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Fiber Optics Research Program

Laboratory and Flow Loop DAS Experiments

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RCP

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Outline

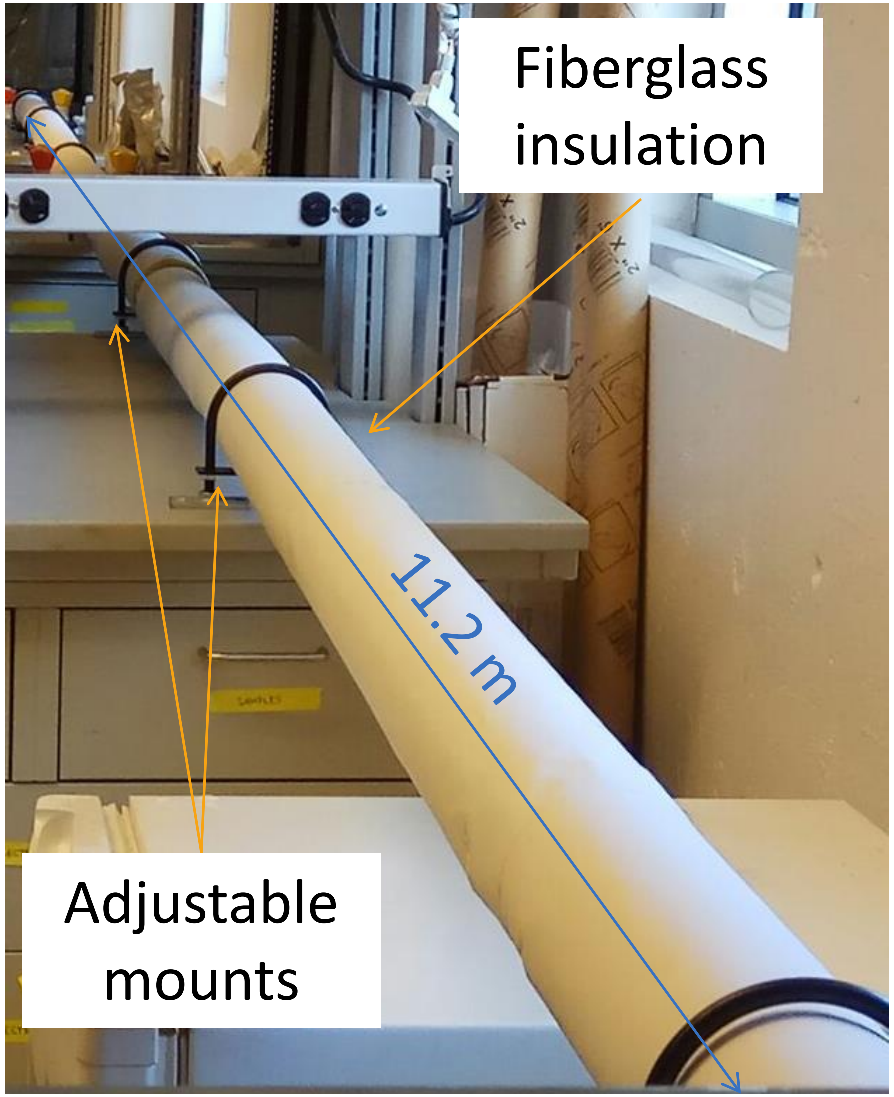
- Linear Fiber Stretcher Experiments
  - DAS Response
  - DAS Spatial Resolution
  - DAS Temperature Response
  - DAS Dynamic Range
  - Conclusions
- Flow Loop Experiments
  - Doppler Effect and Eddy Tracking
  - Slug Flow Monitoring
  - Conclusions
- DAS is More Than Seismometer Array

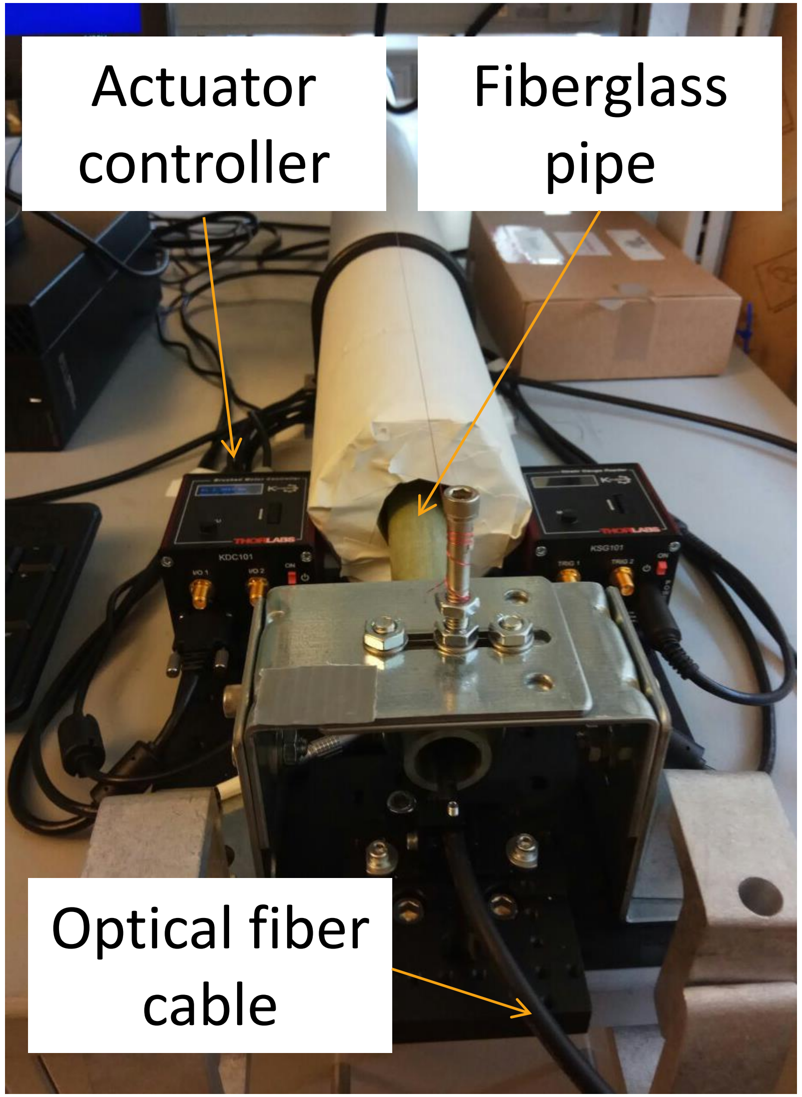
Linear Fiber Stretcher Experiments

Aleksei Titov, Nate Lindsey & Jonathan Ajo-Franklin; *AGU 2019*

Special Thanks to Veronica Rodriguez Tribaldos, Julia Correa, Feng Cheng, Eileen Martin, Michelle Robertson, Yuxin Wu & Ge Jin

