Passive monitoring using traffic noise recordings - case study on the Steinachtal Bridge

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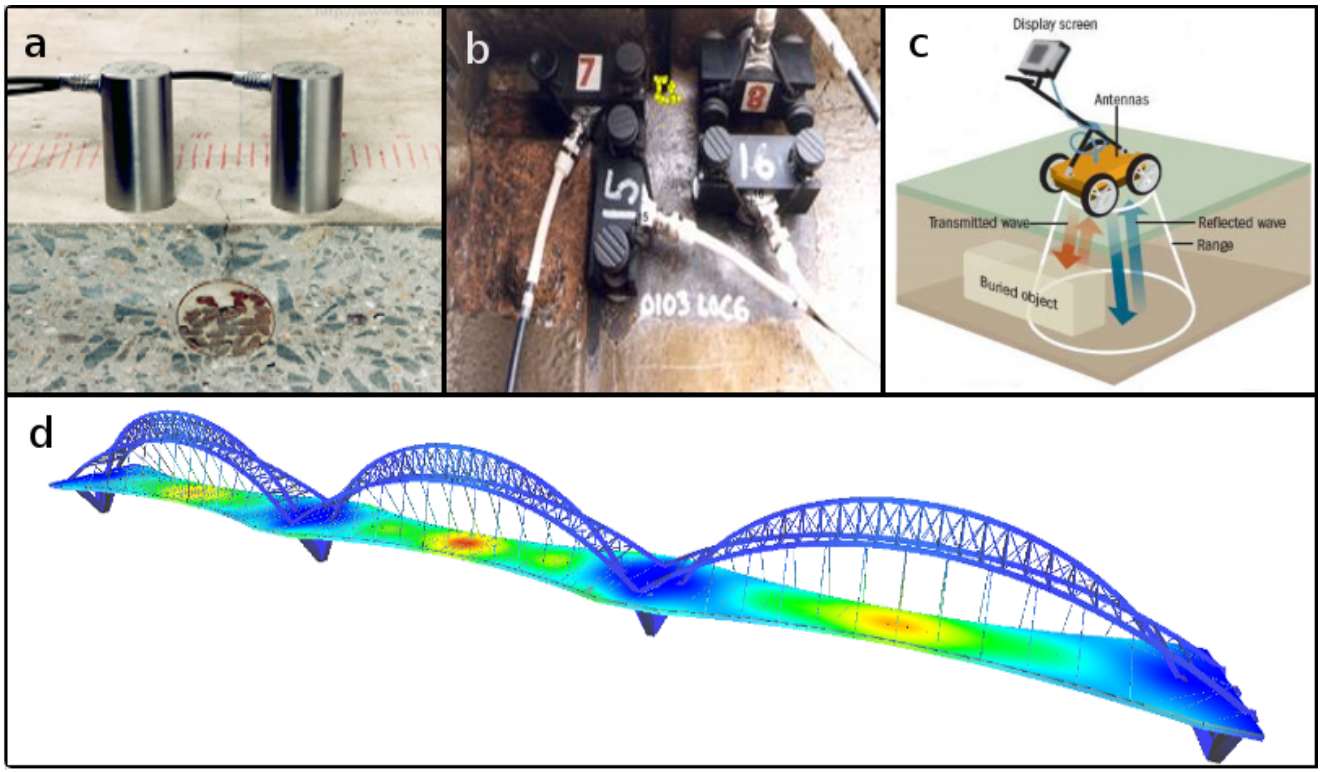
Objective

Is it possible to use ambient and/or traffic noise to monitor small-scale structures?

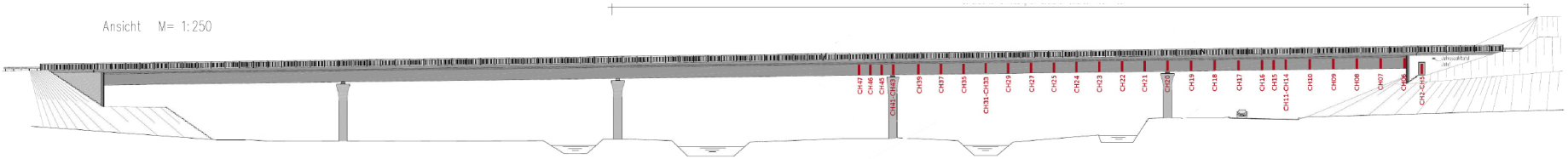
Motivation

Issue: Combination of **precise** and **permanent** monitoring with a **simple** measurement setup and evaluation technique.



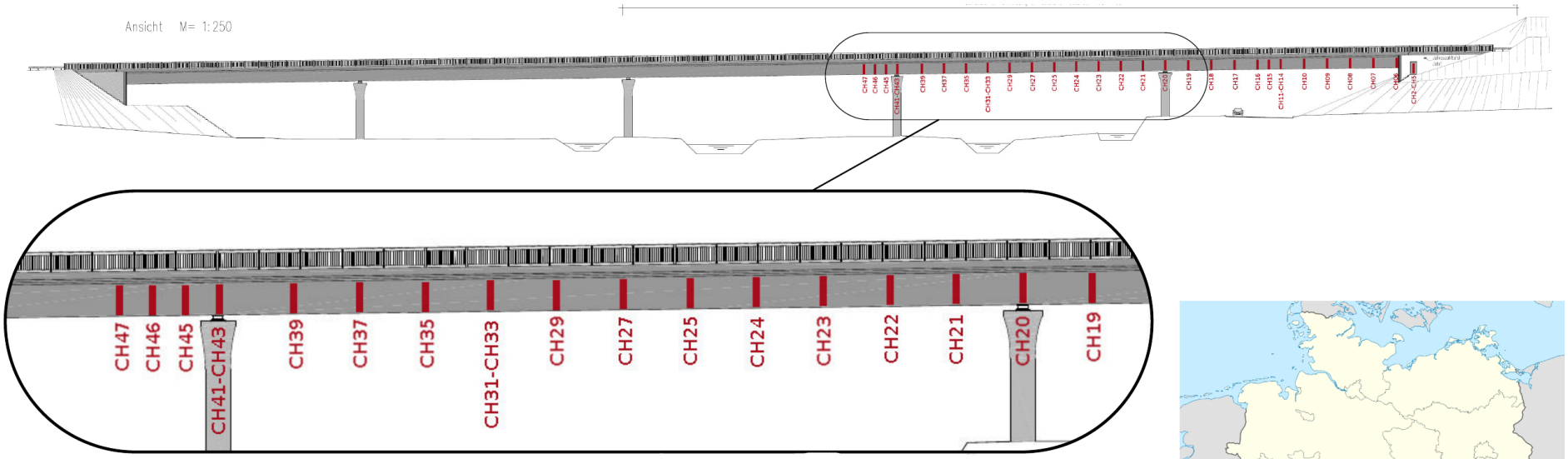
Measurement Setup I

lateral view (Geophone positions)

