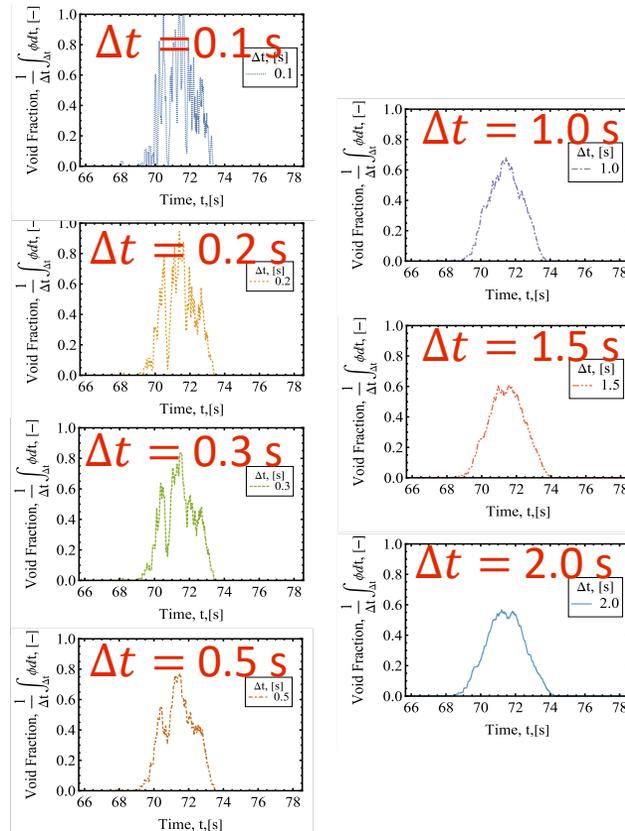
# Introduction – Limitation of time-averaging in a single realization

During a single realization of a fast transient, smoothness and convergence for local two-phase measurement might only be met with a large running-average window.

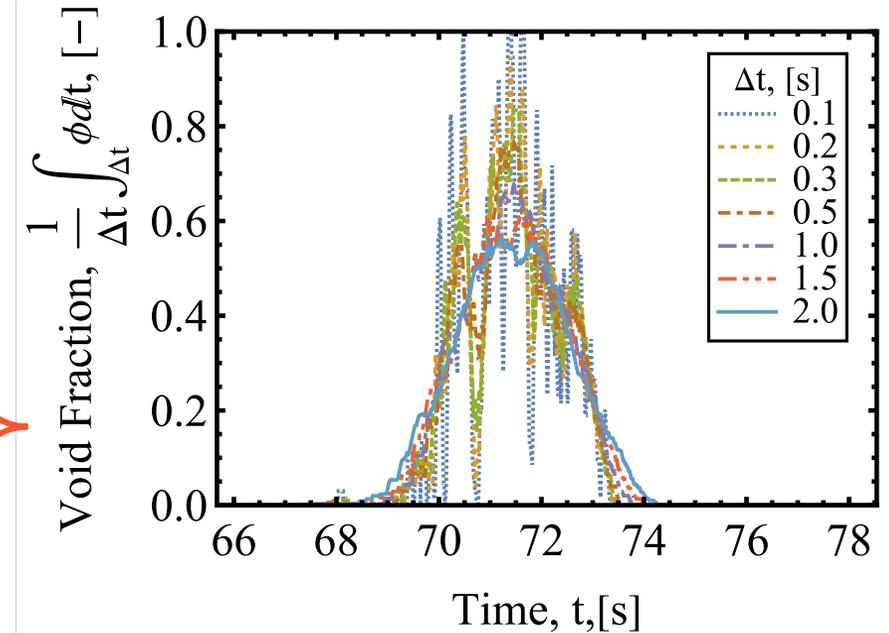
## Point Measurement



Phase Indicator Function



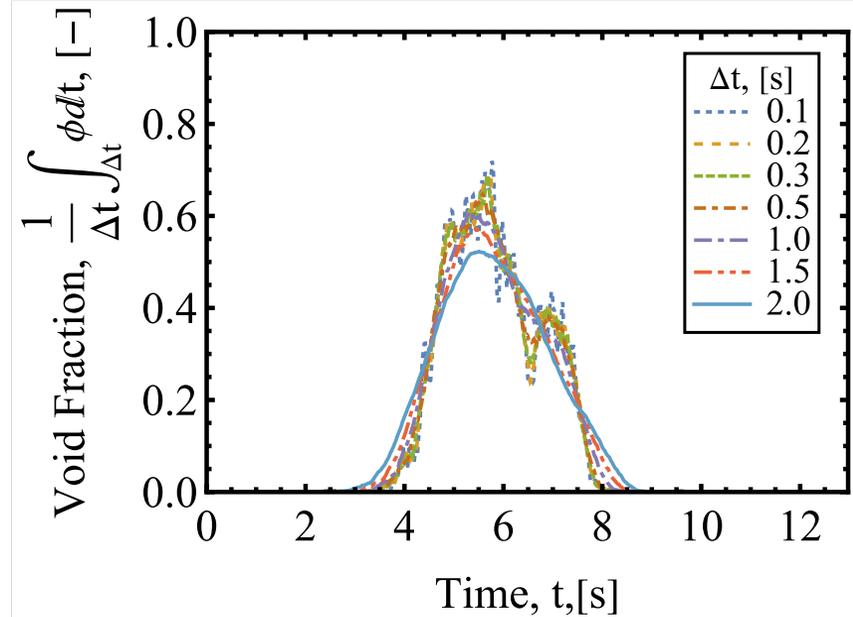
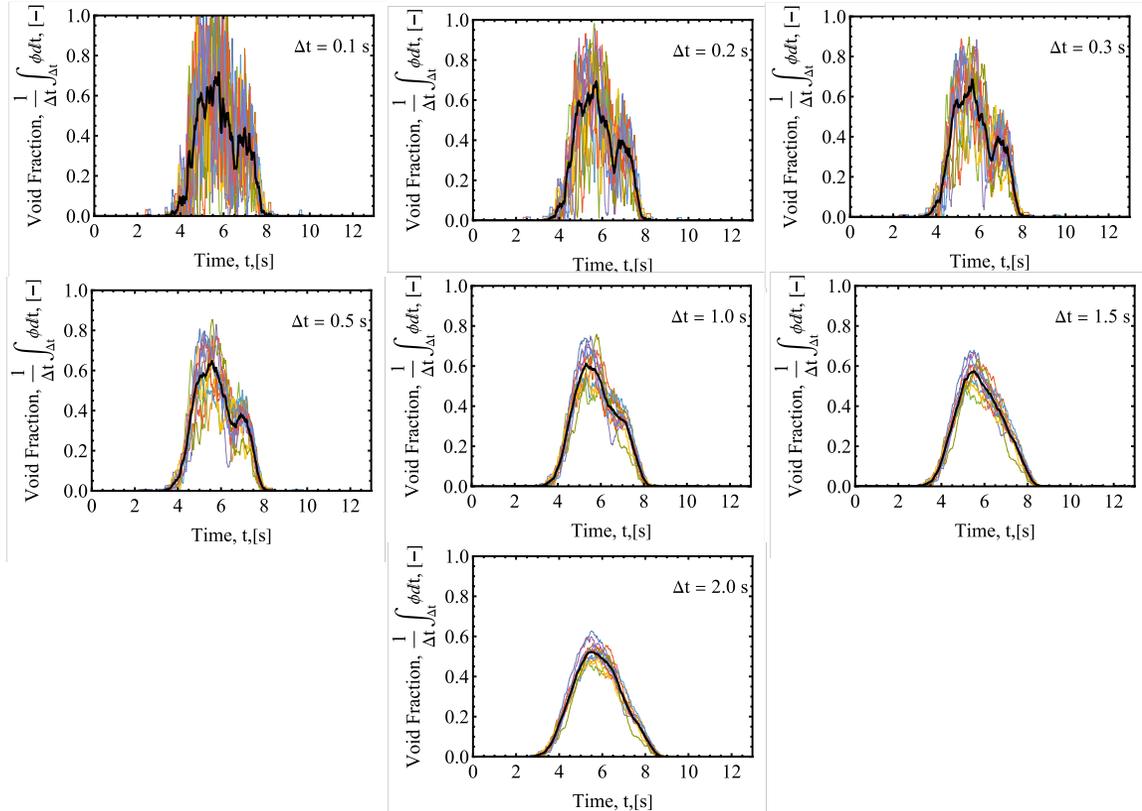
E.g., Local Void Fraction