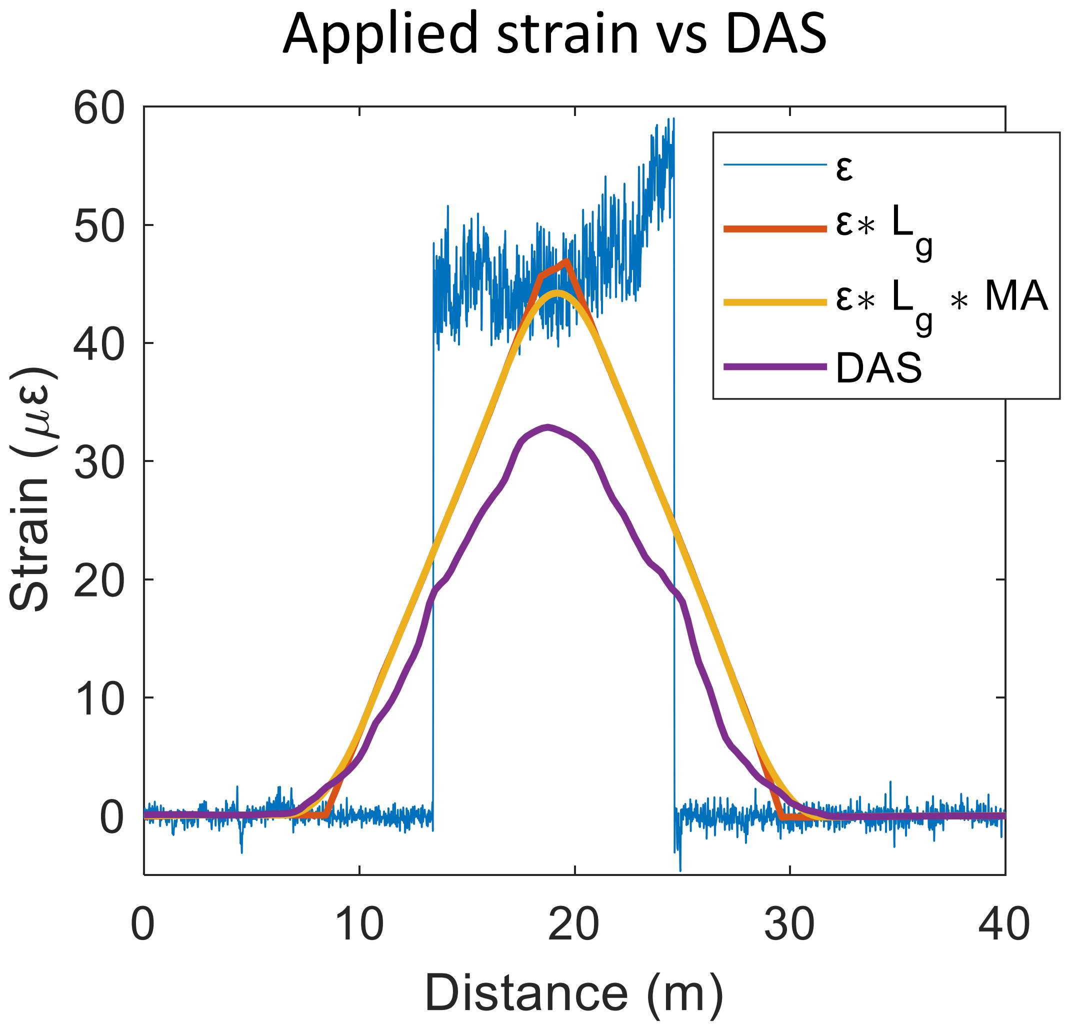
Linear Fiber Stretcher

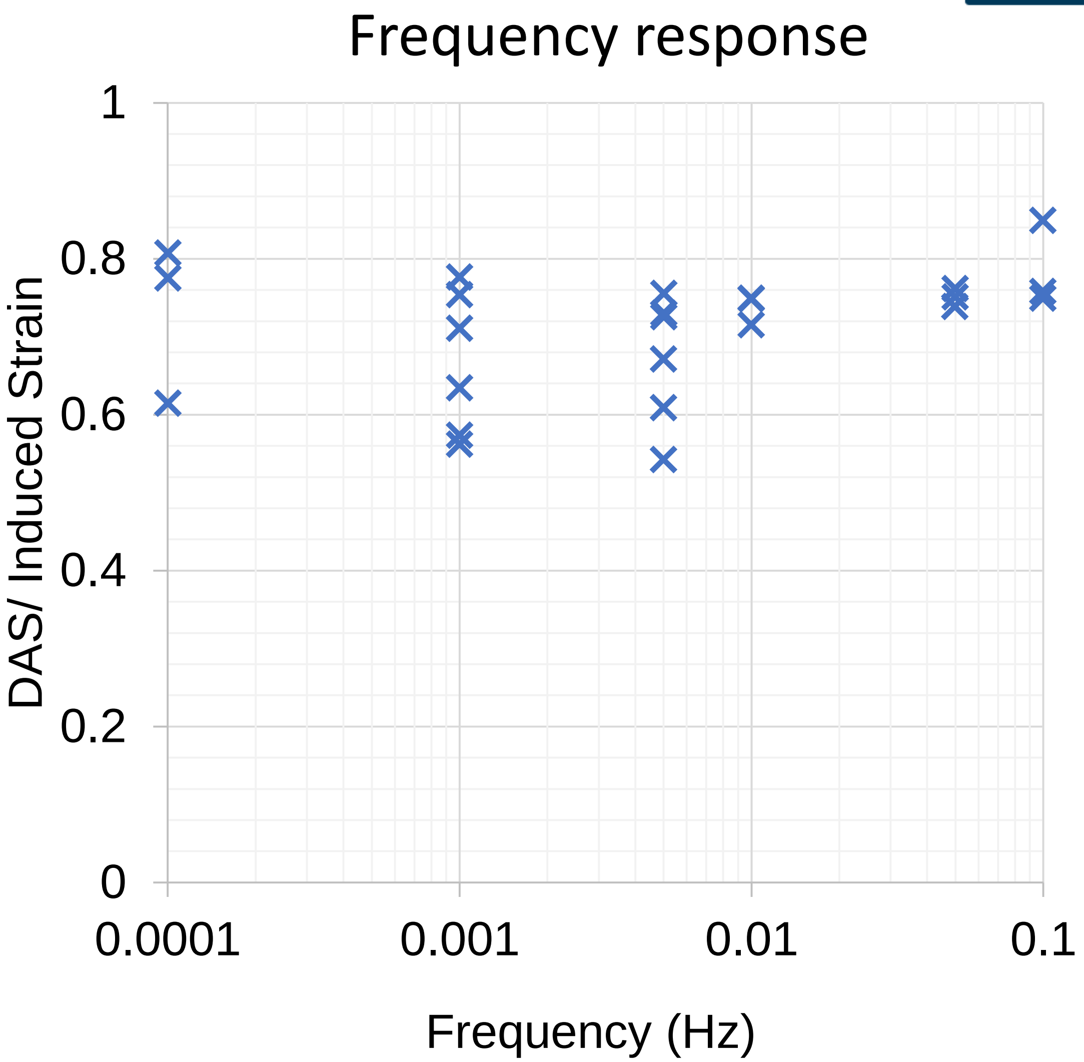




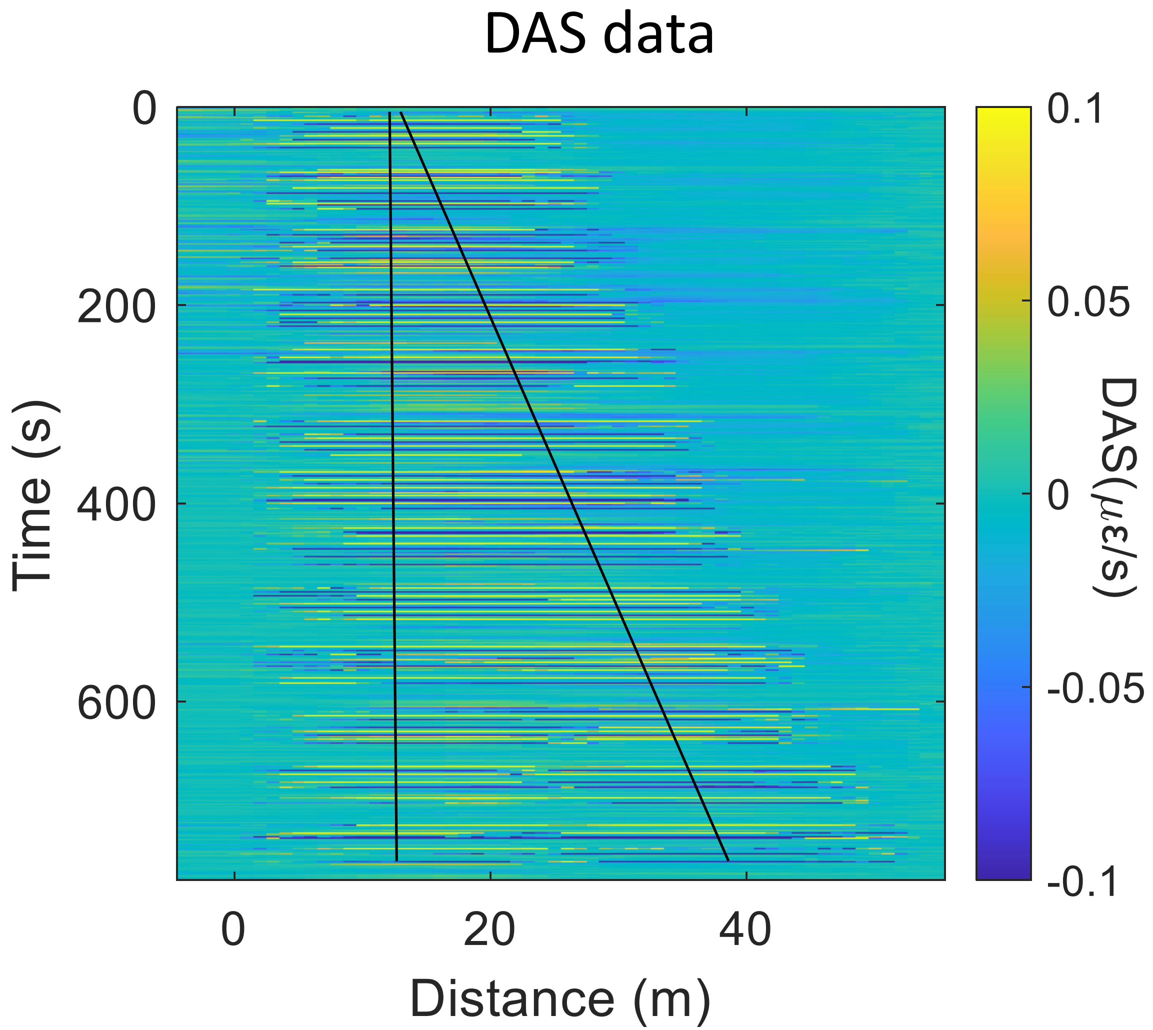
- Stretcher
  - Thorlabs actuator and optomechanical components
  - $\Delta\varepsilon = 2.7\ n\varepsilon$
- Silixa iDAS DAS
  - $L_g = 10\ \mathrm{m}$
  - $dx = 0.25\ \mathrm{m}$
- LUNA ODiSI OFDR
  - $dx = 0.0026\ \mathrm{m}$
- Bare/ Buffered/ Hybrid Cables