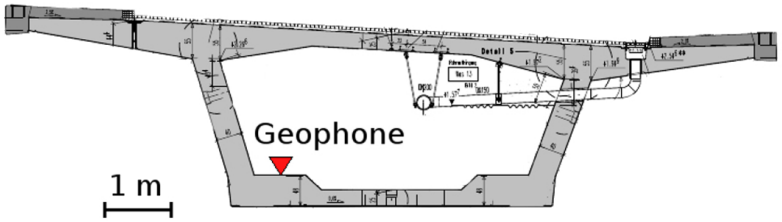


Measurement Setup I

lateral view (Geophone positions)

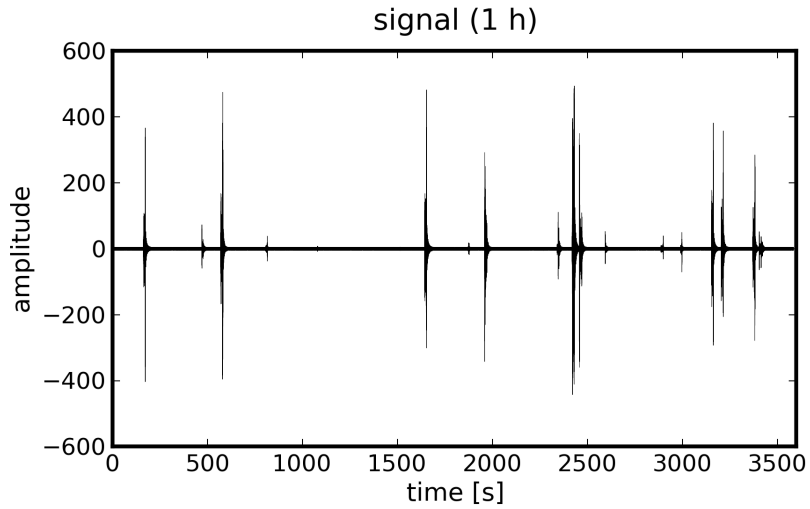


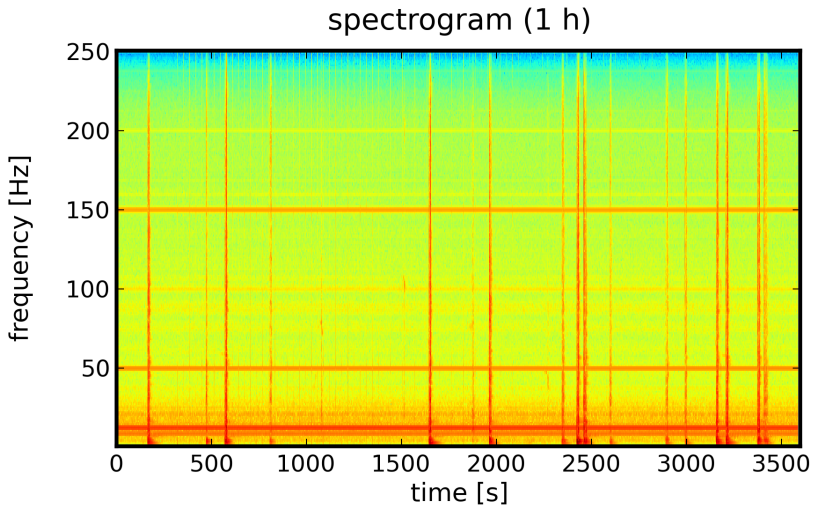
cross-section



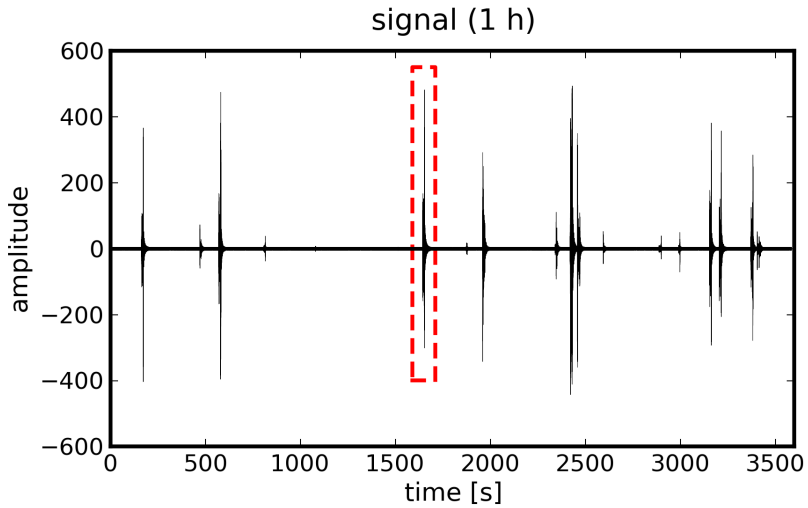
Measurement Setup II: Steinachtal Bridge

