

Stave Cores: Thermal Cycling

BOPING CHEN, CHUNHUI CHEN,
WILLIAM HEIDORN, SHUAIYAN KANG,
SOEREN PRELL, ROY MCKAY, JIE YU

IOWA STATE UNIVERSITY
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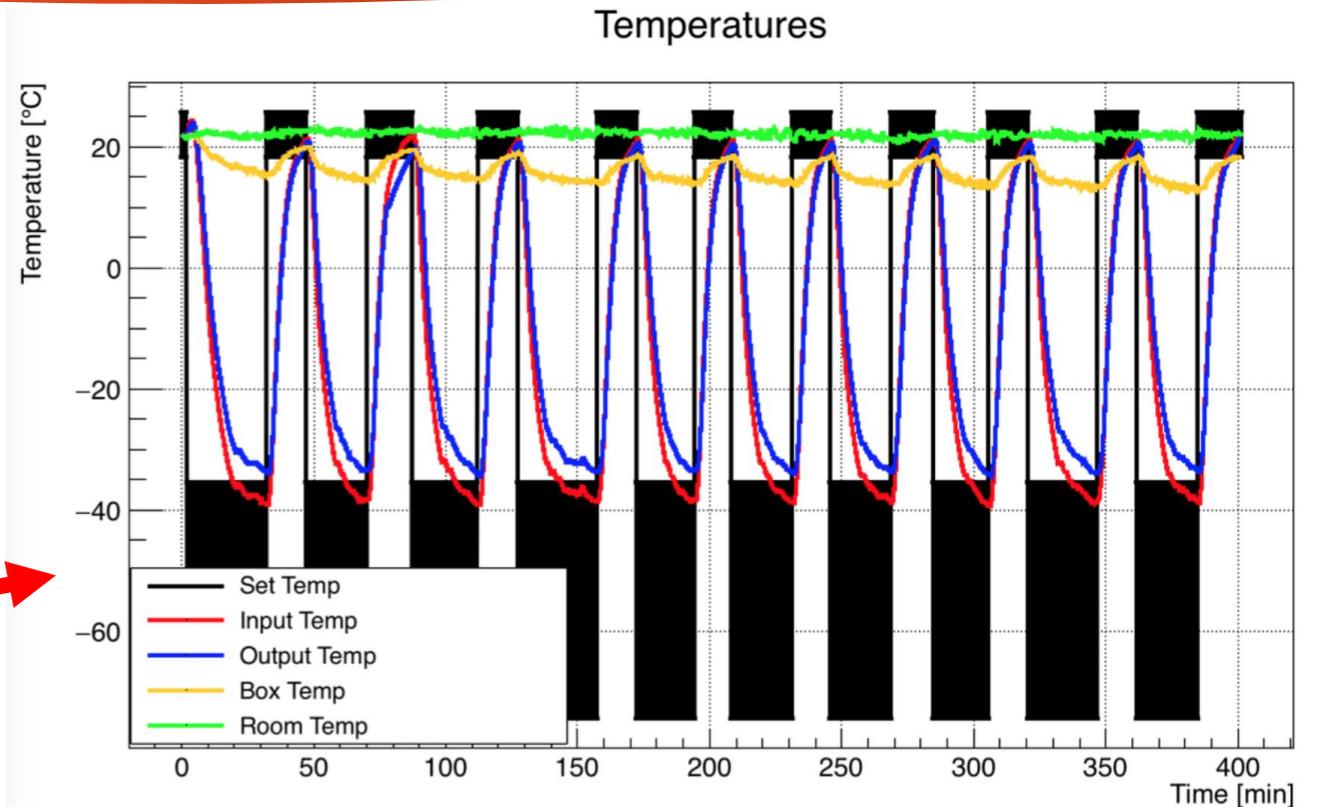


Thermal shock: Motivation

- ▶ Check for effects on the physical structure and defects in stave cores by rapidly cycling it between room temperature (~20 C) and low (~-37 C) temperatures
- ▶ Before and after cycling, the stave core's defects will be measured using two detection methods: Laser Scanning and Thermal Imaging
- ▶ Initially done using US core 2R with 100 "slow" cycles
 - ▶ No new defects or changes in existing defects were found
 - ▶ Not really thermal shocks
- ▶ Increase dT/dt by installing computer controlled actuator valves
 - ▶ Plan to go through shock cycle ~420 times