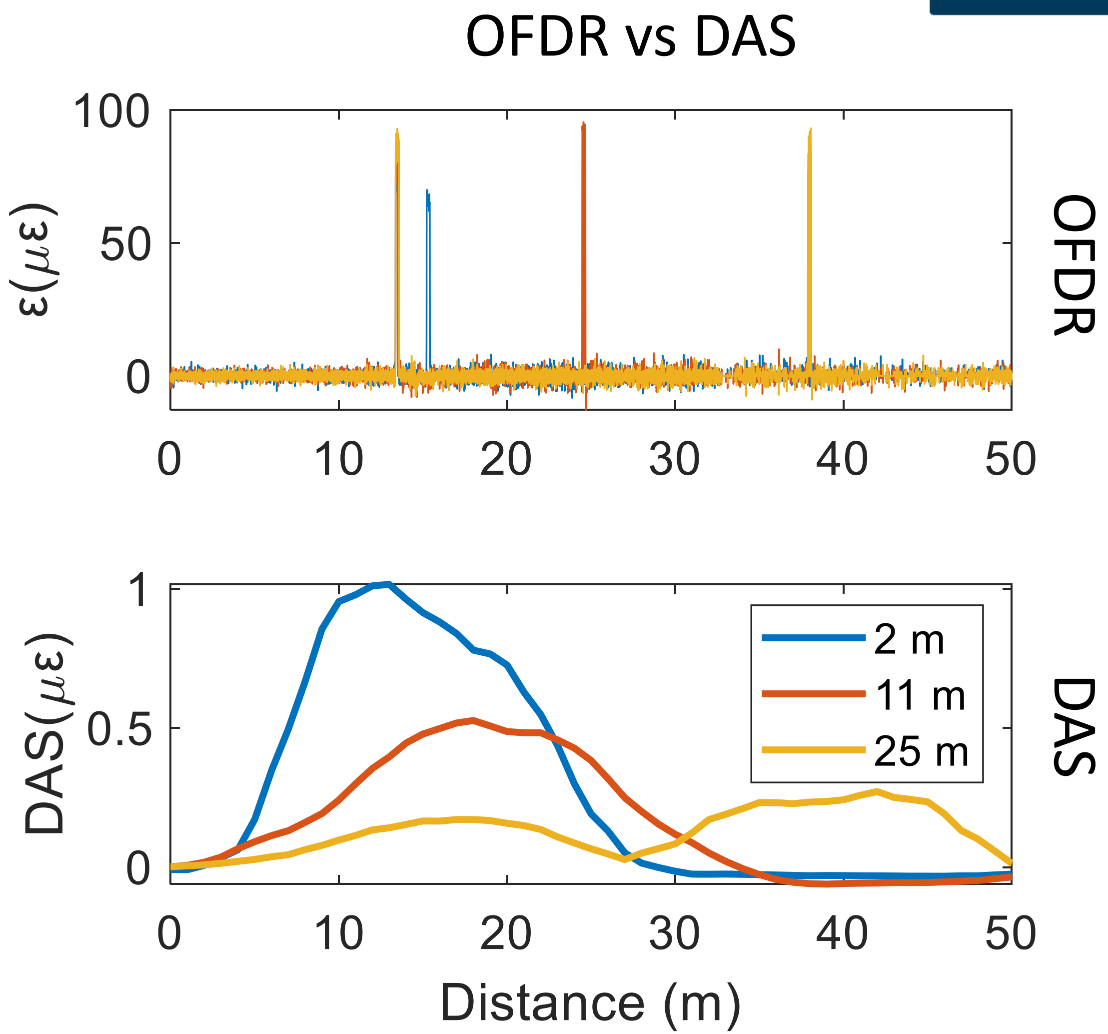
DAS Response



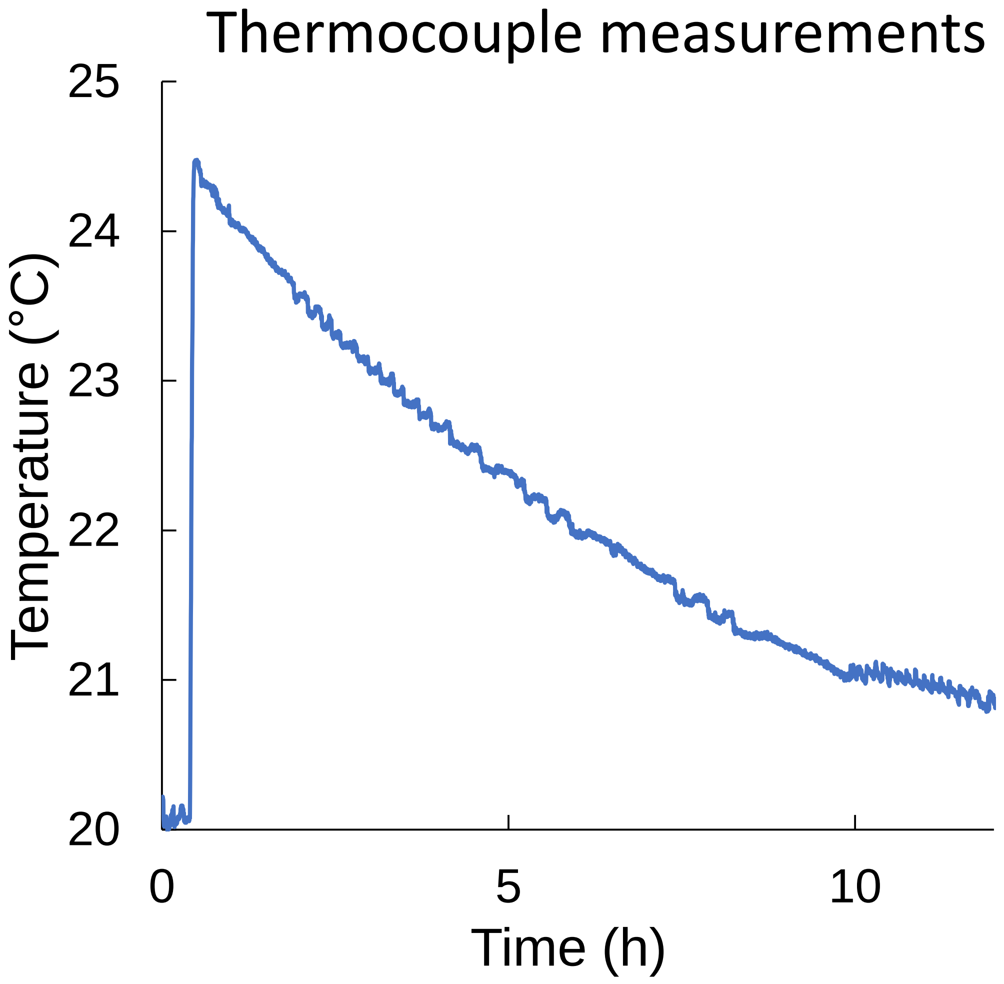


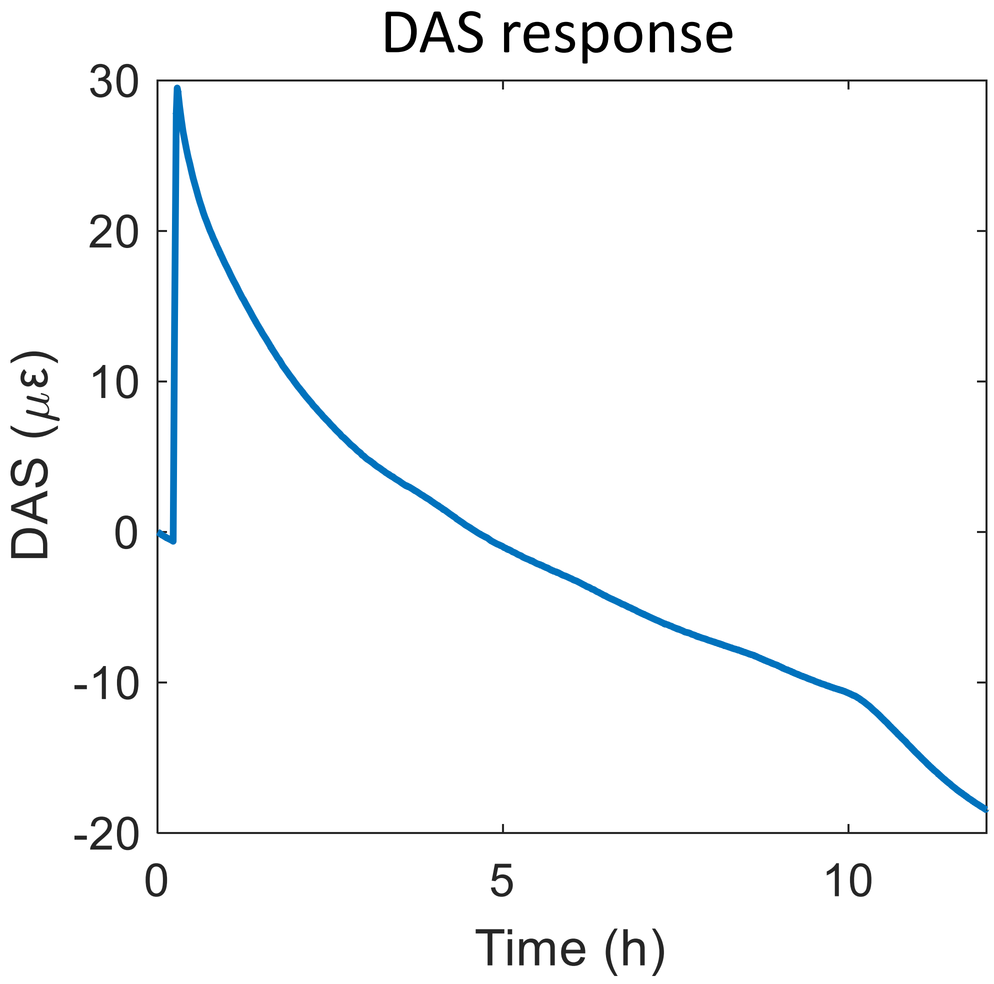
DAS Spatial Resolution





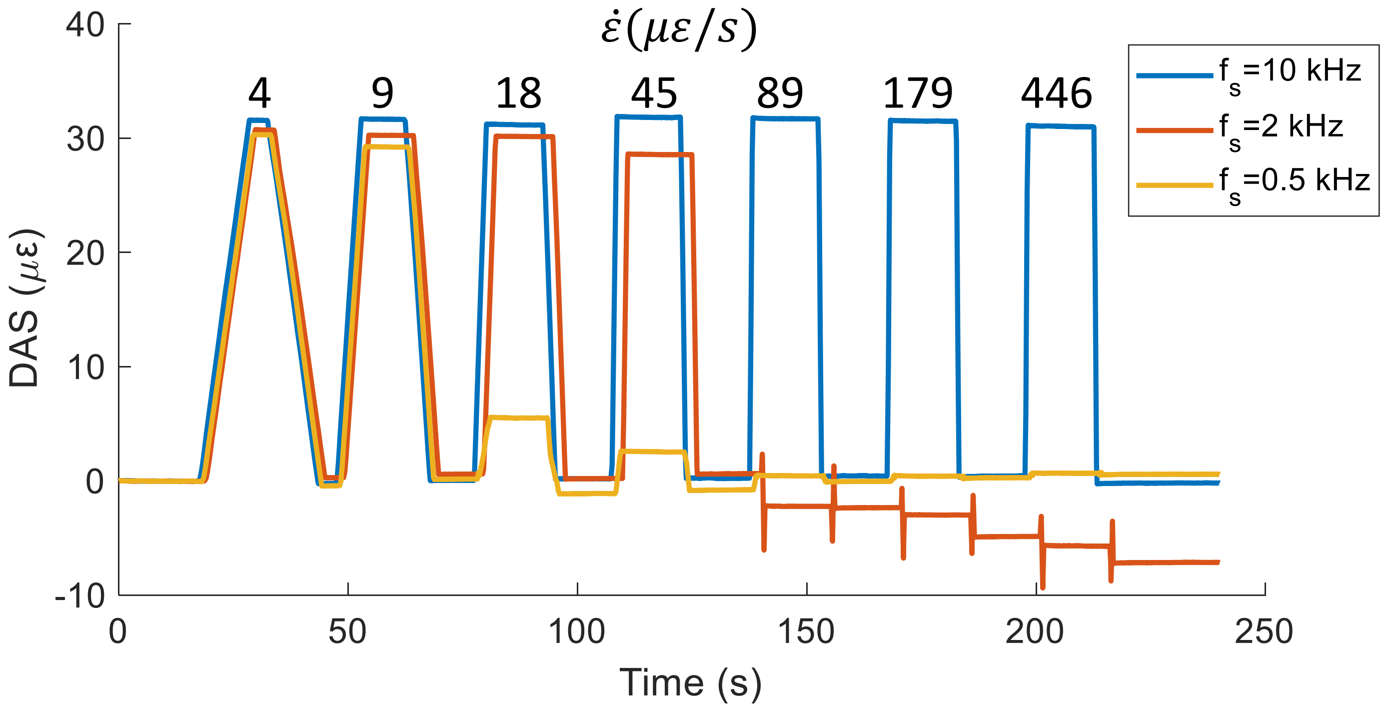
DAS Temperature Response

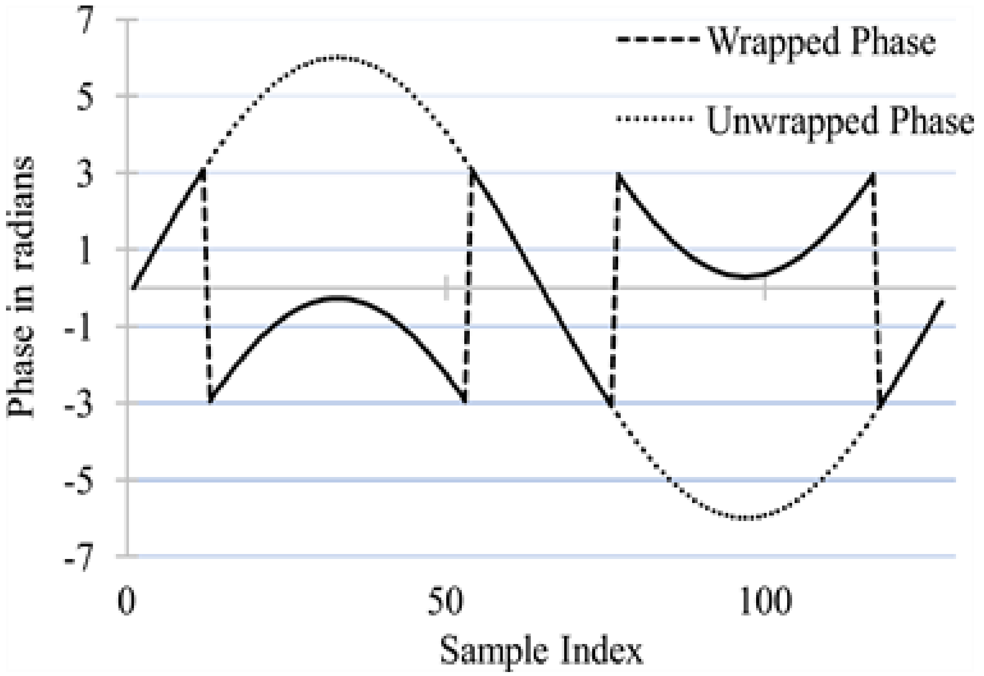




- Estimated $\Delta\varepsilon/\Delta T \approx 11.4\ \mu\varepsilon/°C$

DAS Dynamic Range





Maharjan et al. (2018)

$\Delta\phi = \frac{4\,\pi n\xi L_g}{\lambda}\varepsilon_z$, where n is the refractive index, λ is the probe wavelength, ξ is the photo-elastic coefficient, L_g is the gauge length (Hartog, 2017)

$$\varepsilon_{Z_{max}} = \frac{\lambda\Delta\phi_{max}}{4\,\pi n\xi L_g} = \frac{1550\ nm}{4\ \pi\cdot 1.45\cdot 0.78\cdot 10\ m}\Delta\phi_{max} = 10.9\cdot\pi \approx 35\ n\varepsilon$$