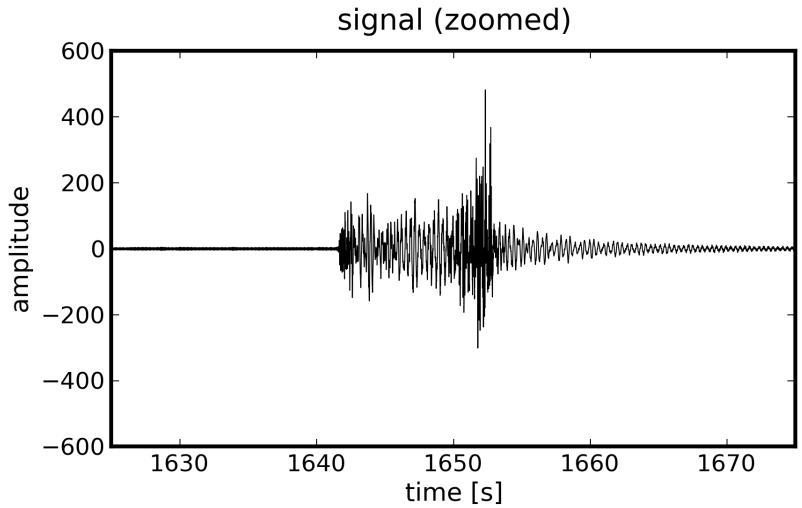
Raw Signal

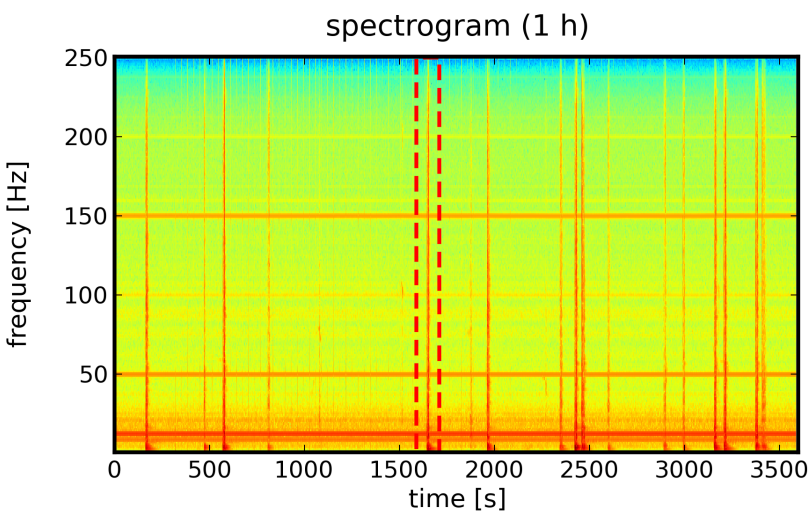

signal (1 h)
amplitude
time [s]
600
400
200
0
−200
−400
−600
0
500
1000
1500
2000
2500
3000
3500

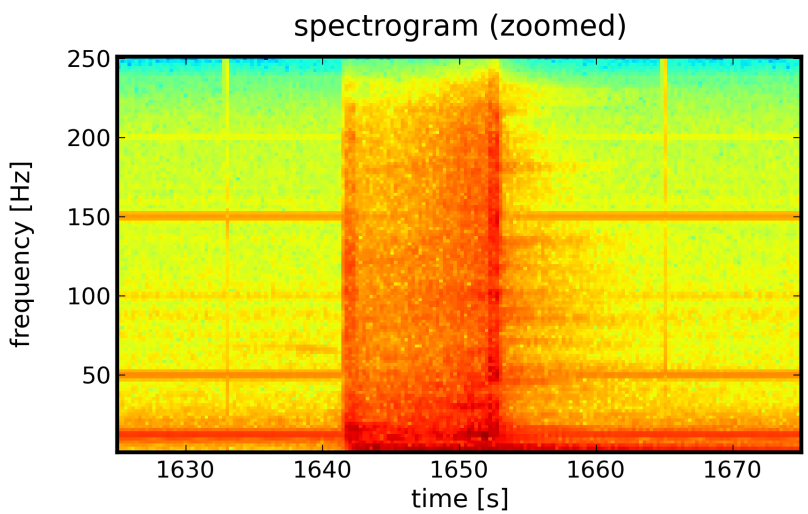

spectrogram (1 h)
frequency [Hz]
time [s]
250
200
150
100
50
0
500
1000
1500
2000
2500
3000
3500

Raw Signal

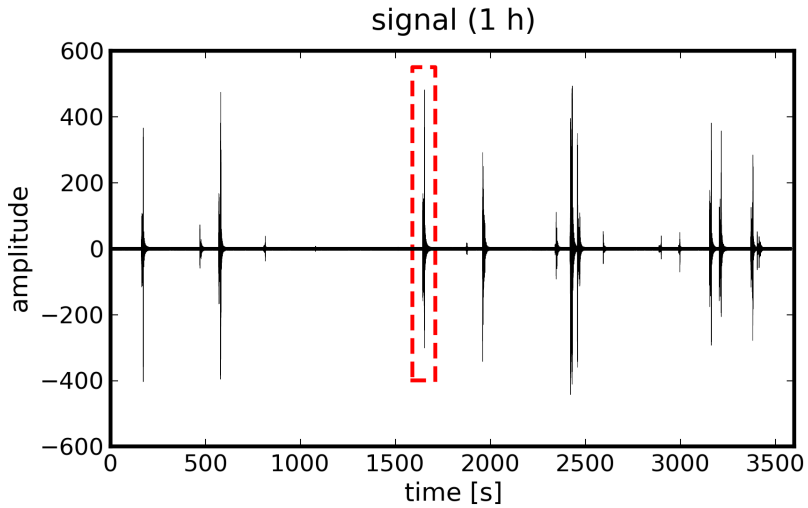

signal (1 h)
amplitude
time [s]

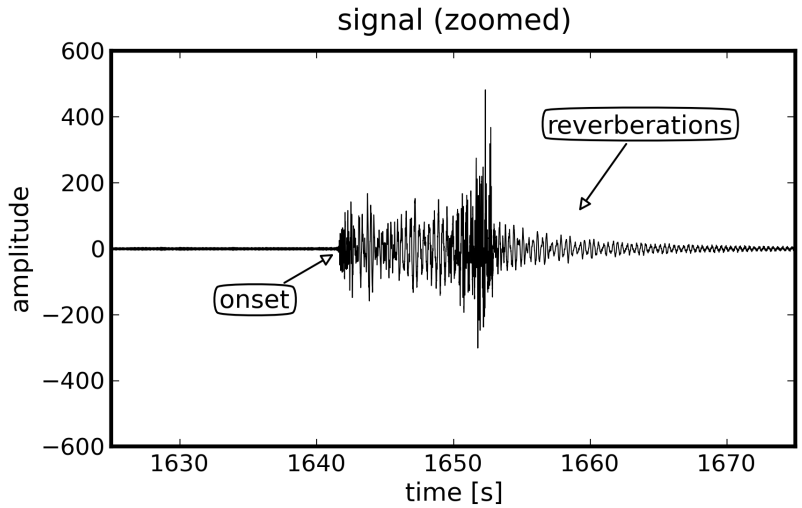

signal (zoomed)
amplitude
time [s]