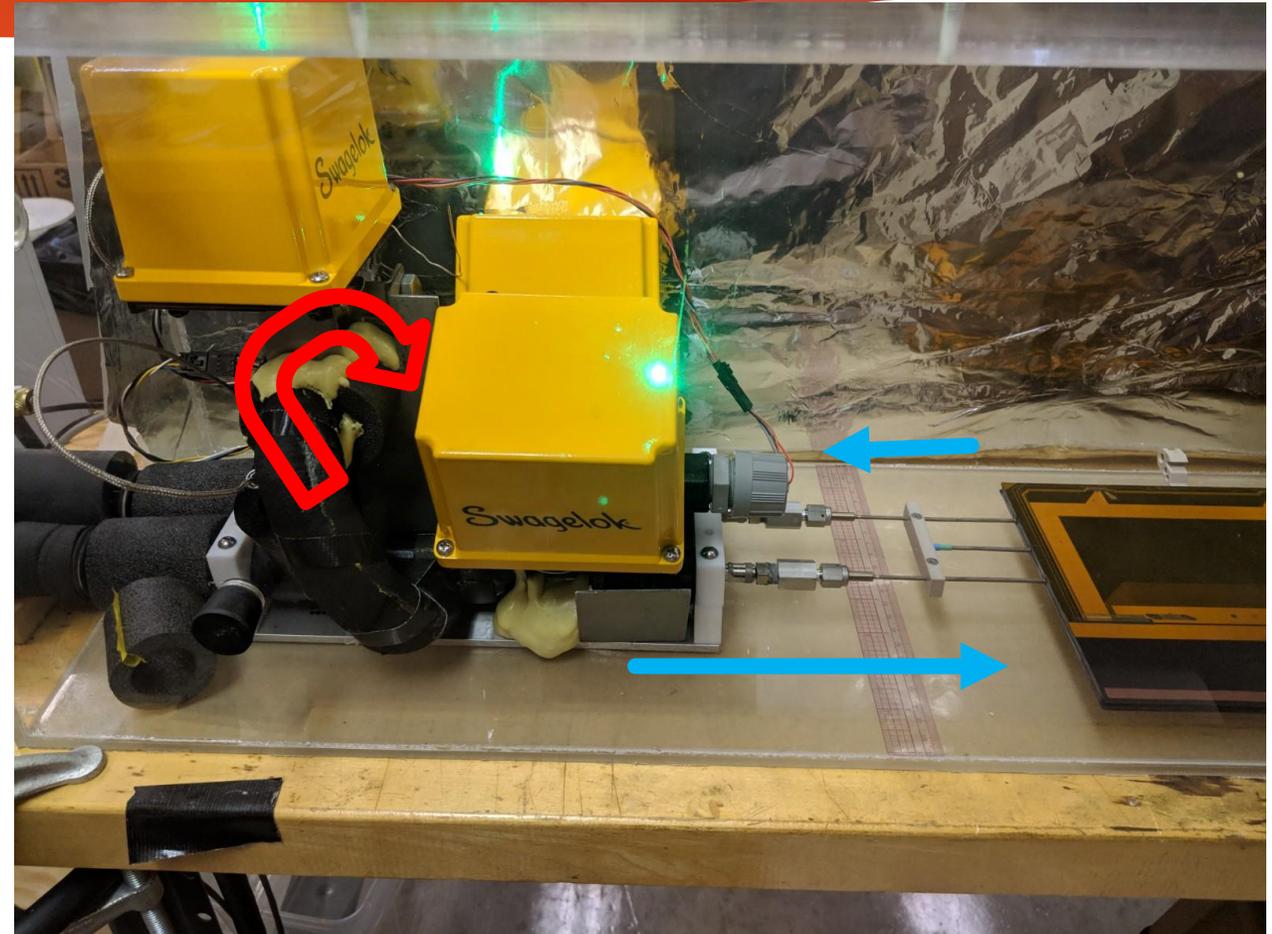
Original “Slow” Thermal Cycling

- ▶ 100 cycles were done on US stave core 2R
 - ▶ Each cycle set the chiller to -55 C then 22 C.
 - ▶ Program waits for avg. stave temp. to get to -35.5 C and 18.3 C respectively. It waits for stabilization before moving onto the next cycle
 - ▶ For cooling $|dT/dt|$ was ~ 0.04 C/sec taking about 20 minutes to reach the cutoff
- ▶ Shown are last 10 cycles
- ▶ No new defects or changes in existing defects were found