Linear Fiber Stretcher Experiments Conclusions

- Strain values extracted from DAS data are 20 to 30% smaller than the actual values

- DAS data are hardly influenced by temperature variation, and careful correction is needed

- The upper limit for a DAS system is about $35\ n\varepsilon$ per time sample

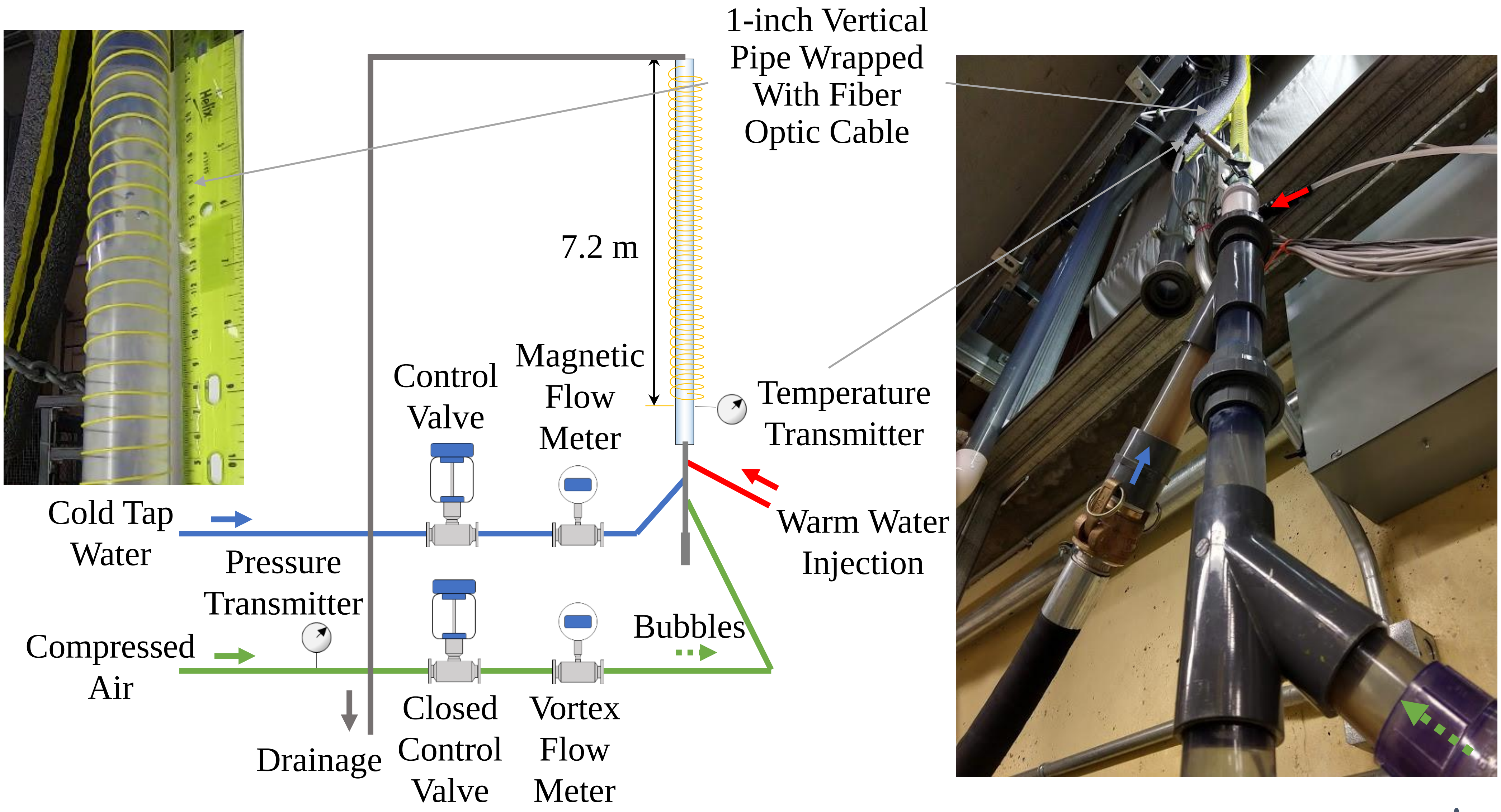
- DAS is not only a strain-rate “acoustic” sensor but also a strain measurement approach for slow geodetic processes as well as a temperature sensor

Flow Loop Experiments

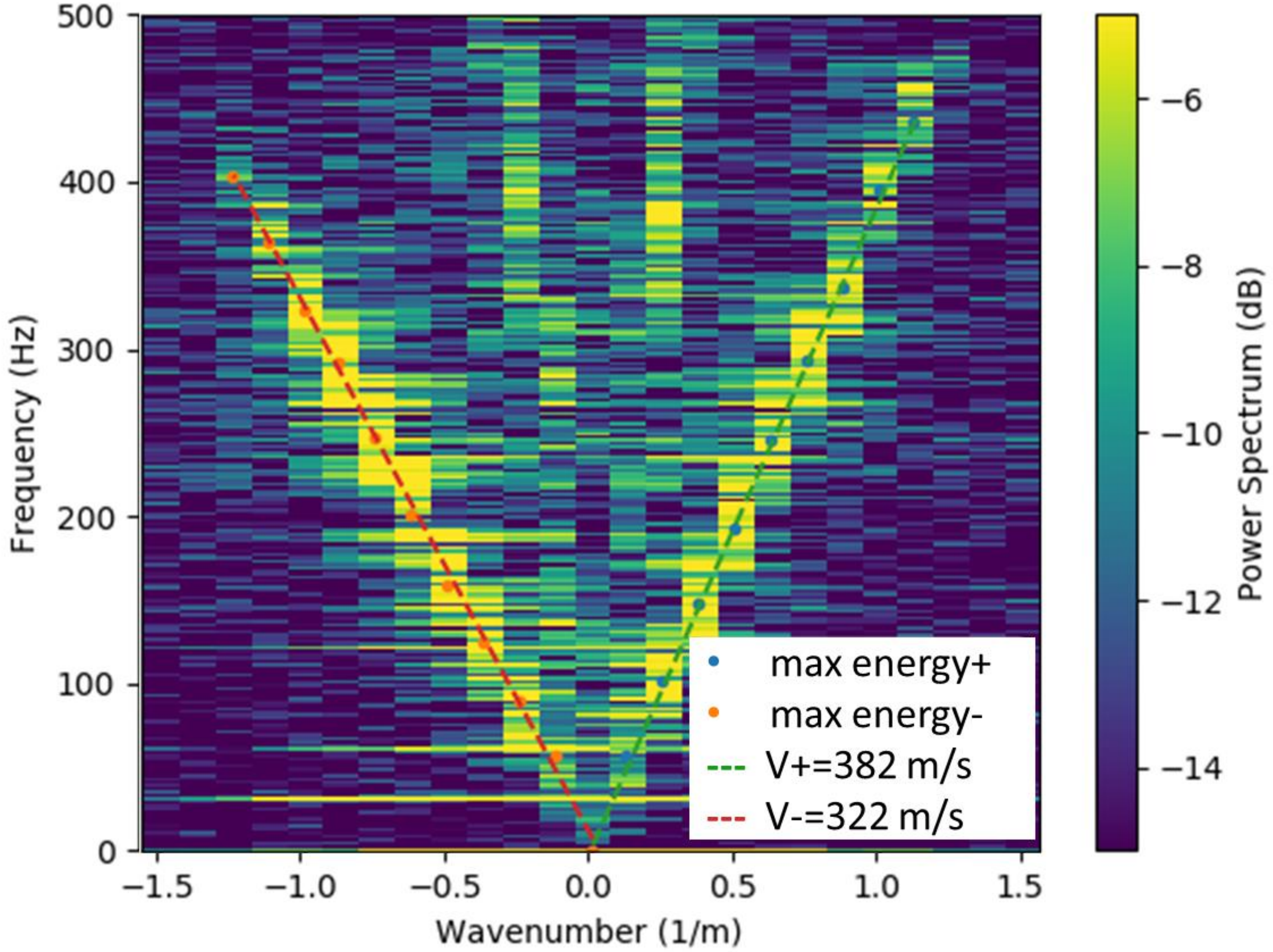
Aleksei Titov, Ge Jin, Yilin Fan, Kagan Kutun, Gary Binder, Jennifer Miskimins & Ali Tura;
EAGE Fibre Workshop 2020, SPE 2020