This window may be too large to precisely resolve the macroscopic time-scale of the phenomena of interest.

# Introduction – Ensemble averaging

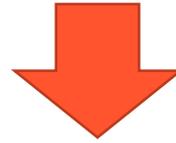
Ensemble-averaging can compensate this sampling insufficiency at the potential cost of extra difficulty in reproducing transients.



12 realizations (colorful) and their mean (black)

## Introduction – Periodicity

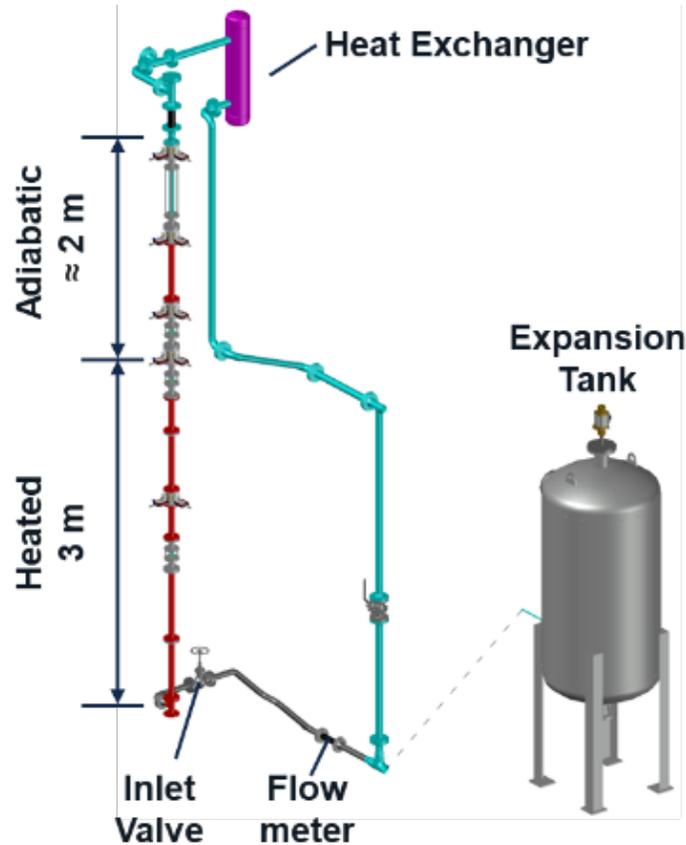
**Periodic flow** repeats its realization continuously.



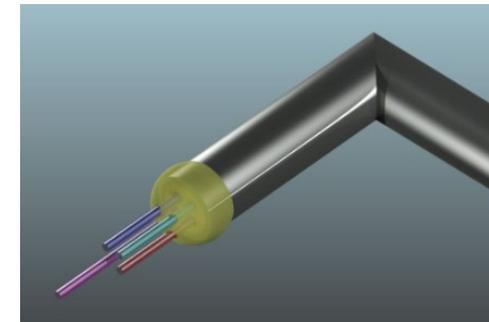
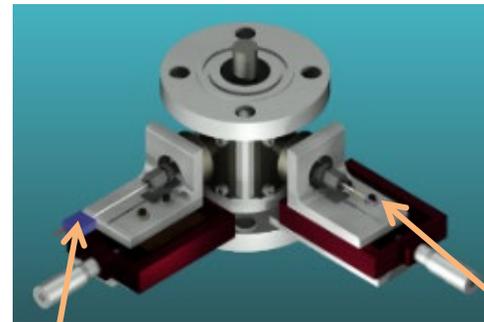
Collecting periodic mean flow is a good option for generating a transient two-phase flow dataset beyond steady states.

# Method – A practice on a natural circulation facility

The idea is demonstrated on a low-pressure natural circulation facility with flashing instability.