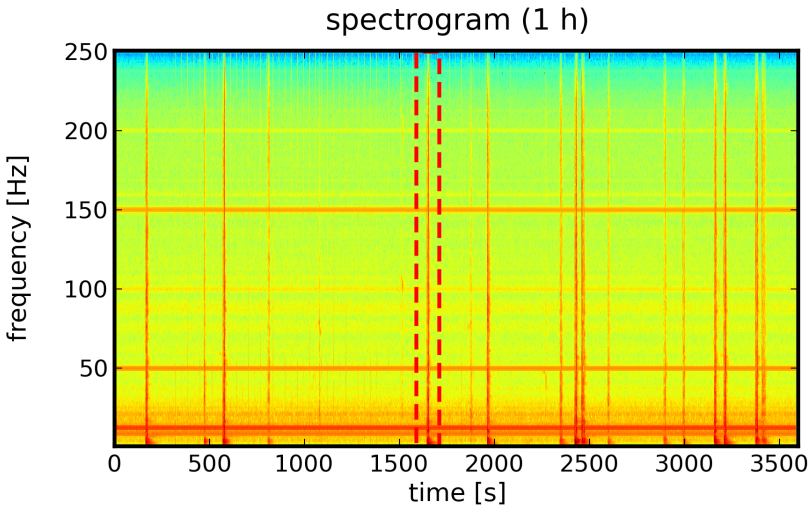

spectrogram (1 h)
frequency [Hz]
time [s]

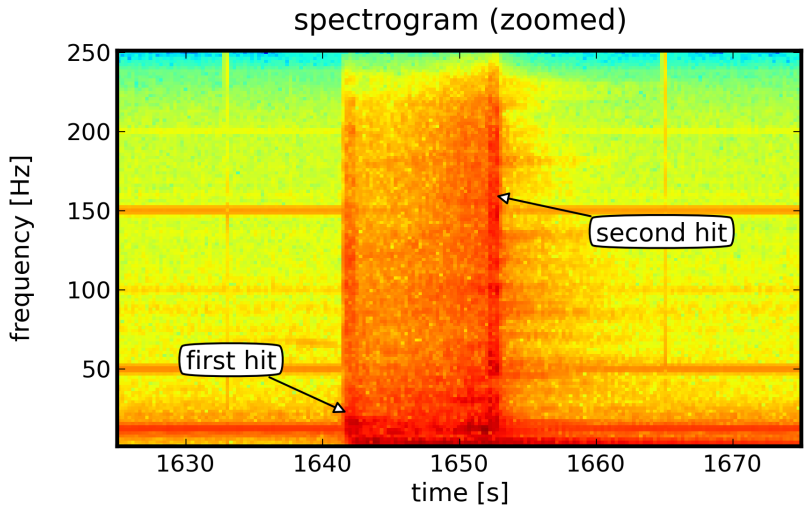

spectrogram (zoomed)
frequency [Hz]
time [s]

Raw Signal

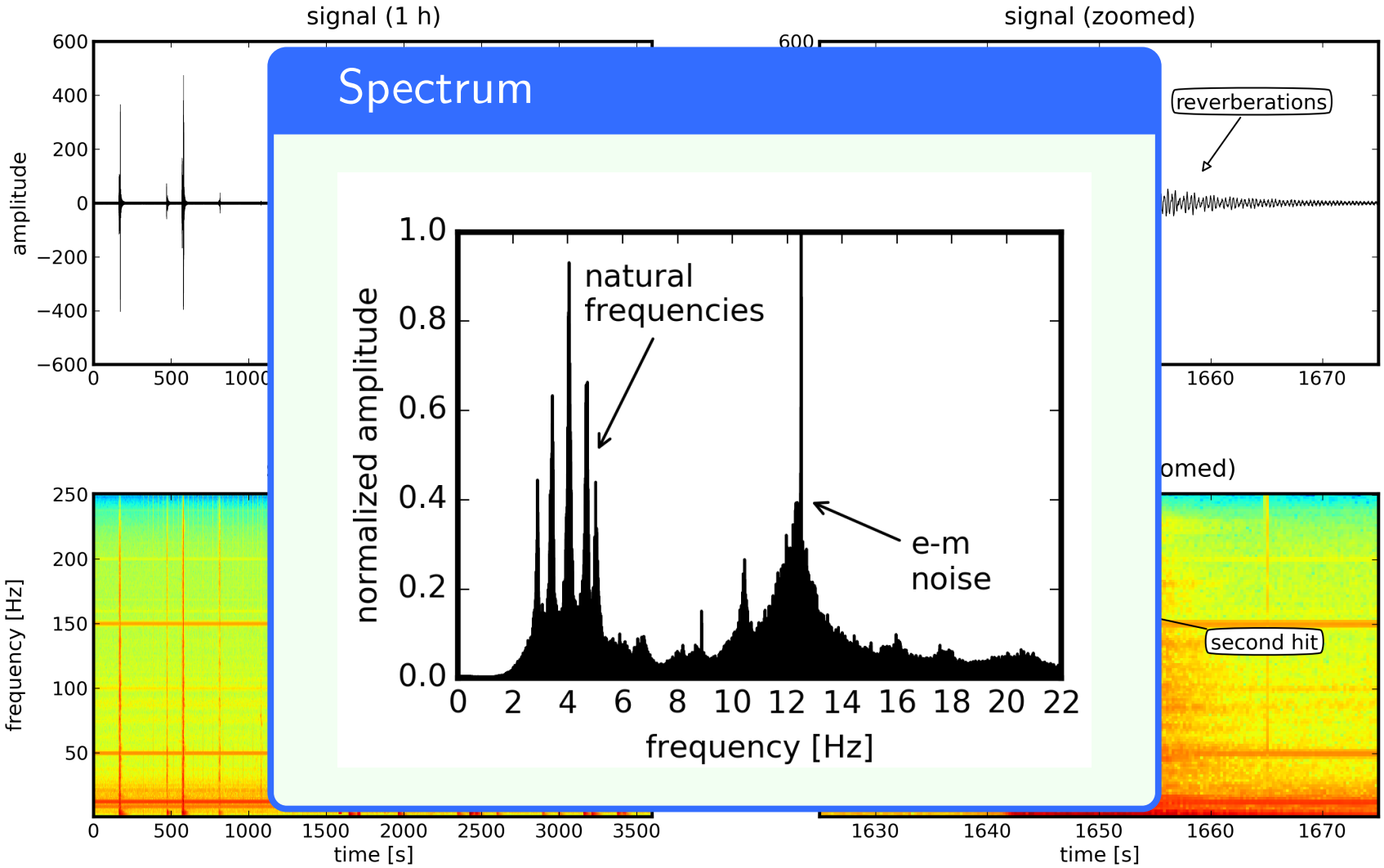

signal (1 h)
amplitude
time [s]


signal (zoomed)
reverberations
onset
amplitude
time [s]