Special Thanks to Ana Garcia-Ceballos, Lisa LaFlame, Steve Cole, Martin Karrenbach

Vertical Flow Loop



Doppler Effect Approach



What Fluid is Flowing and How Fast?

$$c_{DAS} = \frac{382 + 322}{2} = 352\ m/s$$

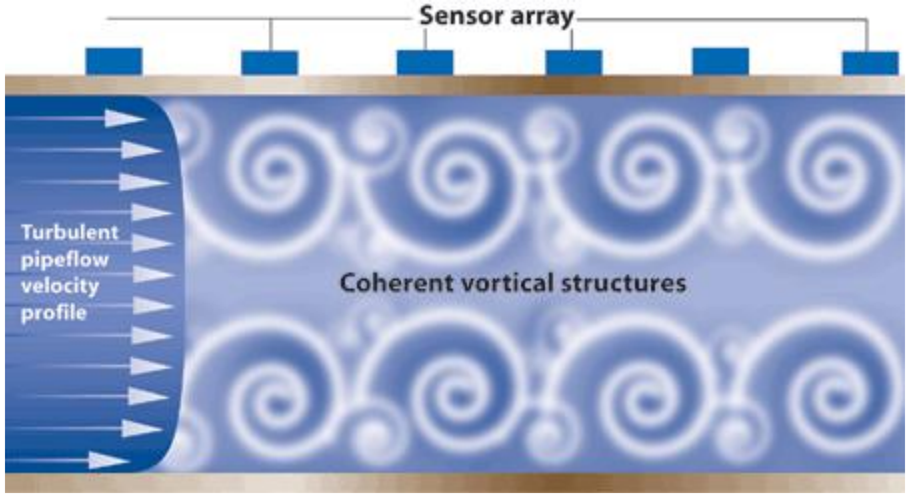
$$v_{DAS} = \frac{382 - 322}{2} = 30\ m/s$$

Air, 30 m/s

$$v_{Flowmeter} = 28\ m/s$$

Approach is described in e.g. Finfer et al. (2014)

Eddies Tracking Approach

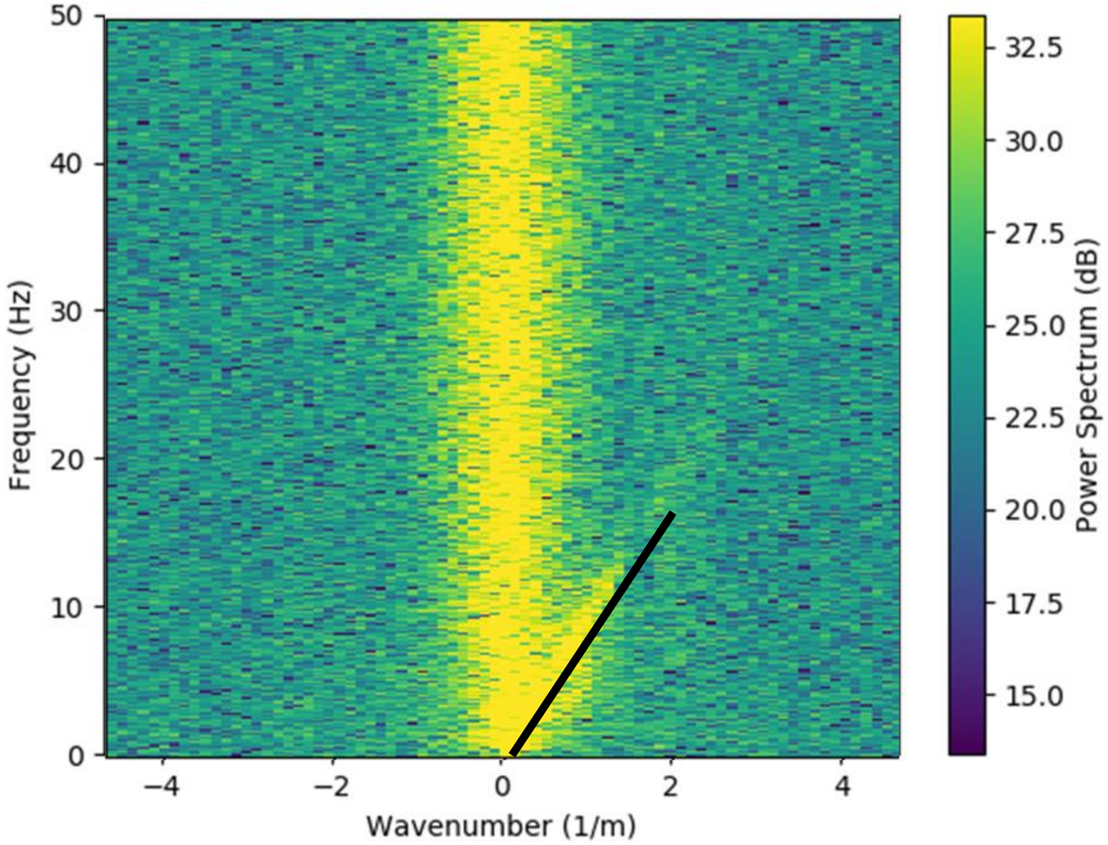


Gysling & Loose (2003)

Eddies found for $f < 20$ Hz:

- Asymmetric shape of F-K plot (propagation with the flow direction)
- Observed for different types of flow patterns

Approach is described in e.g. Finfer et al. (2014)

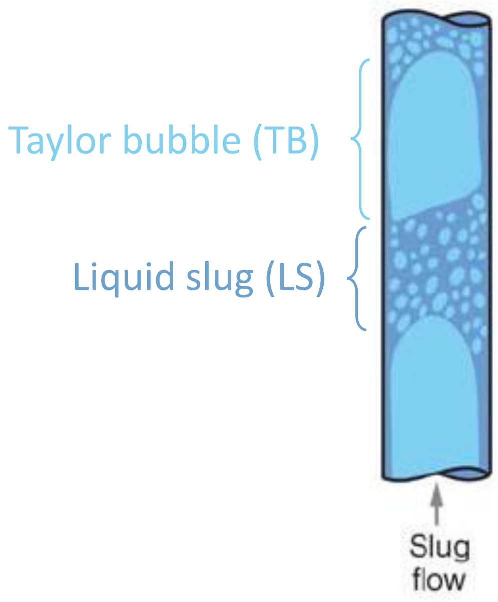


$v_{DAS} = 8\ m/s$

$v_{air} = 7\ m/s$

$v_{water} = 0.2\ m/s$

Slug Flow



- Slug flow is one of the most common flow patterns encountered in two-phase upward flows in vertical and inclined wellbores and facilities
- Real-time detection of such flow can prevent unnecessary cost (onset of liquid loading, electrical submersible pump damage, etc.)
- How we can use DAS to
  - Detect slug flow
  - Generate production log for slug flow
- What is the physics of acoustic and thermal energy generation, propagation, and attenuation?

Guet et al. (2006); Fan et al. (2019)

Data Processing Workflow

Video recording

RGB analysis

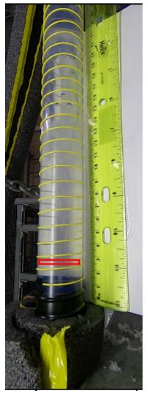
Cross-correlation

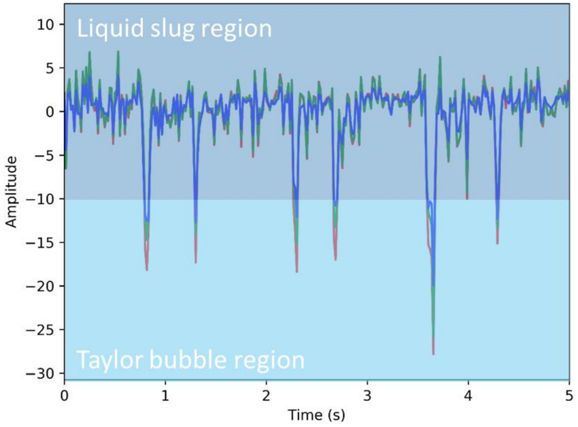
Spectral analysis

Bubble velocity v_B

Bubble rate f_B

Holdup H_L





DAS

Low-Frequency DAS (LFDAS)