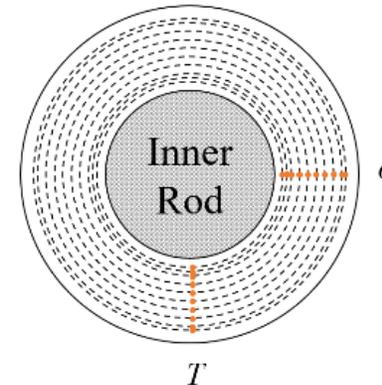


## Point Measurement Instruments

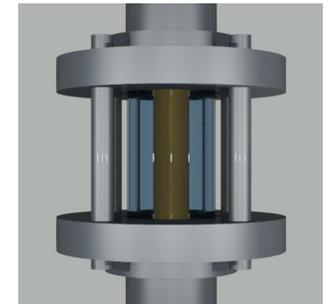


Thermocouple

Four-sensor Conductivity Probe



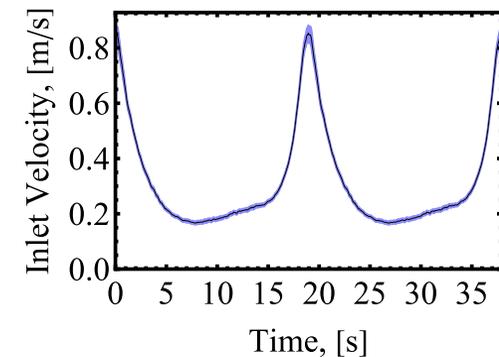
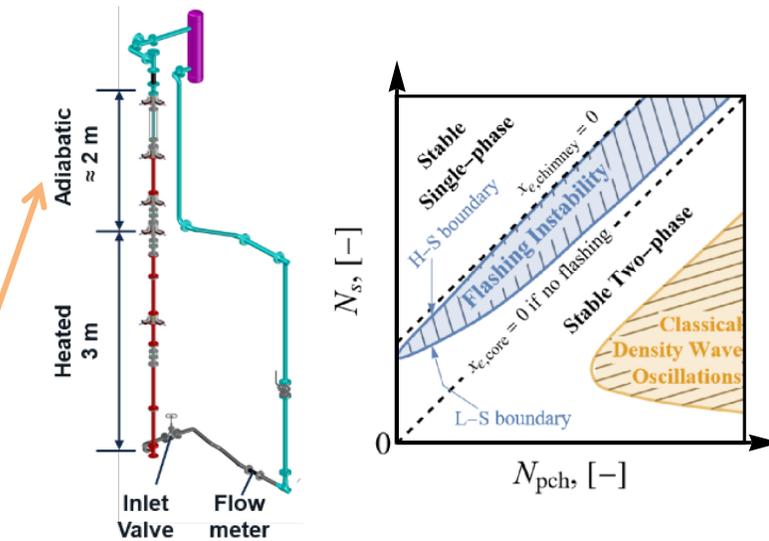
## Viewport



# Method – Flashing instability and its periodic flow

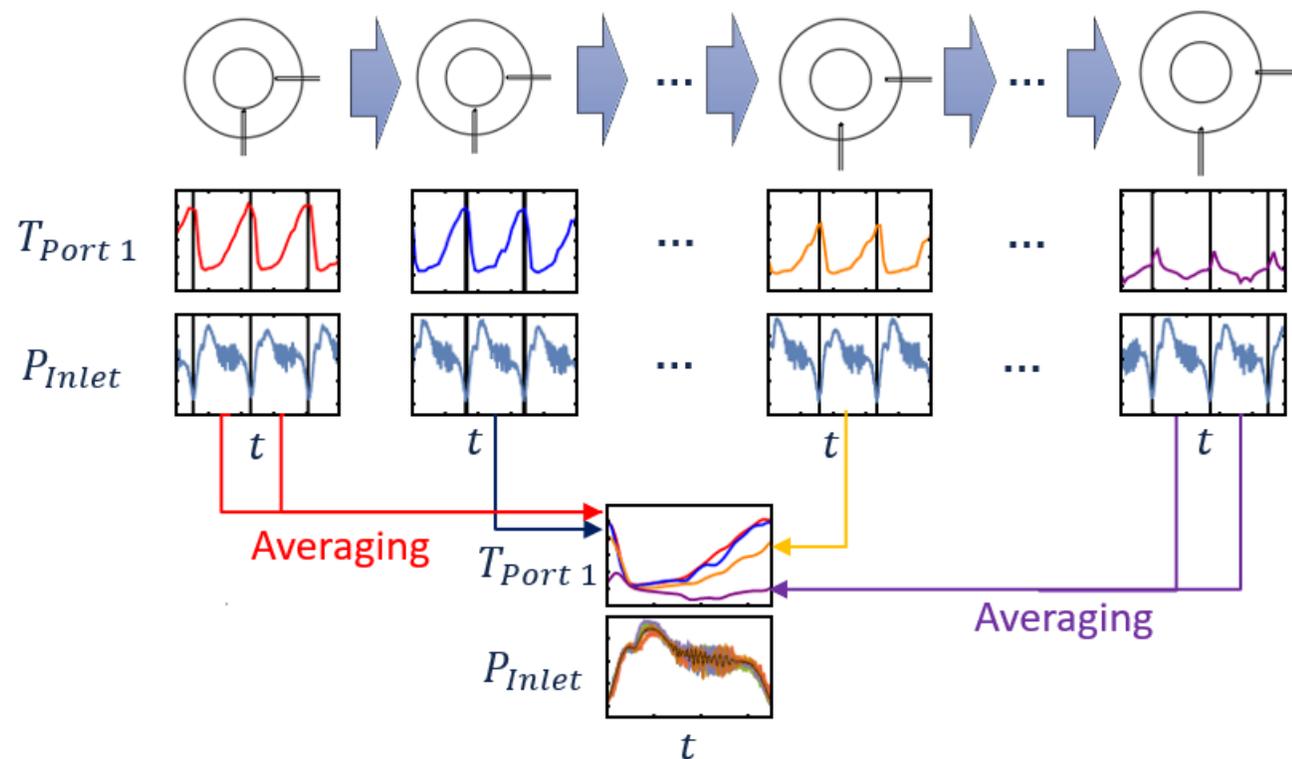
Flashing instability leads to *periodic flow* with low frequencies and large amplitudes.

- It occurs in *low-pressure natural circulation* systems which experience the transition from single-phase to two-phase operation.
- The anticipated but never reached steady states have *flashing vaporization* initiated within the adiabatic chimney.
- It is widely reported to lead to *periodic flow*.
- It leads to *low-frequency* oscillations. The period is in the same order of magnitude of the fluid residence time in the hot leg. For the current practice, this period ranges from 7s to 30s.
- It can cause *strong oscillations*. Inlet velocity can change from 0.2 m/s to 0.8 m/s in some tests.



## Method - Measurement of periodic flow

Utilizing the periodicity, signals can all be “synchronized”, including those measured during different cycles or at different locations



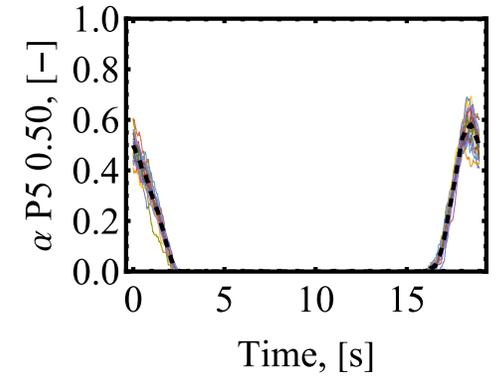
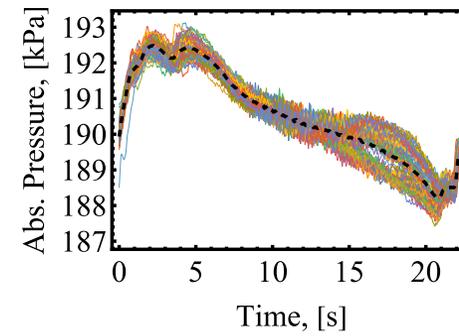
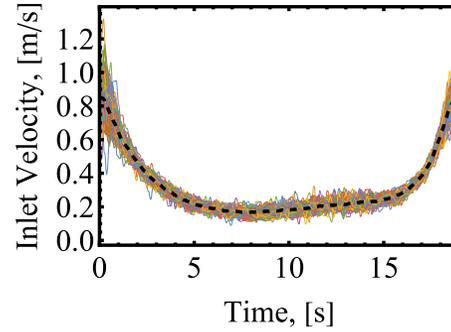
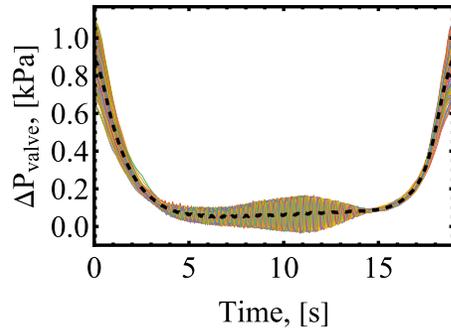
Time stamps separating oscillation cycles can be extracted from the signal of one parameter following a clean waveform.