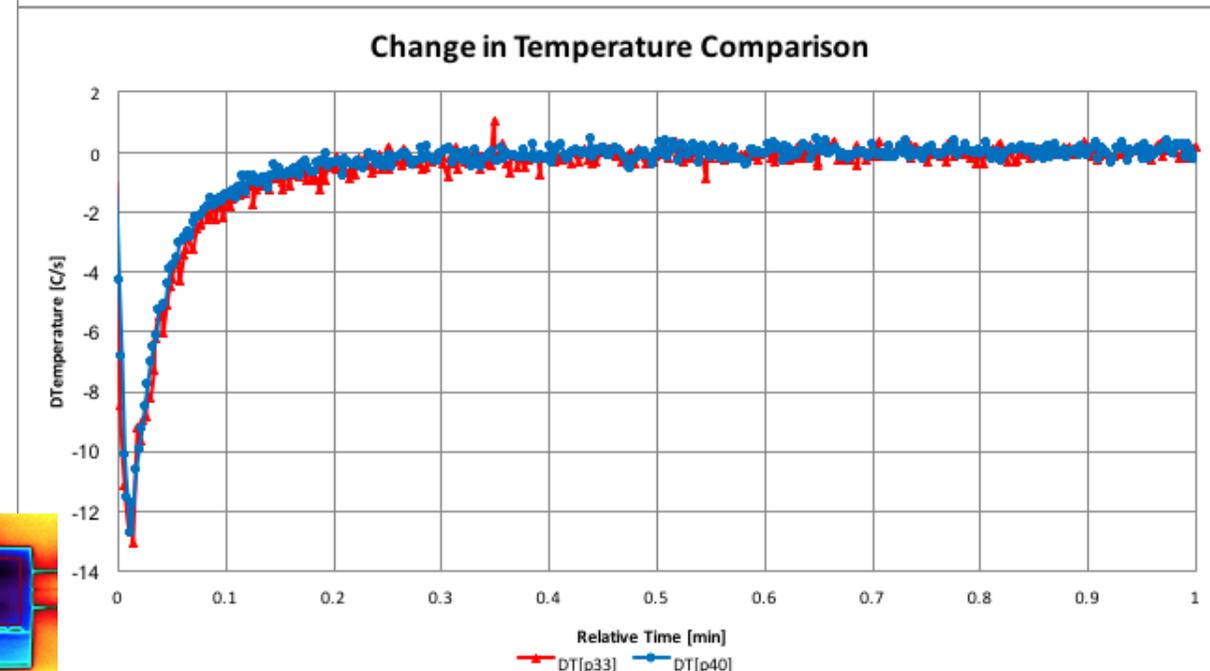
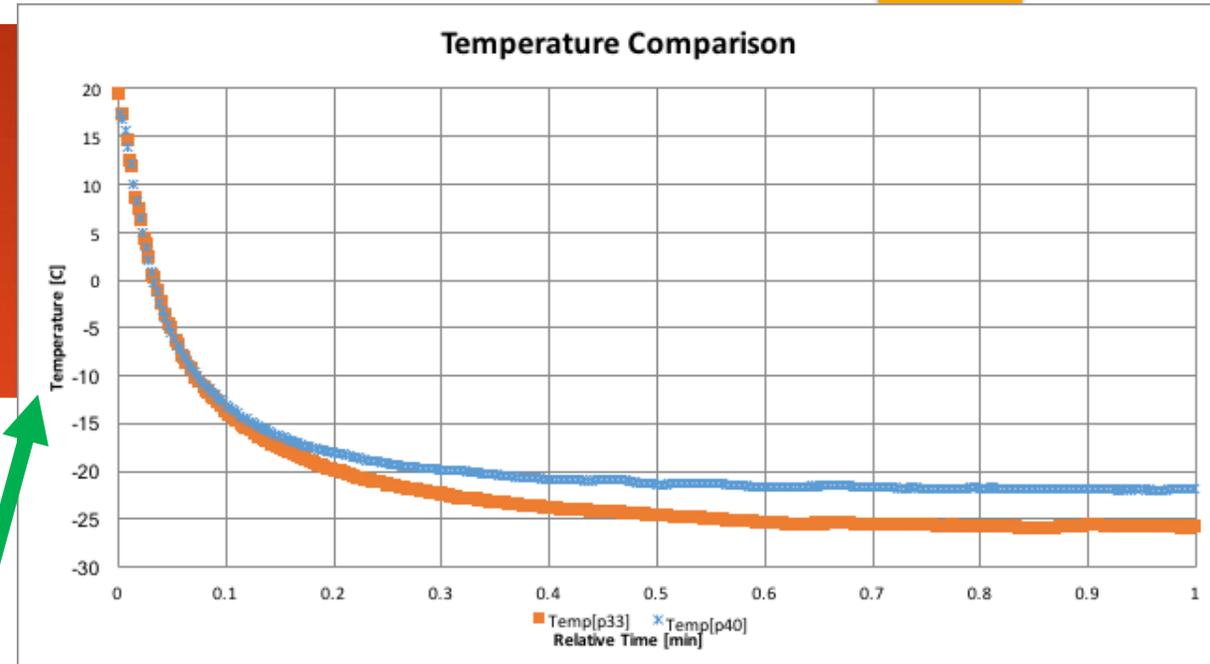
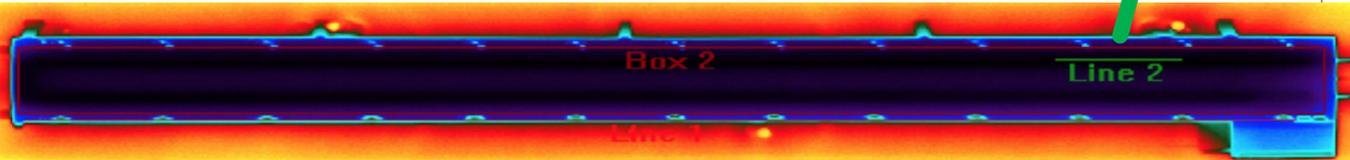
Thermal Shock: Improved Setup

- ▶ Installed computer controlled actuator valves with a fluid bypass
 - ▶ Created two distinct actuator modes:
 - ▶ **Bypass**- fluid only goes through bypass
 - ▶ **Stave**- fluid only goes through stave core
 - ▶ Allows for cycling with fast temperature changes by cycling between the two modes
- ▶ Installed flow meter
- ▶ Improved control code
 - ▶ Changed temperature equilibrium definition to use set temp and chiller reservoir temp instead of basing equilibrium on reaching a predefined temperature from the chiller setting