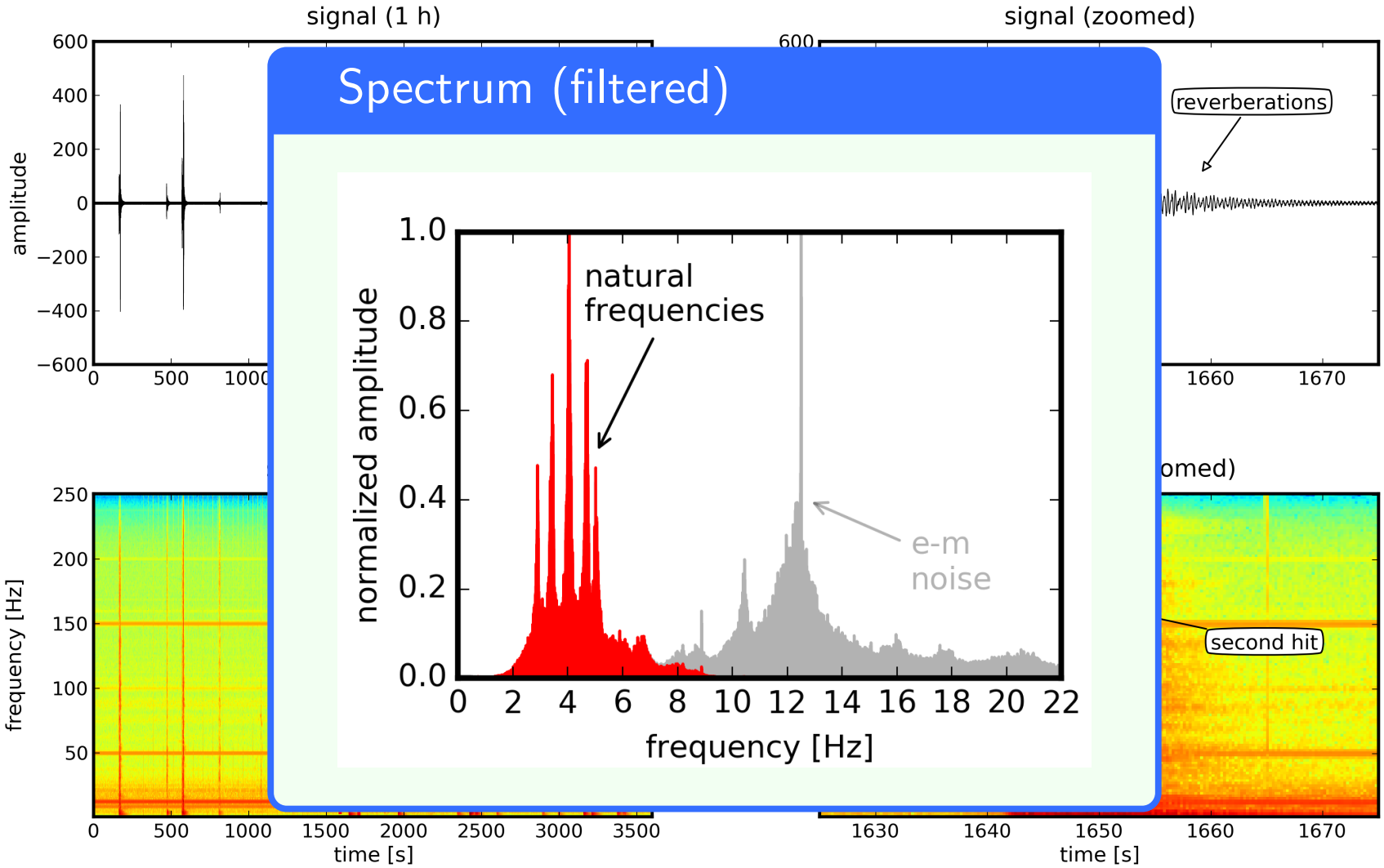

spectrogram (1 h)
frequency [Hz]
time [s]


spectrogram (zoomed)
second hit
first hit
frequency [Hz]
time [s]