Cross-correlation

Spectral analysis

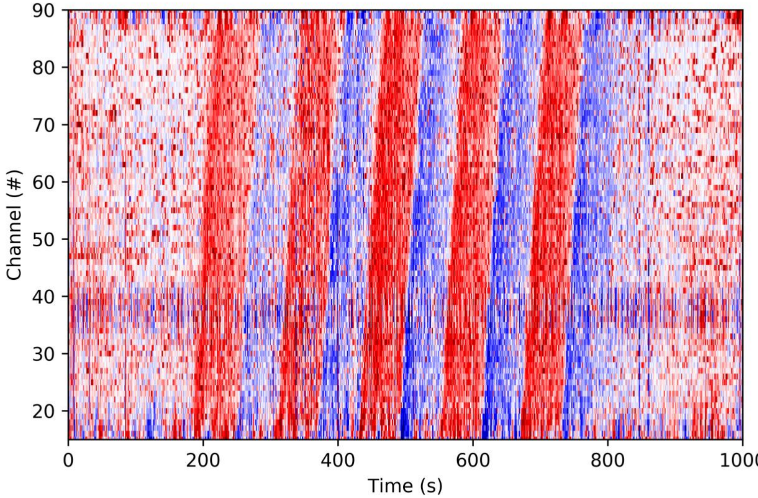
Multispectral analysis

Thermal slug velocity v_T

Thermal dissipation

Bubble velocity $\widetilde{v_B}$

Bubble size



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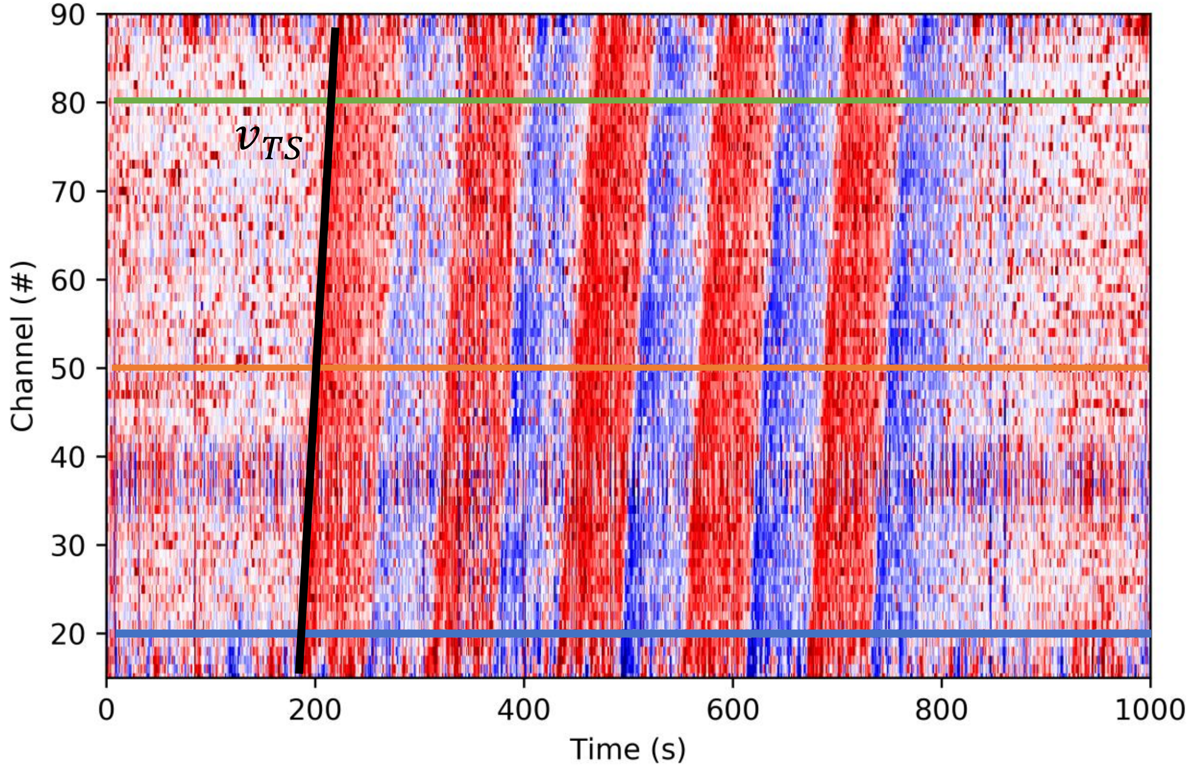
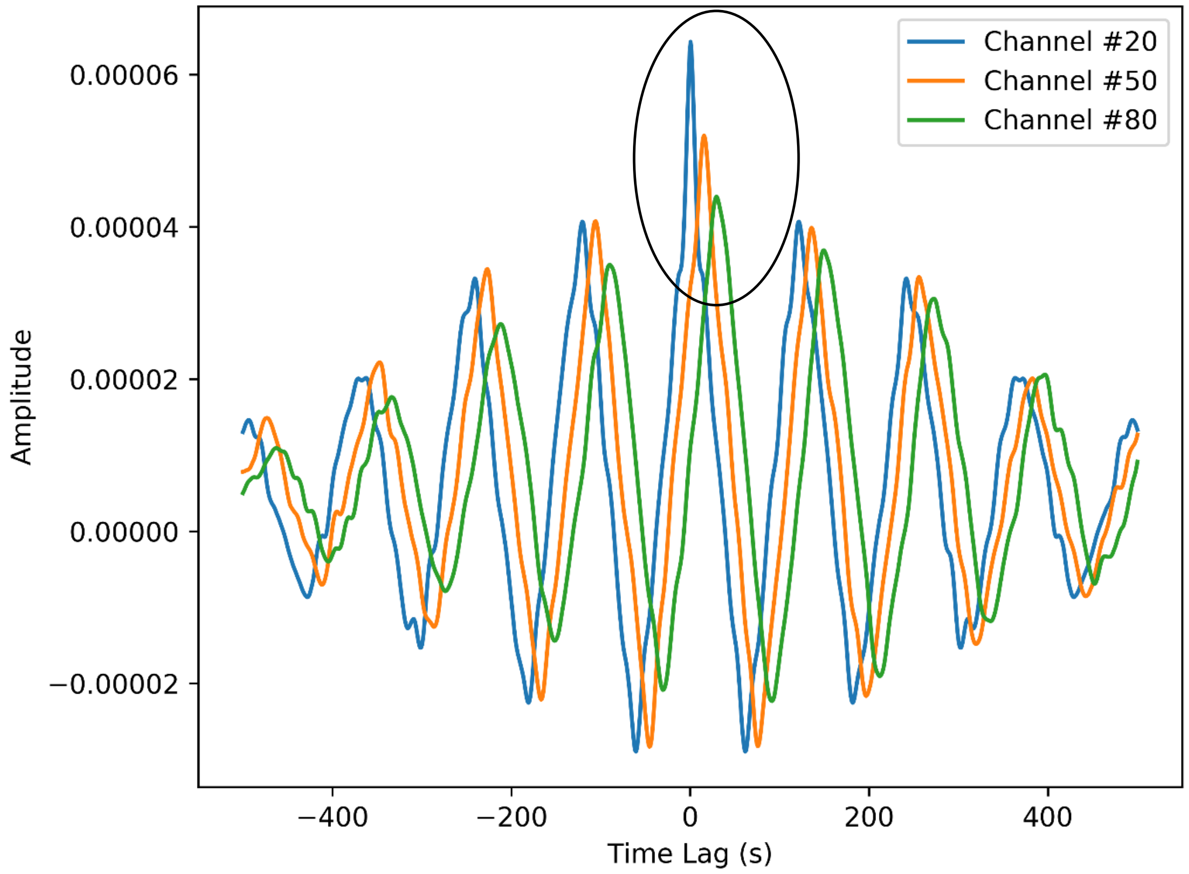
Cross-Correlation (Water Only)

LFDAS data ($< 0.5\ Hz$)



Cross-correlation with channel #20



- $v_T \approx 0.19$ m/s, similar to measured $v_w \approx 0.17$ m/s

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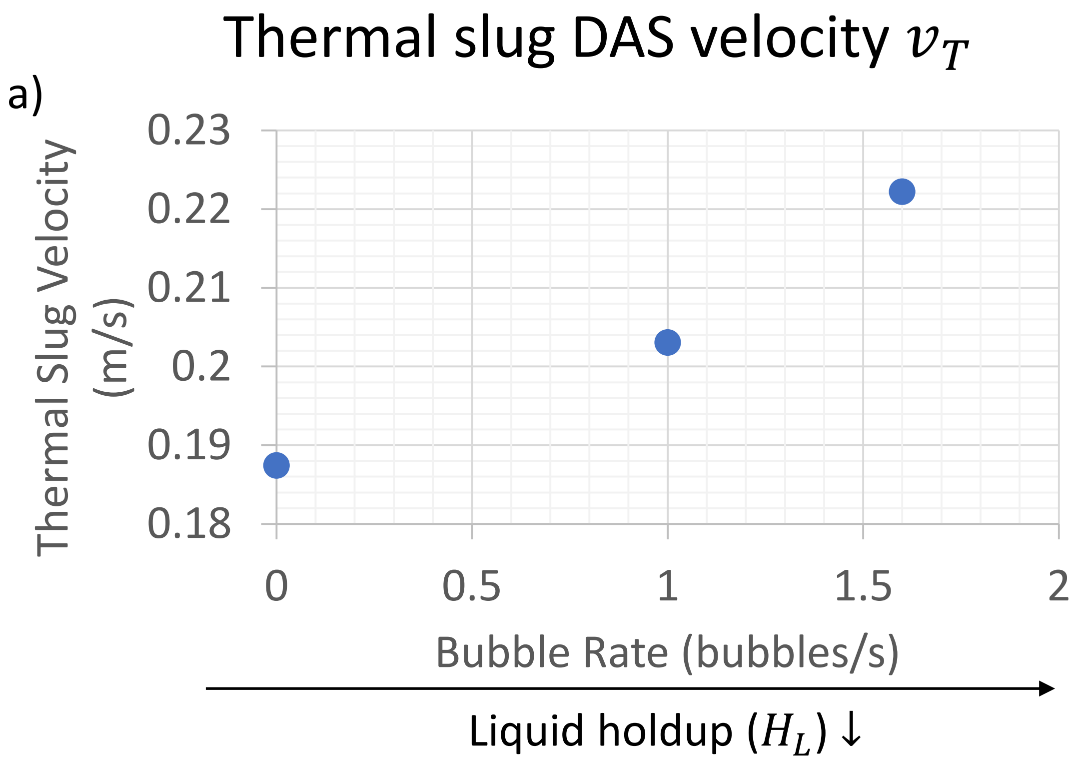
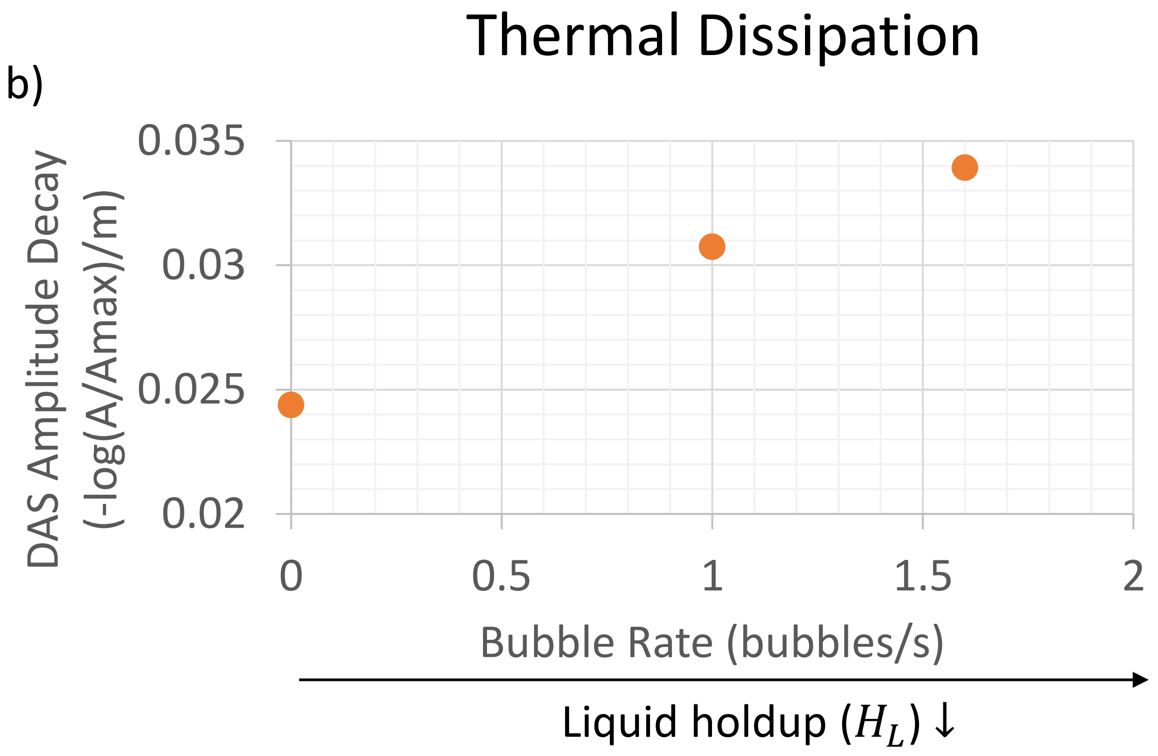
Results of Cross-Correlation Analysis