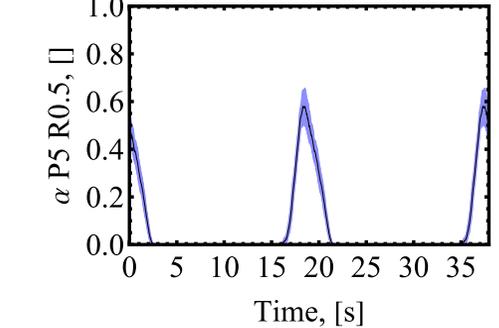
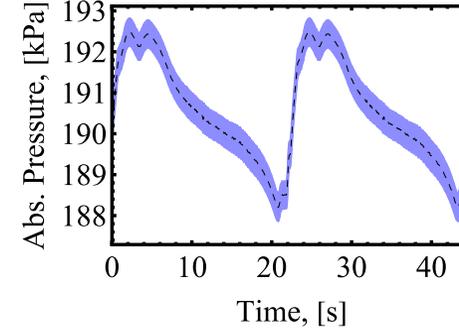
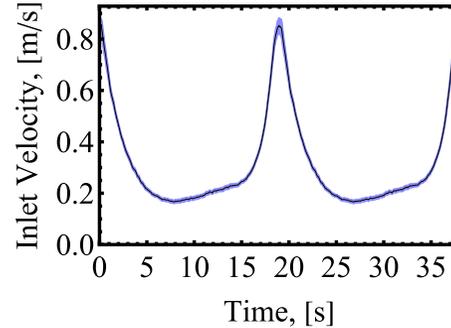
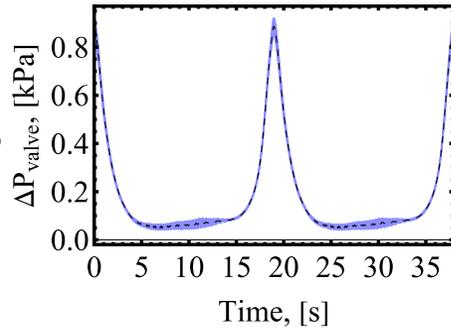
All signals are then aligned onto **one representative period.**

# Method - Measurement of periodic flow

Aligned Signals

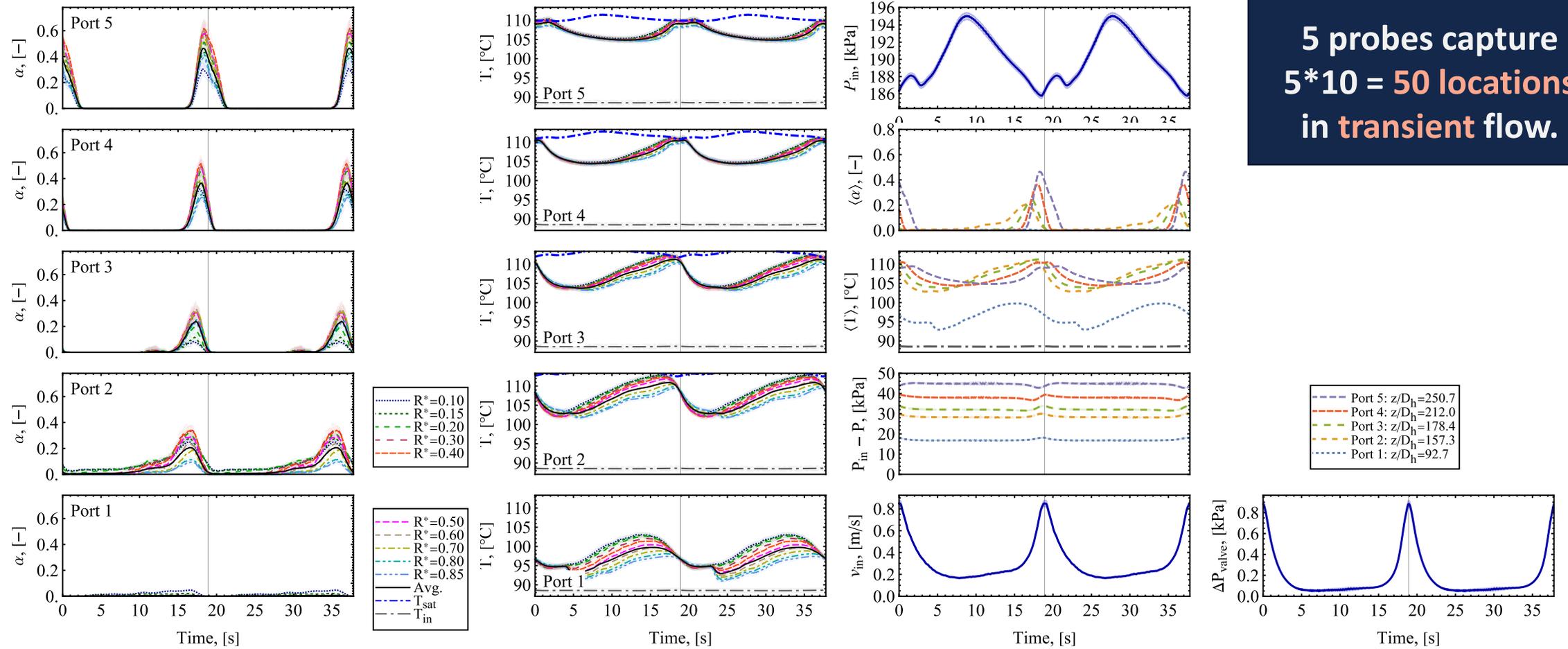


Mean waveforms



Over 200 realizations for the globe parameters.  
Over 10 realizations for each local point measurements.