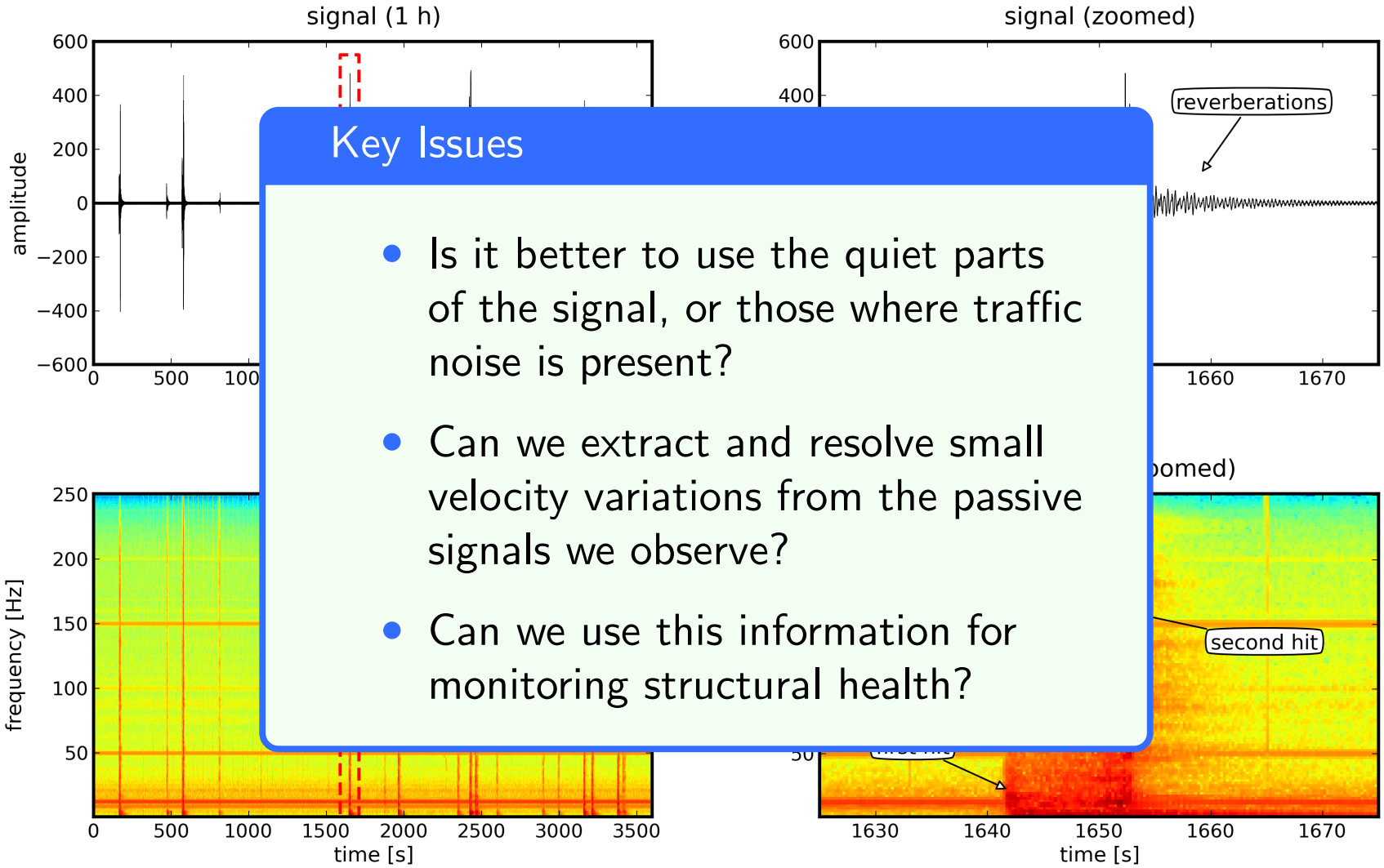
Raw Signal


signal (1 h)
signal (zoomed)
amplitude
reverberations
frequency [Hz]
second hit
time [s]
time [s]
Spectrum
normalized amplitude
natural frequencies
e-m noise
frequency [Hz]

Raw Signal


signal (1 h)
signal (zoomed)
amplitude
reverberations
Spectrum (filtered)
normalized amplitude
natural
frequencies
e-m
noise
frequency [Hz]
omed)
second hit
frequency [Hz]
time [s]
time [s]

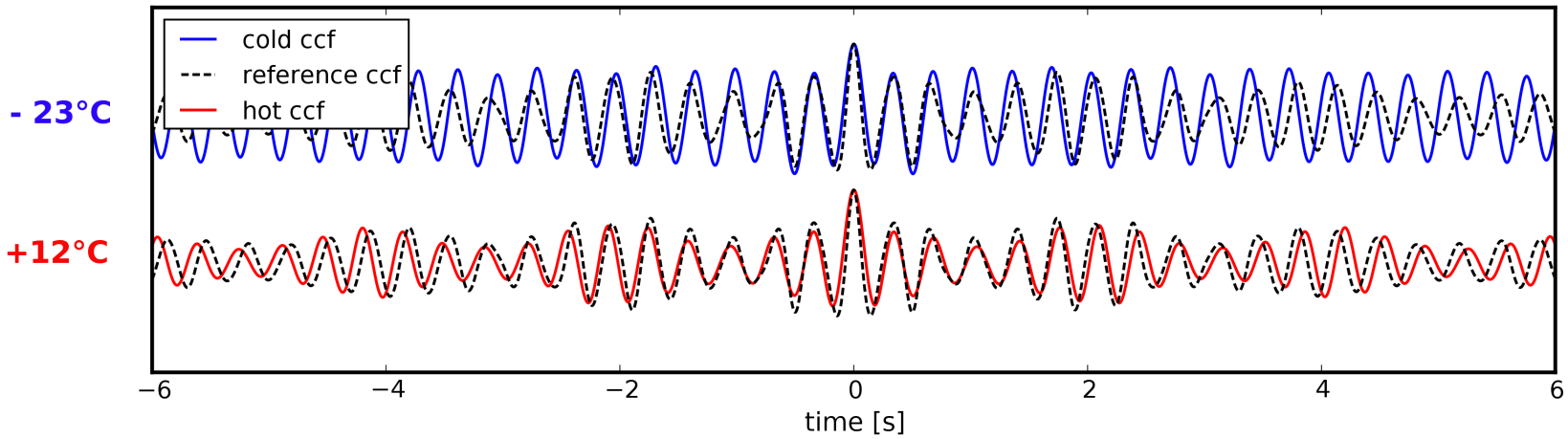
Raw Signal



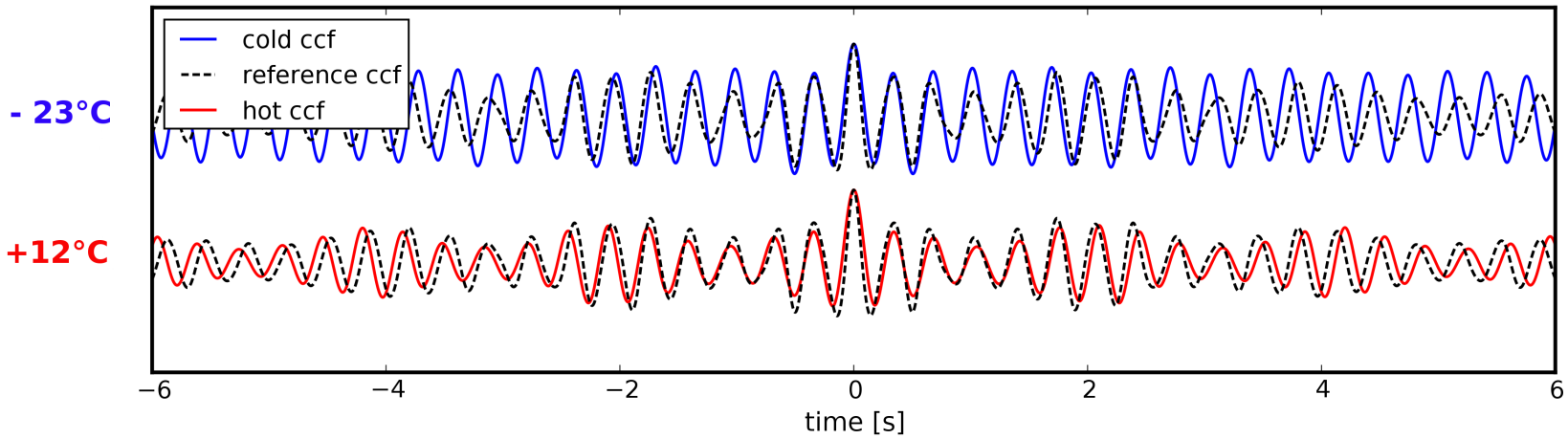
Key Issues

- Is it better to use the quiet parts of the signal, or those where traffic noise is present?
- Can we extract and resolve small velocity variations from the passive signals we observe?
- Can we use this information for monitoring structural health?