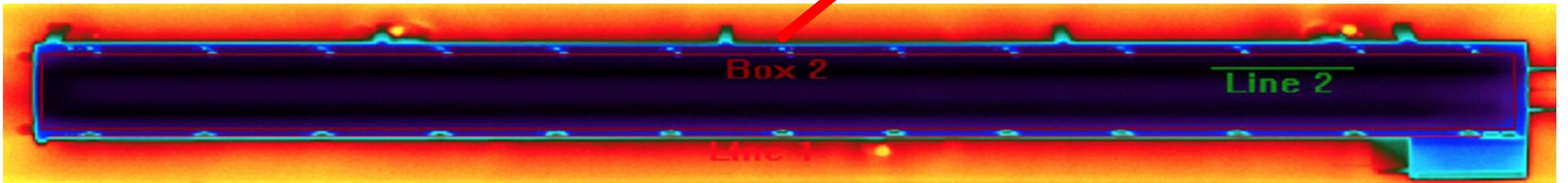
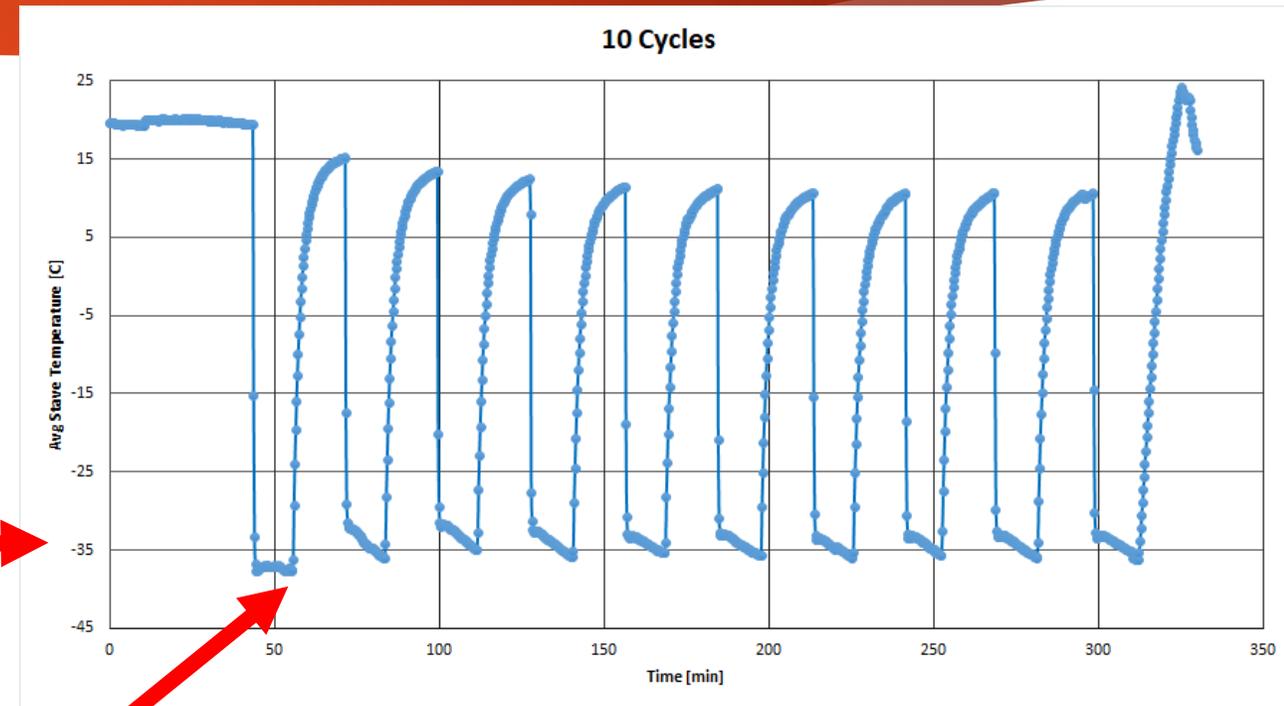
Thermal Cycling: Shock Tests

- ▶ Average stave temp extracted from stave core images taken during the cycling
 - ▶ Inlet Temp is an average from **Line 2**