# Results – Captured waveforms of mean flow oscillations



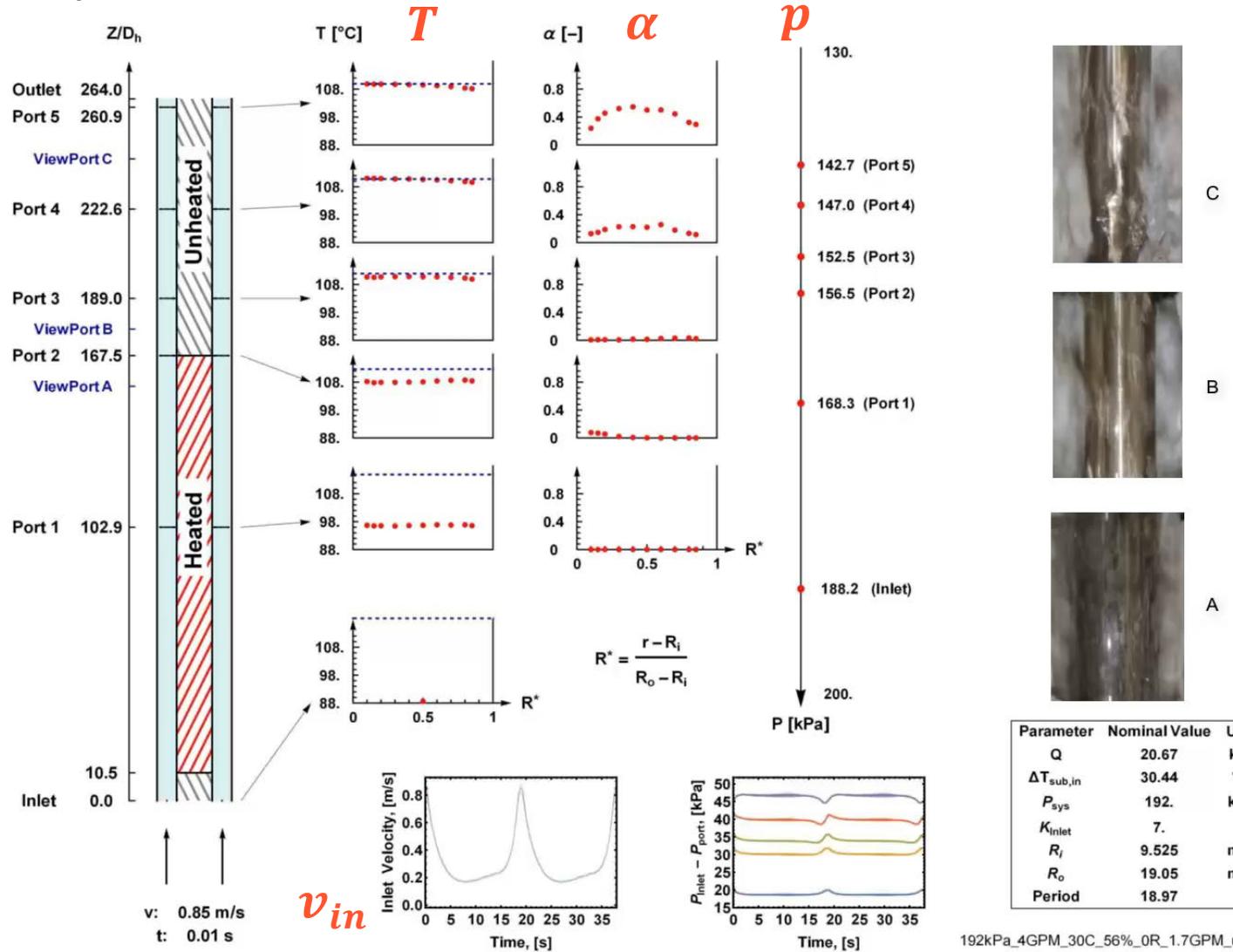
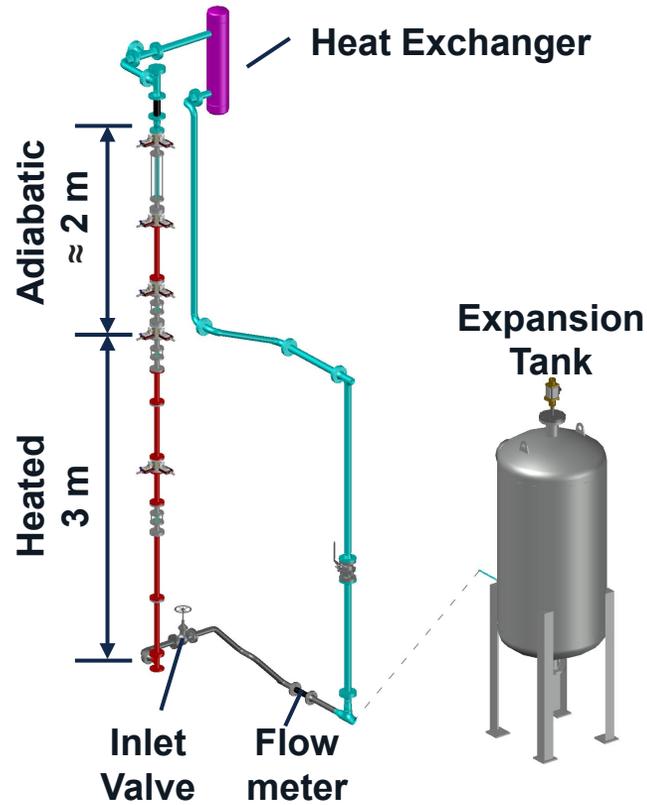
5 probes capture  
5\*10 = 50 locations  
in transient flow.

Colors: axial or radial locations

Shades: uncertainty

# Results – Animation with synchronized flow visualization

Visualization can also be included following the same approach.