CWI & Cross-correlations



CWI & Cross-correlations



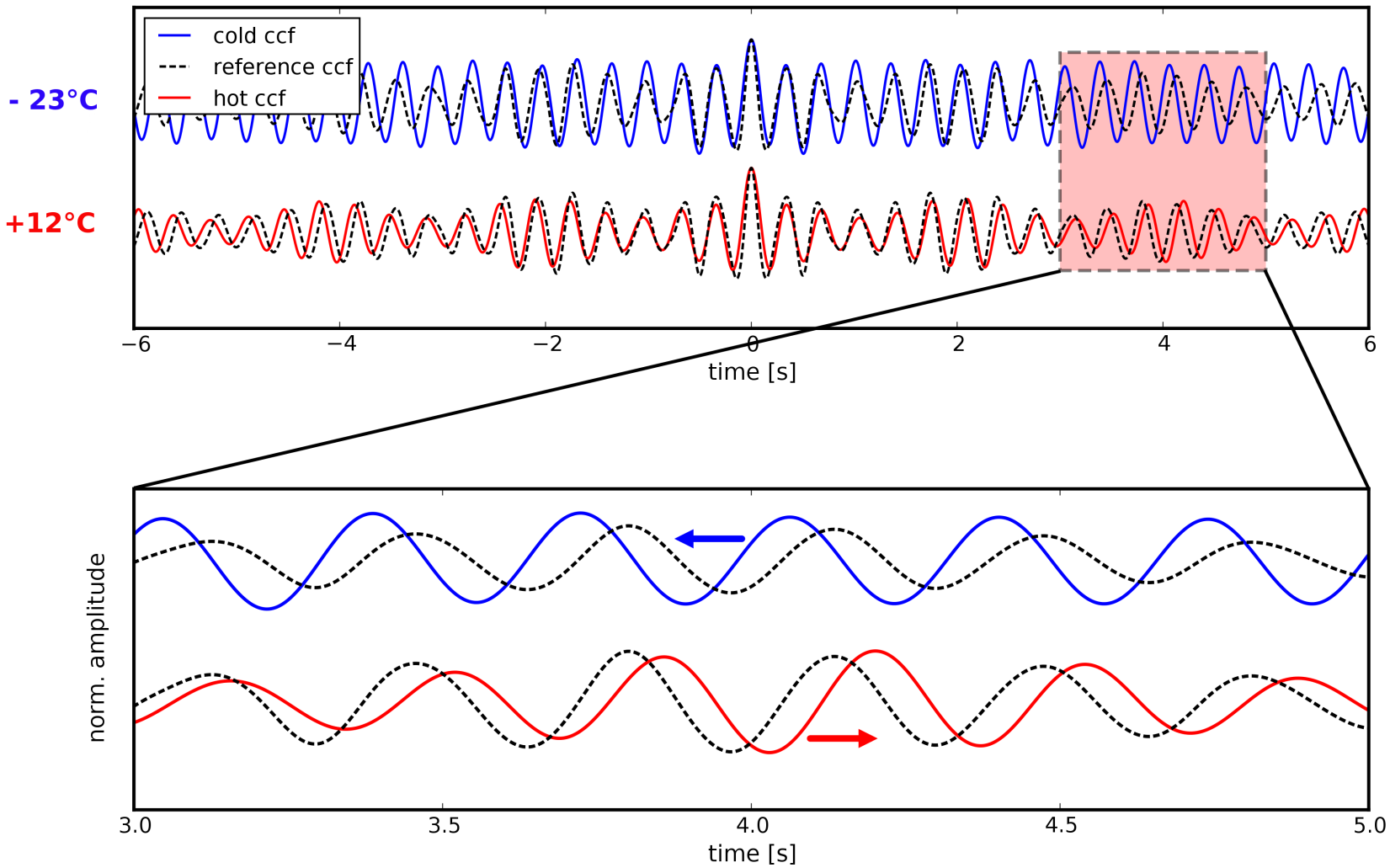
Hourly cross-correlations for receiver pairs