- ▶ Tests found that we could achieve a max $|dT/dt|$ of ~ 13 C/sec by having the actuators in bypass mode then switching the actuators to stave mode



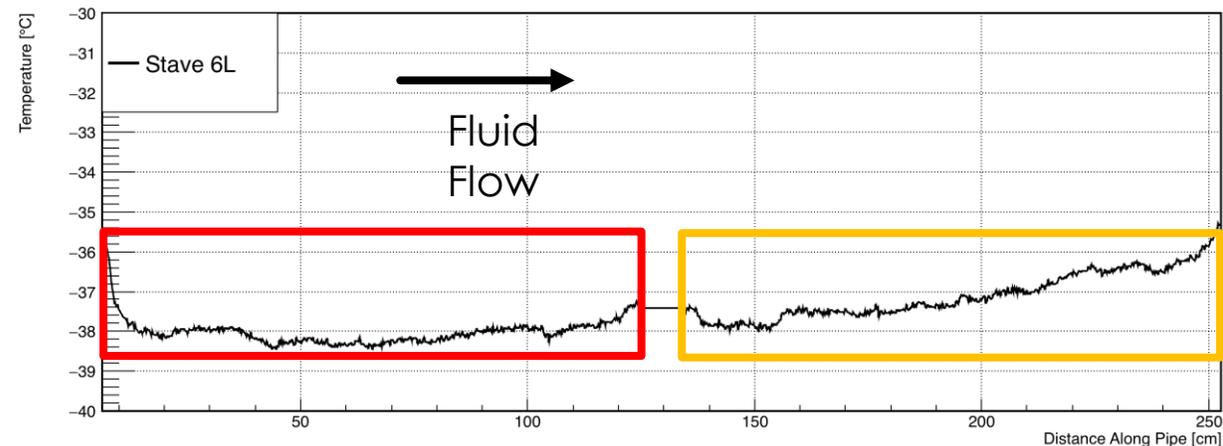
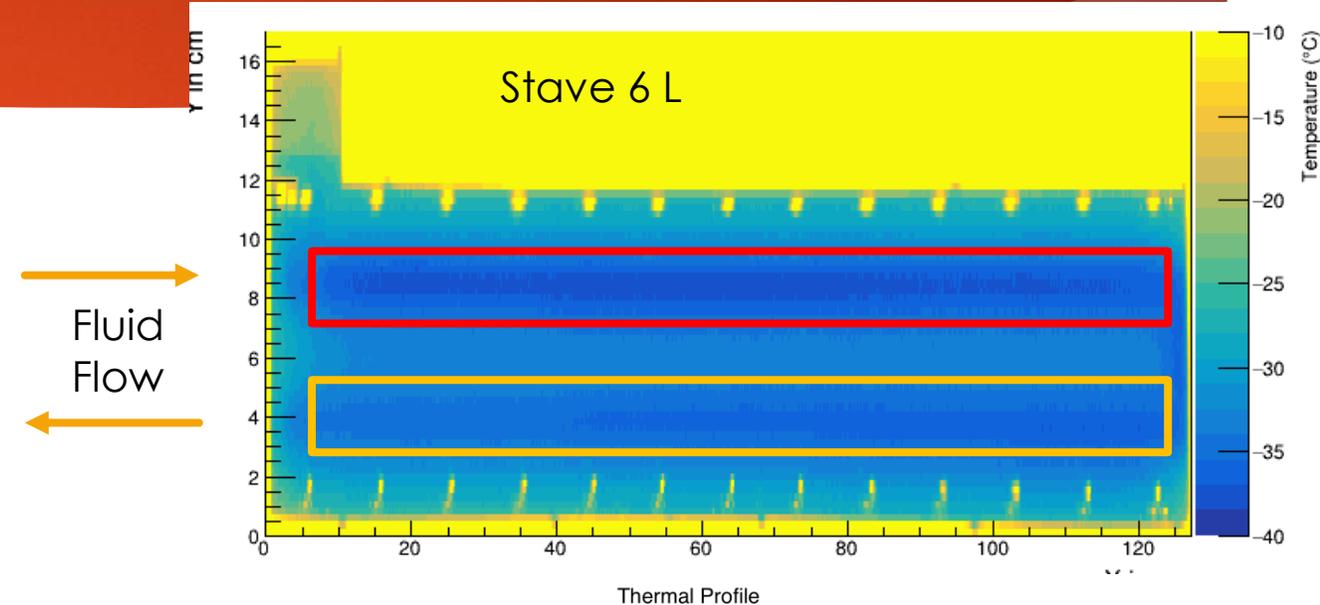
Thermal Cycling: Shock Cycling