C



B



A

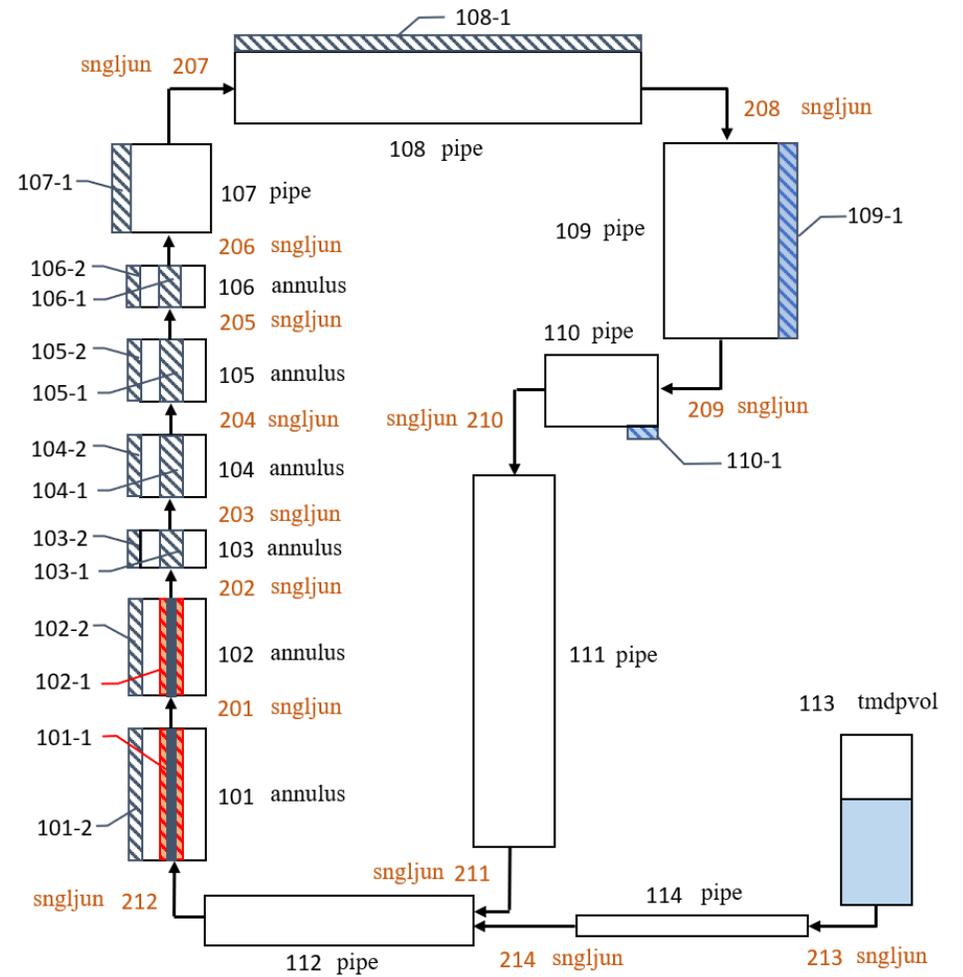
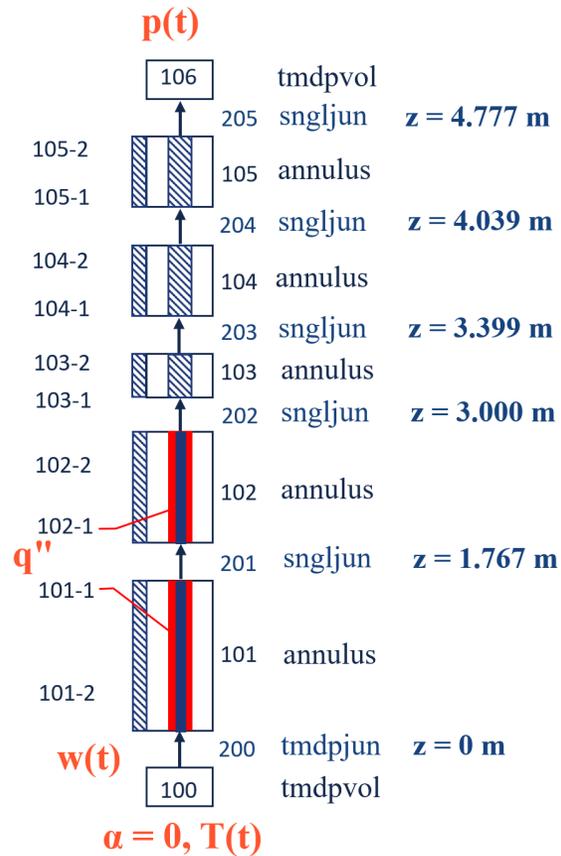
192kPa\_4GPM\_30C\_56%\_0R\_1.7GPM\_unstable\_t\_3

# Results – Using the data as a benchmark for code validation

Captured data can be used as a benchmark for code validation.

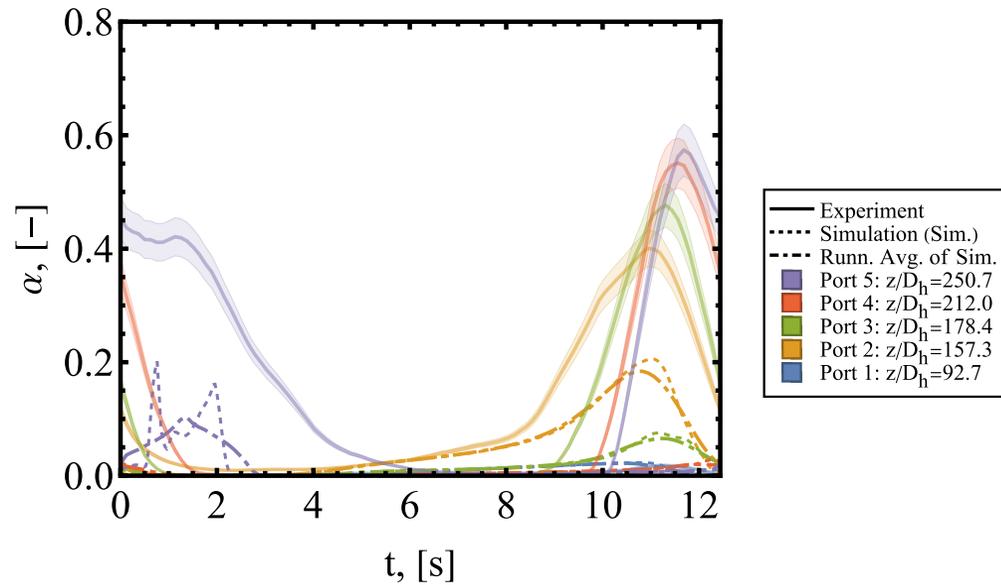
- Single-channel and full-loop models were built in the:

*Advanced Fluid Systems Thermal Hydraulics Analysis, Version 3 (ASYST VER3).*

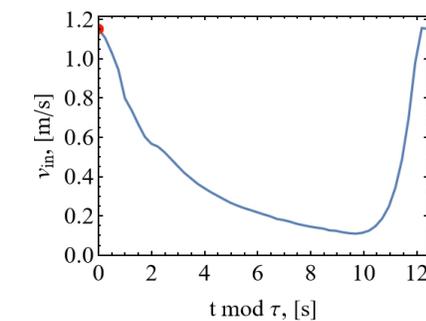
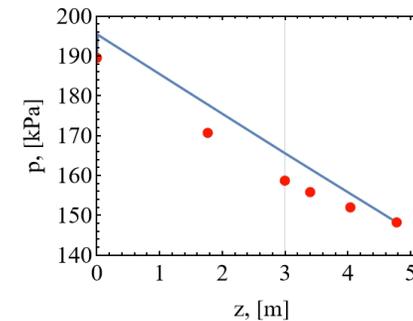
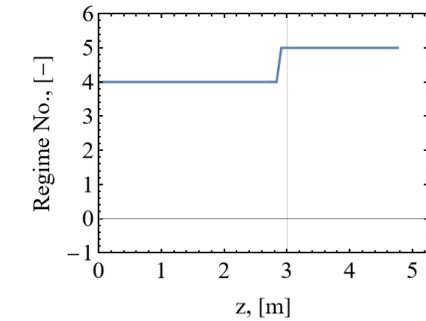
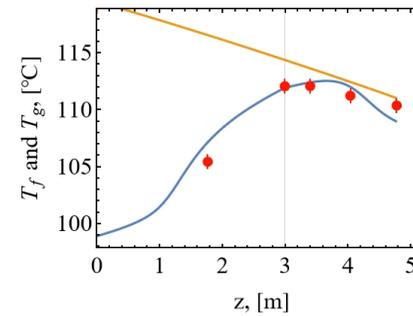
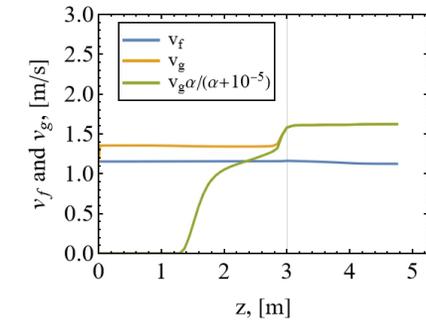
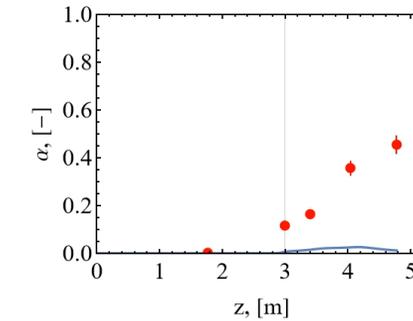