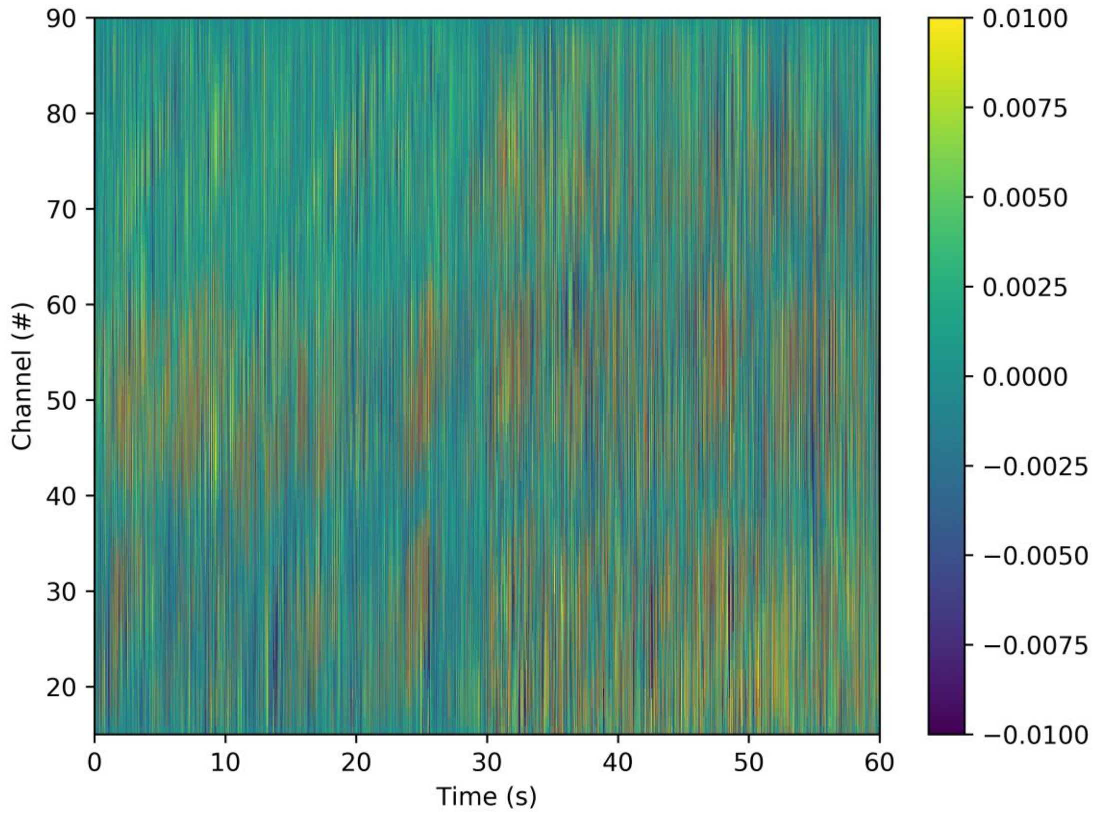




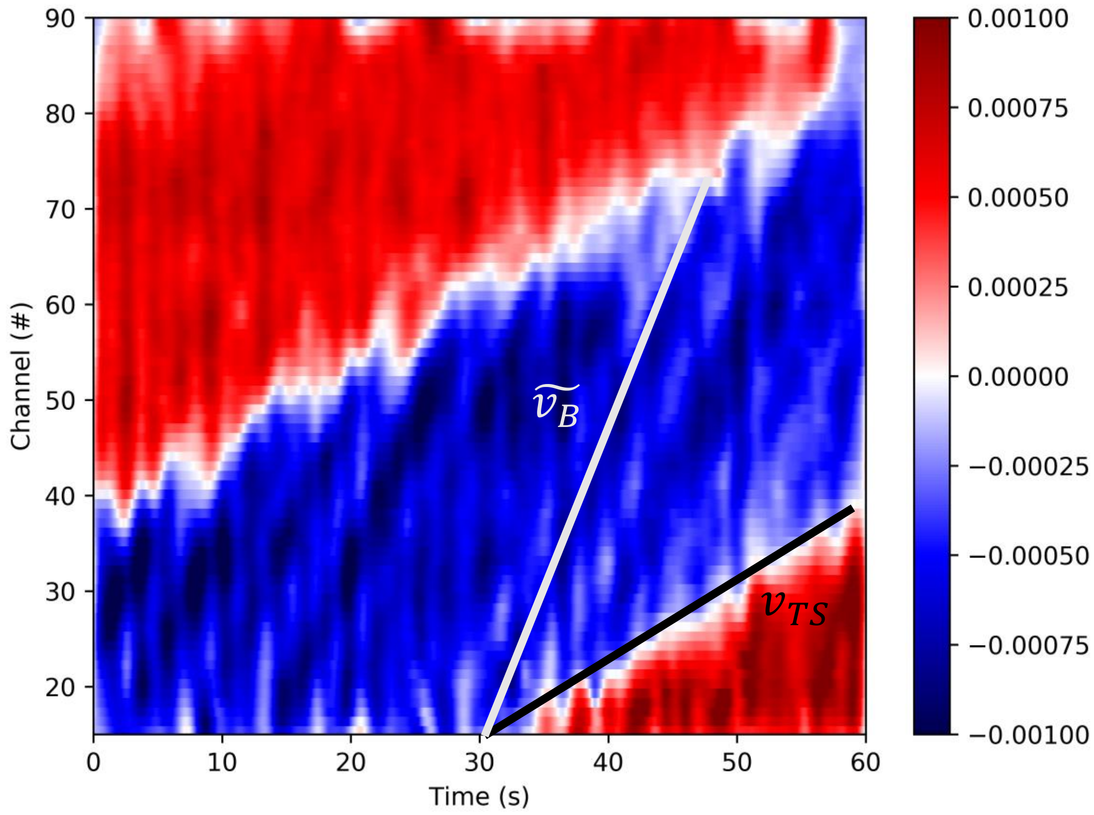
- $v_T \uparrow$ as $H_L \downarrow$. Effective pipe diameter for liquid fraction becomes smaller
- Heat exchange accelerates with f_B, due to increased turbulence

Velocities Extraction From LFDAS Data

Raw data

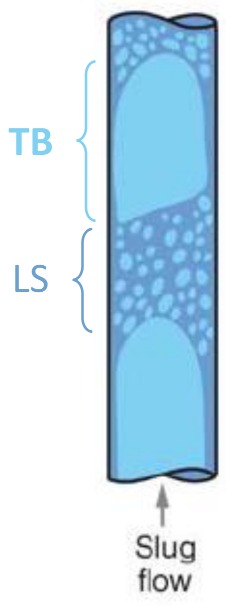


LFDAS data ($< 0.5\ Hz$)