- ▶ Cycled US core 6 with chiller temp set to -55 C and a flow rate through the core of ~1l/min cycling 400 times as follows:
 - ▶ Wait in bypass mode: (Stave core returns to 11C over 18 min)
 - ▶ Wait in stave mode: (Stave core drops to -36 and holds it for around 12 min)
- ▶ Second set of 10 cycles:  average temperature across the stave core from thermal image



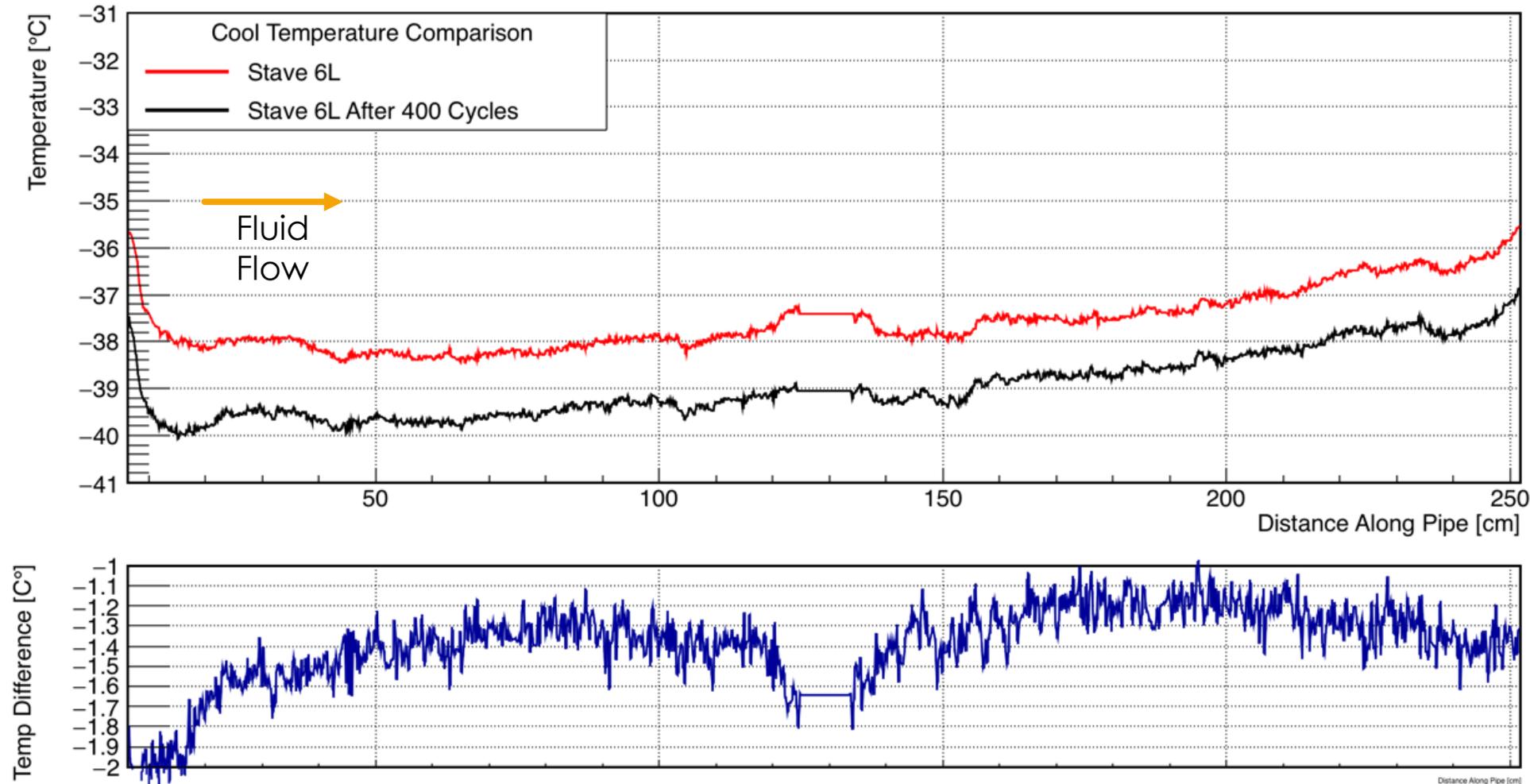
Thermal Imaging Comparison Technique

- ▶ Thermal Images of the stave core are taken before and after cycling 400 times
 - ▶ Cooled to -40C with fluid flowing 1 l/min through it
 - ▶ Imaged with IR camera and minimum temperature along cooling pipe is extracted
 - ▶ Comparison plots are used to check for any differences



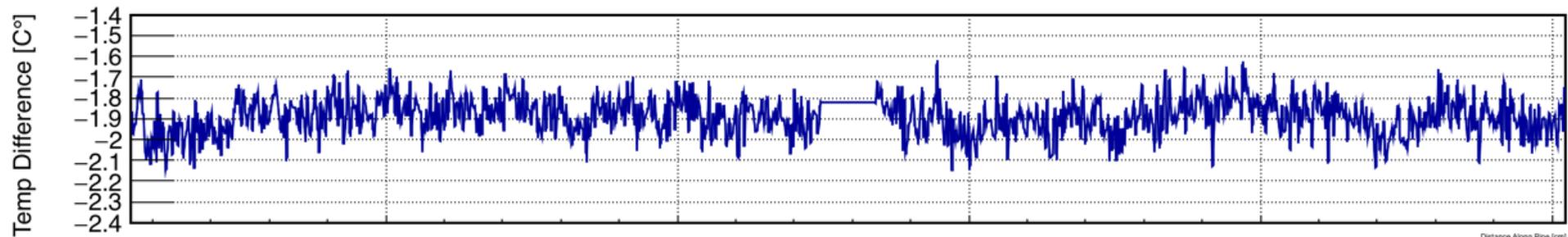
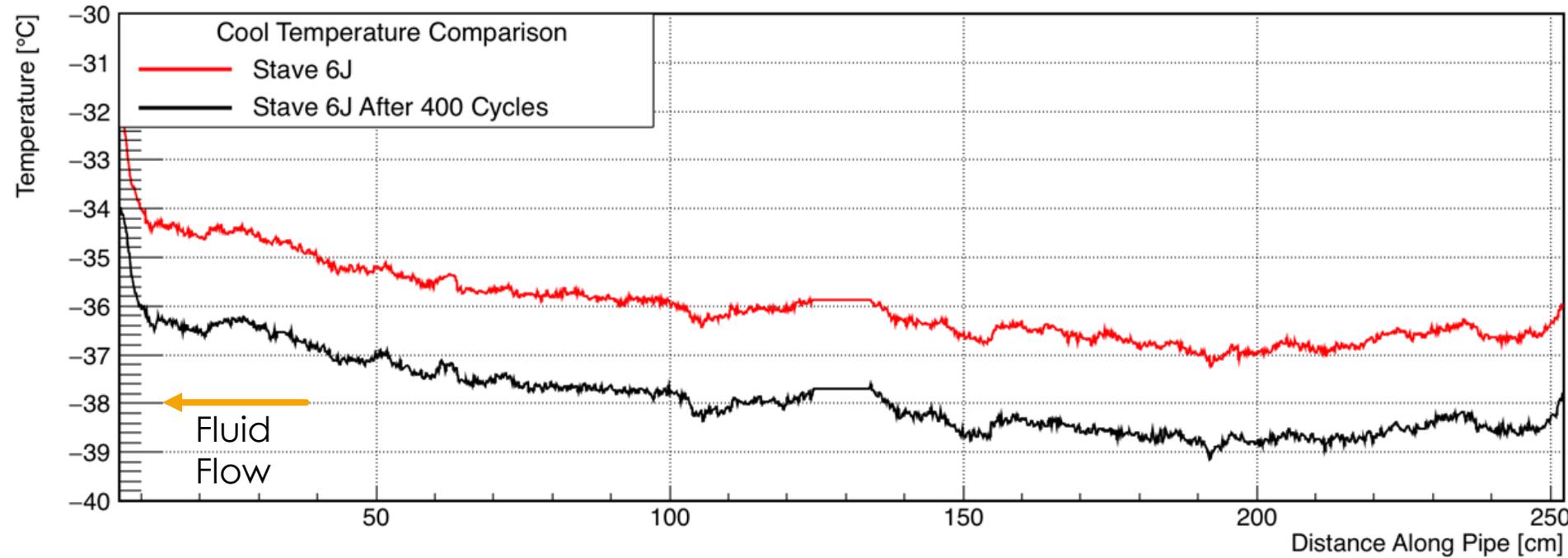
Cold L Side Comparison