# Results – Using the data as a benchmark for code validation

Validation with a single-channel model shows the **prediction performance under actual mean flow rate and other BCs**

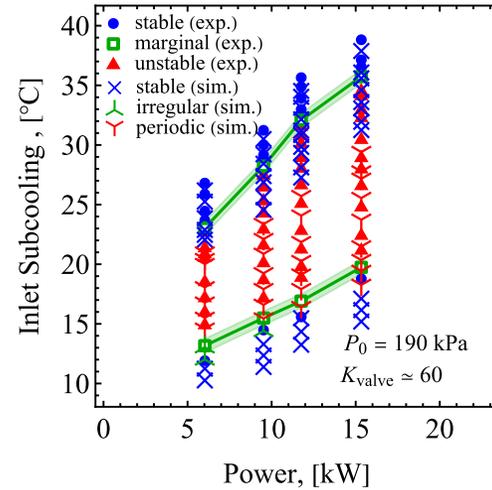


t = 360.76 s  
t/τ mod 1 = 0.0 %

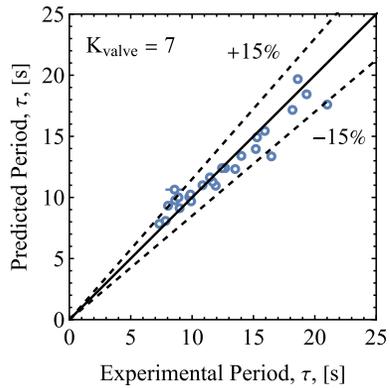


# Results – Using the data as a benchmark for code validation

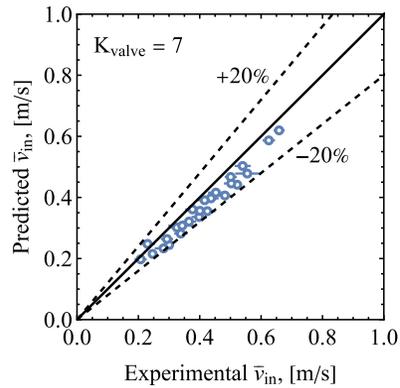
Validation with a full-loop model tests the code's overall capability in capturing stability and predicting oscillations