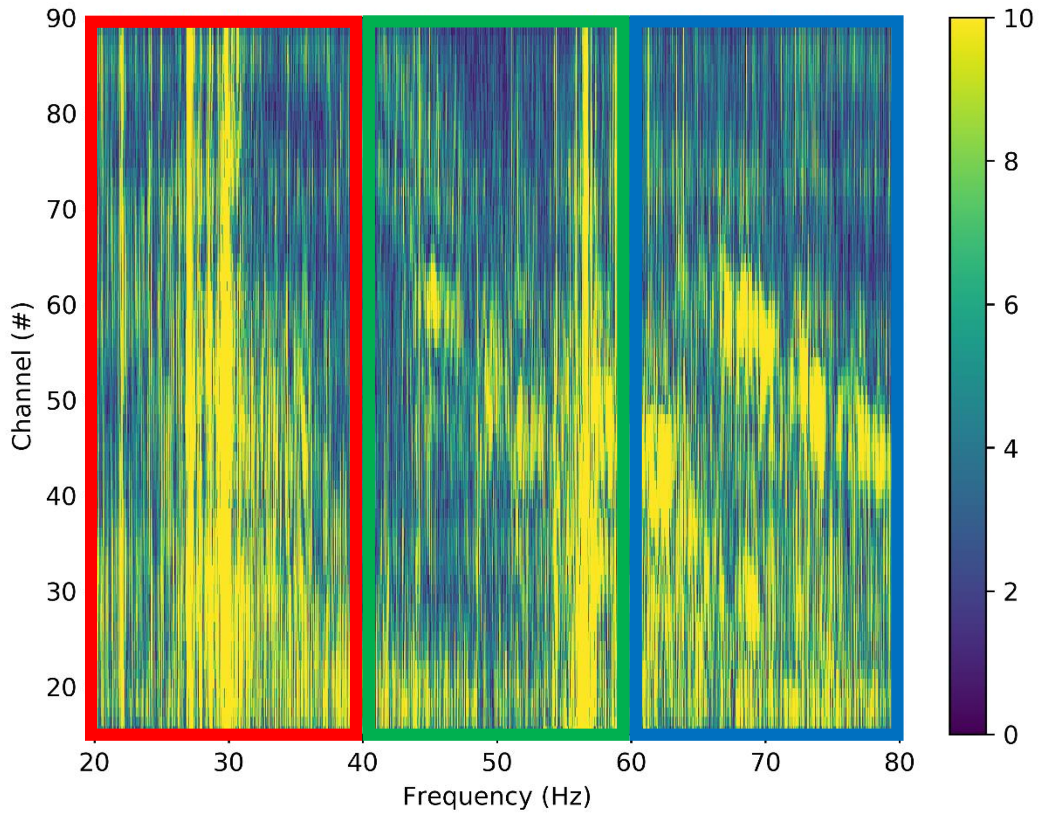


- $v_T \approx 0.075$ m/s, is slightly higher than $v_w \approx 0.070$ m/s
- $\widetilde{v_B} \approx v_B \approx 0.3$ m/s

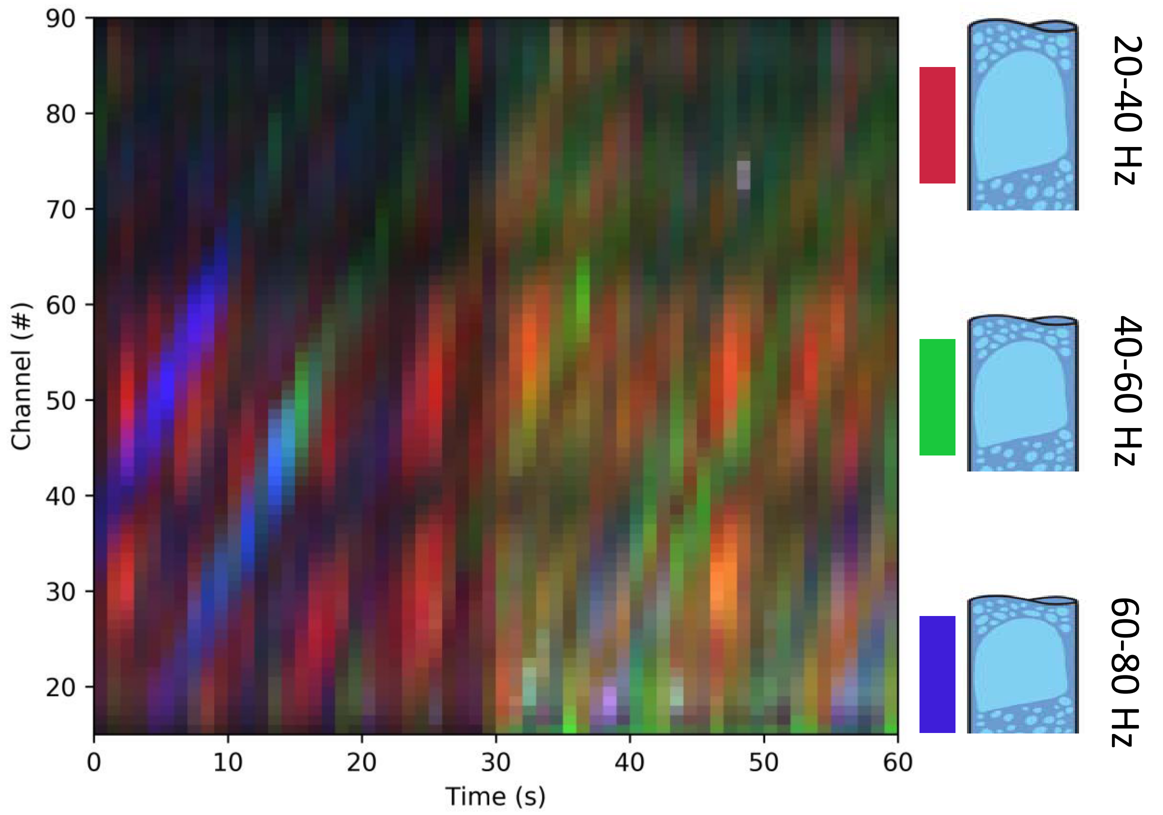
Multispectral Analysis & Bubble Size



Channel-by-channel variations of spectrum



Multispectral plot



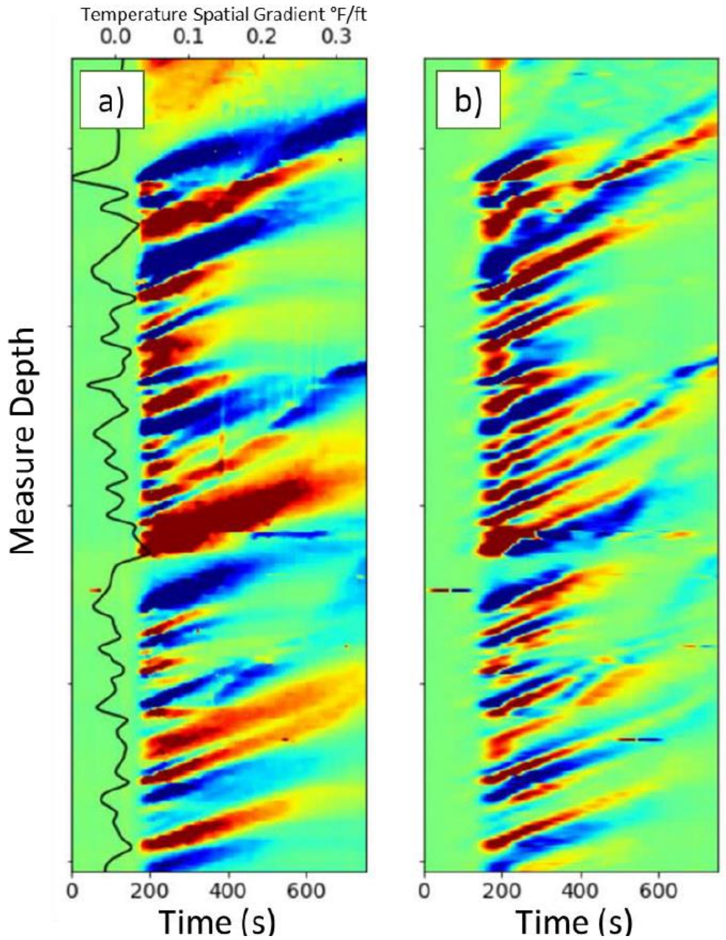
- DAS can be used to estimate size of a Taylor bubble

Flow Loop Experiments Conclusions

- Flow profiling with DAS can be implemented using Doppler effect and Eddies tracking
- Thermal slug velocity extracted from DAS data and evaluation of thermal dissipation allows characterizing two-phase slug flow
- Multispectral analysis of DAS data allows tracking velocity and estimate the size of the Taylor bubble

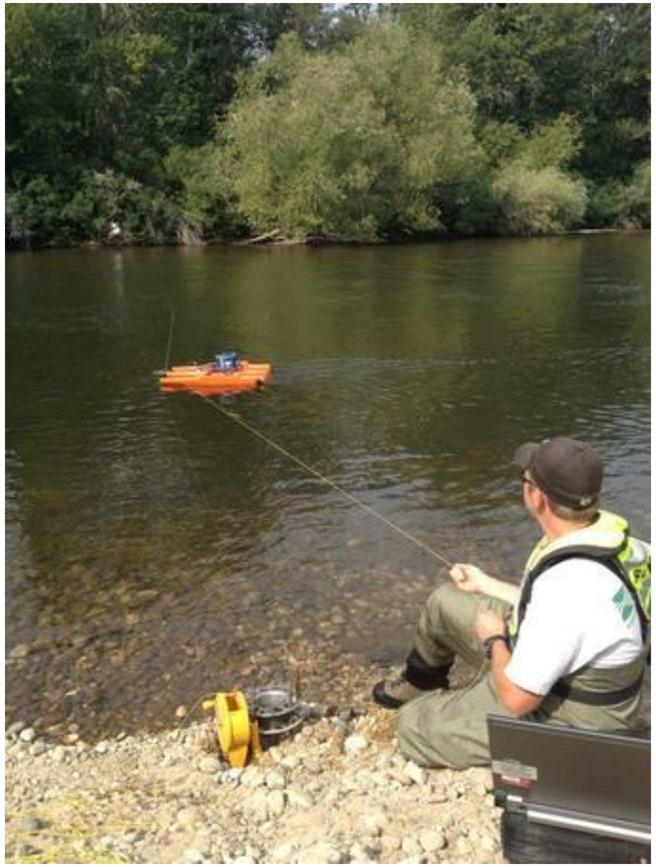
DAS is More Than Seismometer Array

DAS as thermometer (10^{-5} °C)



Thermal DAS flow profiling
Jin et al. (2019)

DAS as Doppler current profiler



Streamflow measuring
Credit: Tim Merrick, USGS

DAS as sensitive microphone

Methane bubble
Credit: BBC

Acknowledgements

from RCP to:

Thank you to Phase XVIII Consortium Members

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from LBNL to: Edna Bailey Sussman Fund, US DoD SERDP grant RC-2437, USDOE DE-AC02-05CH11231, NSF GRFP and SILIXA

Thank you!

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