- ▶ No changes that indicate any new flaws
- ▶ Main differences due to being at slightly different equilibrium points
 - ▶ Causes global differences near EOS card and pipe bend



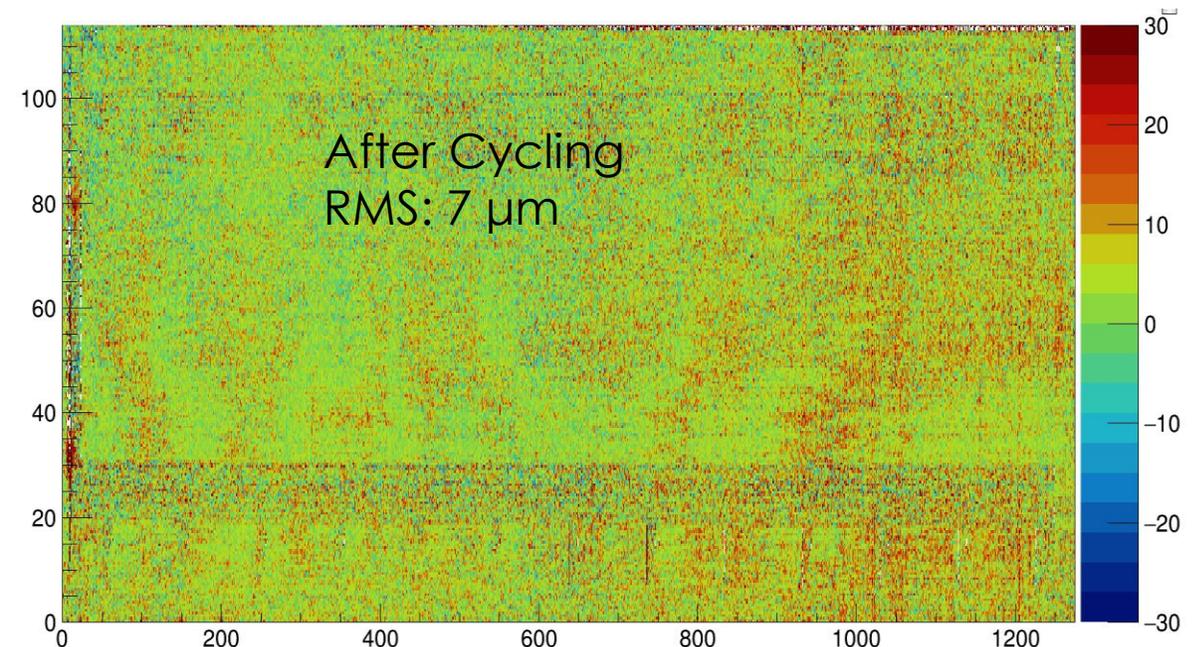
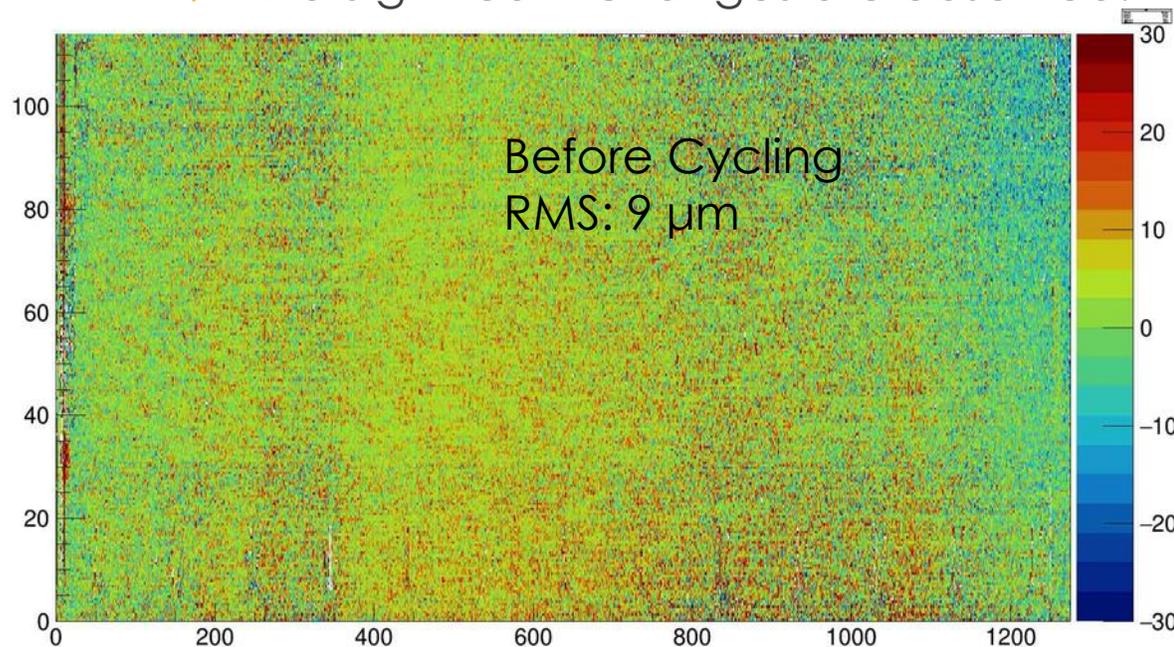
Cold J Side Comparison

- ▶ No changes that indicate any new flaws
- ▶ Excellent agreement between both measurements!