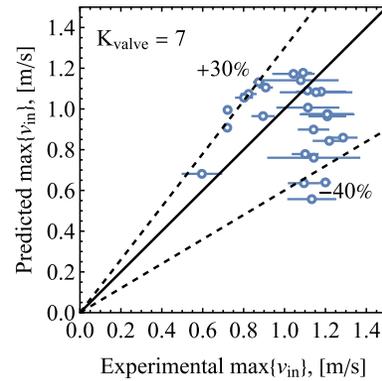
## Stability



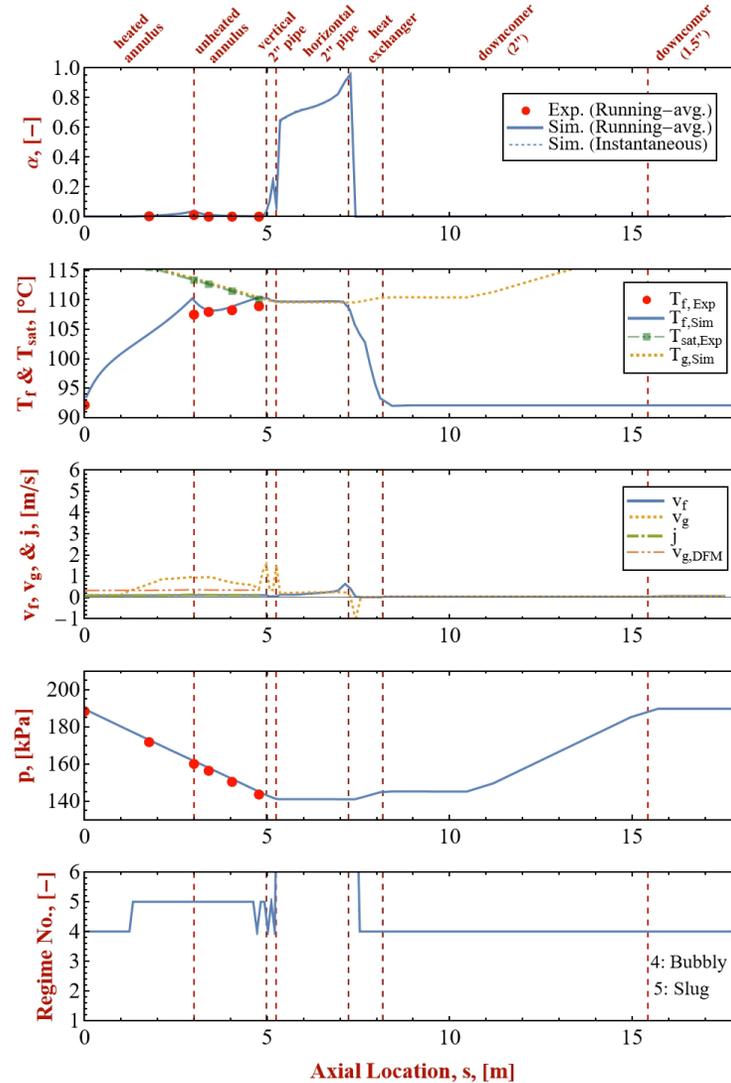
## Period



## Avg [ $v_{in}$ ]



## Max [ $v_{in}$ ]



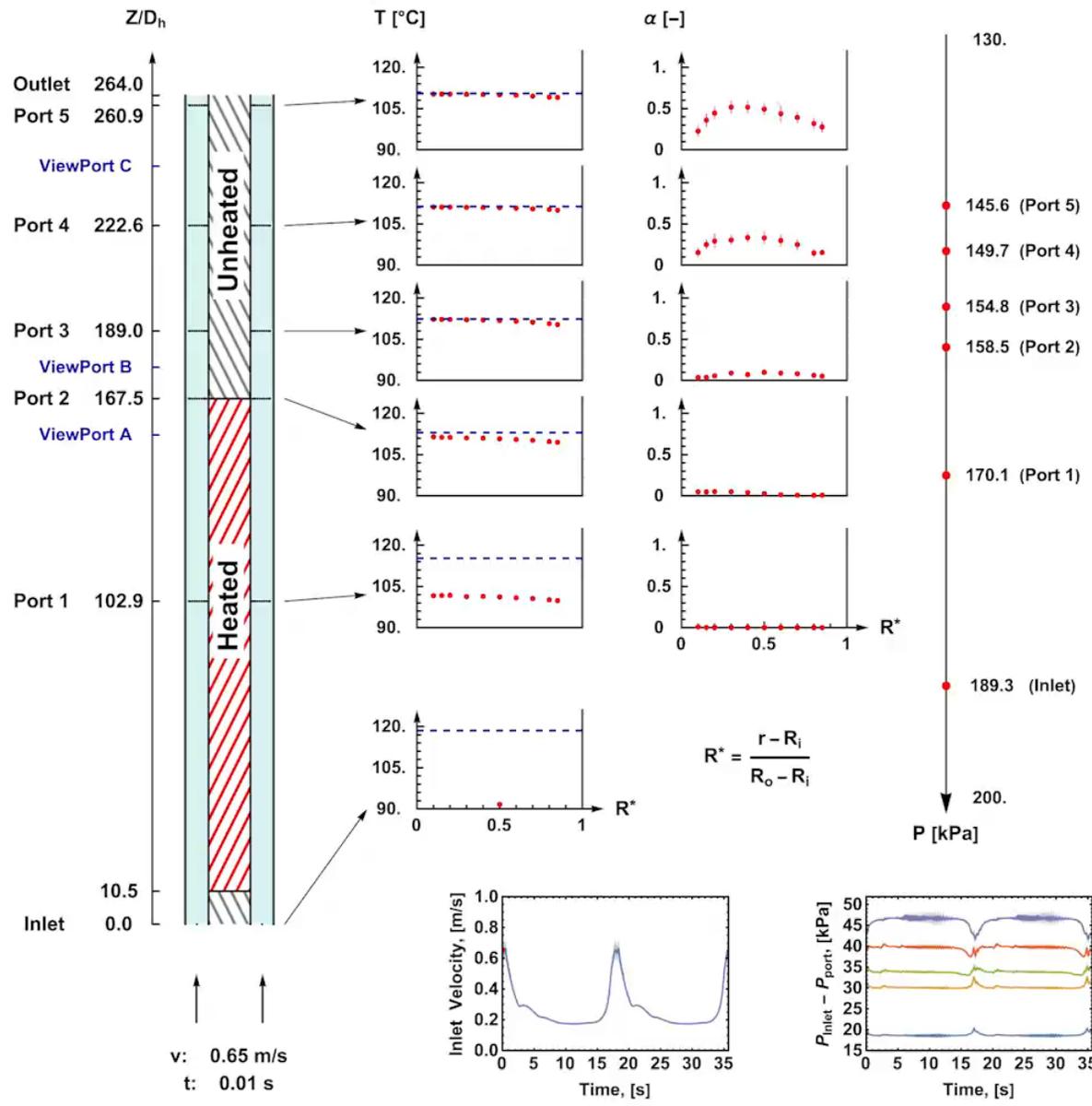
# Conclusion

Periodic flows are valuable options for practically collecting high-quality two-phase flow dataset **beyond steady states**.

The periodicity of flow facilitates the collection of data for

- modeling **two-phase phenomena beyond steady state**.
- generating transient benchmark for **code validation**.
- testing the performance or investigating the convergence criteria for **transient measurement devices**.
- ...

**Thank you!**



C

B

A

## Case #123 (used in full-loop validation)

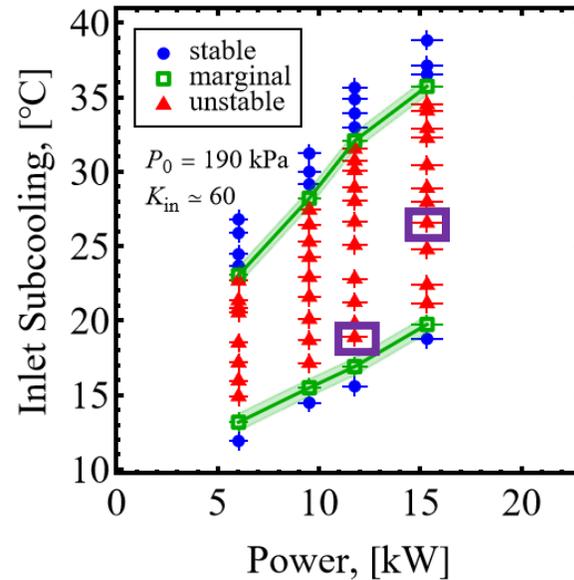
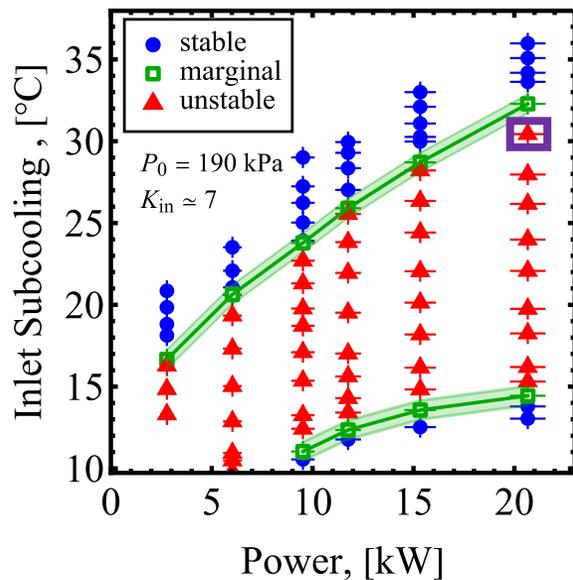
Parameter	Nominal Value	Unit
Q	15.33	kW
ΔT <sub>sub,in</sub>	26.57	°C
P <sub>sys</sub>	190.1	kPa
K <sub>valve</sub>	60.	-
R <sub>i</sub>	9.525	mm
R <sub>o</sub>	19.05	mm
Period	17.85	s

190kPa\_2.3GPM\_26.5C\_46%\_5R\_0.94GPM\_unstable\_t\_3



# Results – Test Matrix

This methodology has been practiced in the stability tests on this facility, capturing more than 70 periodic conditions with details.



  marks the examples.

Nominal System Pressure, [kPa]	190	
Nominal Inlet Valve Loss Coefficient, [-]	7	60
Inlet Subcooling, [°C]	10.5 – 36.0	11.9 – 38.8
Heating Power, [kW]	2.7 – 20.7	6.0 – 15.3
Tested Conditions, [-]	86	67
<b>Comprehensively Recorded Conditions, [-]</b>	<b>38</b>	<b>37</b>