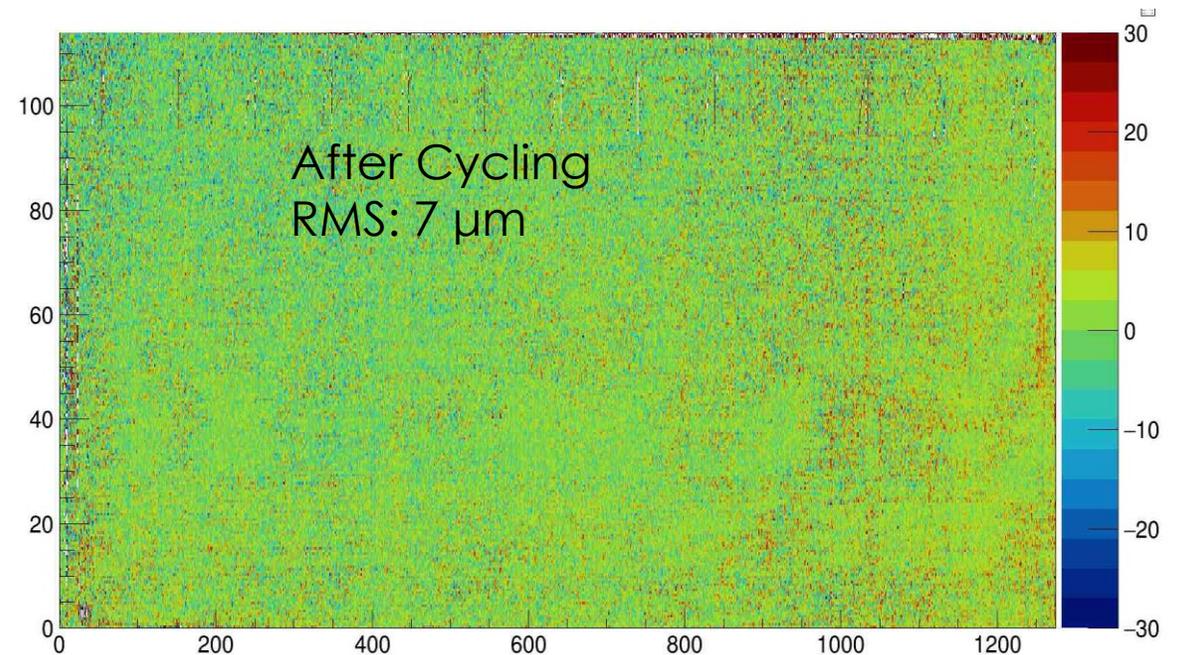
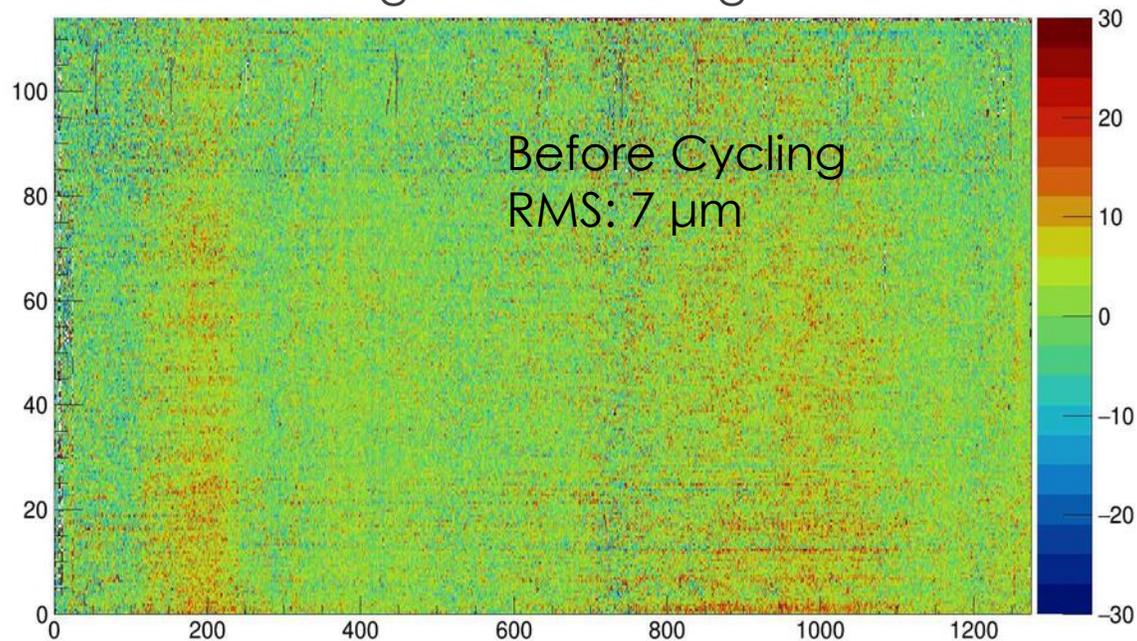
Laser Scanning J Side

- ▶ The Stave Core is scanned 5 times with and without 5 psi N₂
- ▶ Averages of the scans are subtracted
- ▶ No Significant changes are observed!



Laser Scanning L Side

- ▶ The Stave Core is scanned 5 times with and without 5 psi N2
- ▶ Averages of the scans are subtracted
- ▶ No Significant changes are observed!



Conclusions

- ▶ US Stave Core #6 was shock cycled ~400 times
- ▶ Thermal measurements of the stave core before and after show no significant differences
- ▶ Laser scanning measurements of the stave core before and after show no significant differences
- ▶ The stave core was found to have no significant changes due to the thermal shocking