Unilateral sources and reverberations

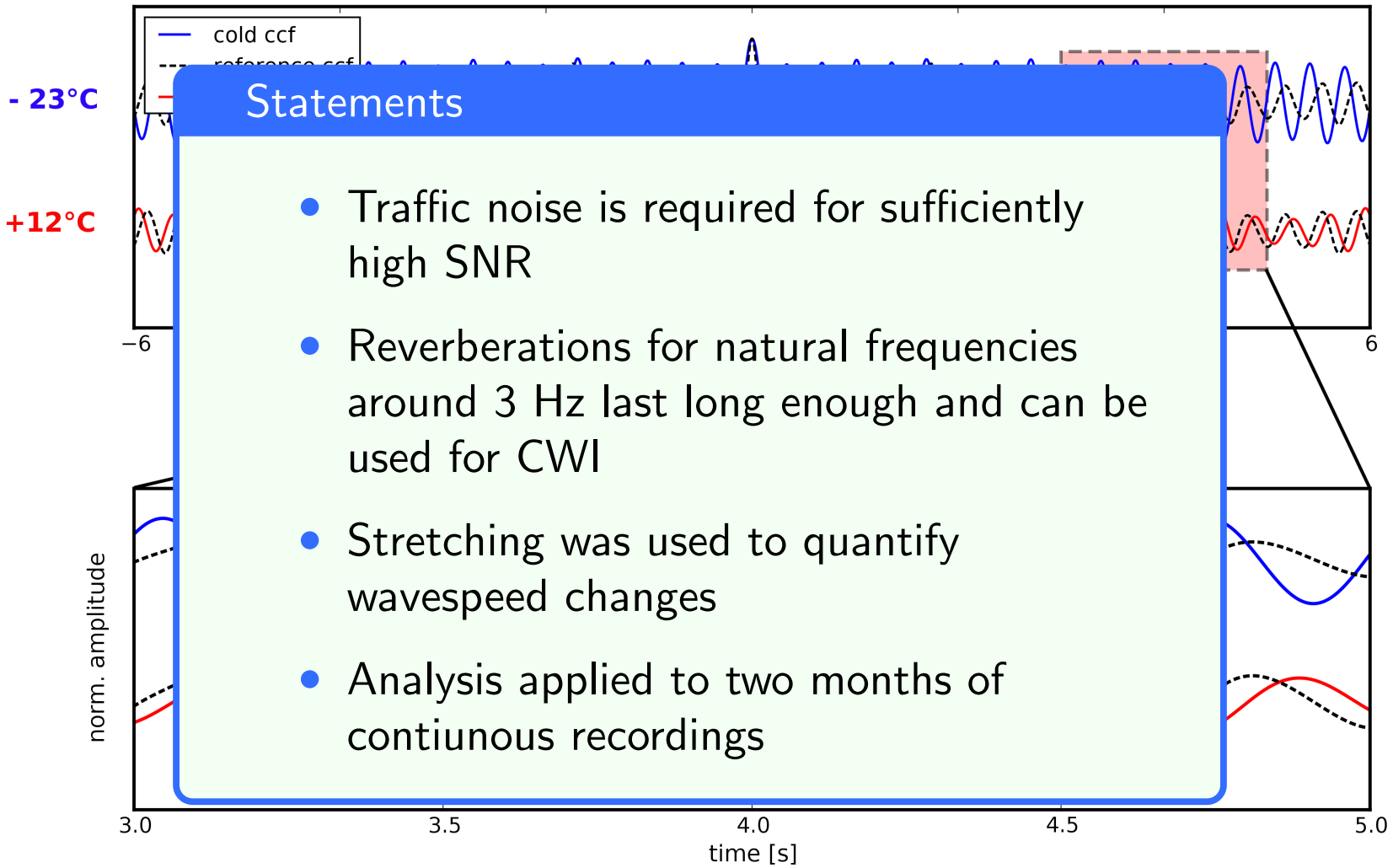
⇓

no perfect Green's functions

CWI & Cross-correlations



CWI & Cross-correlations

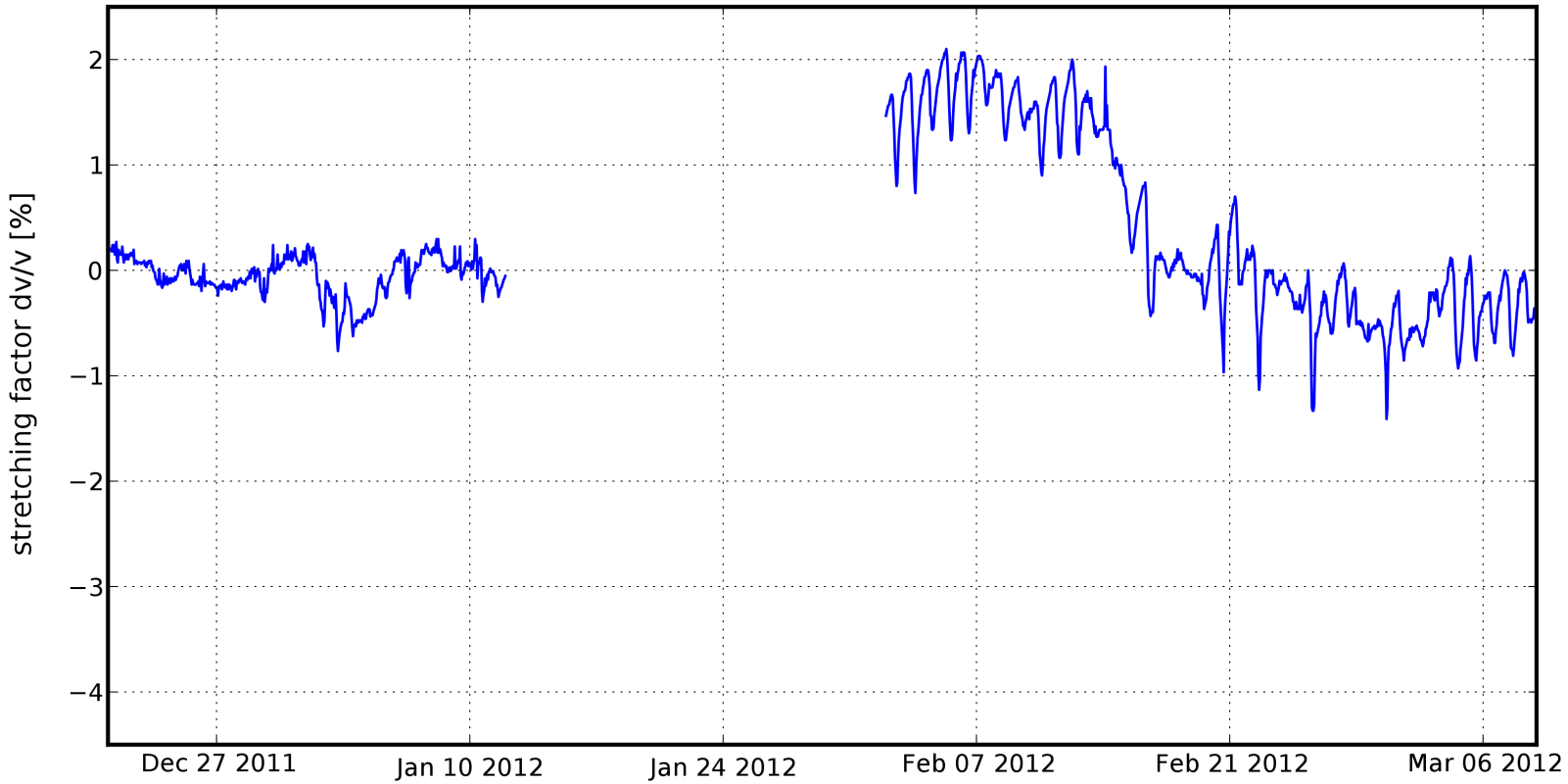


Statements

- Traffic noise is required for sufficiently high SNR
- Reverberations for natural frequencies around 3 Hz last long enough and can be used for CWI
- Stretching was used to quantify wavespeed changes
- Analysis applied to two months of contiunous recordings

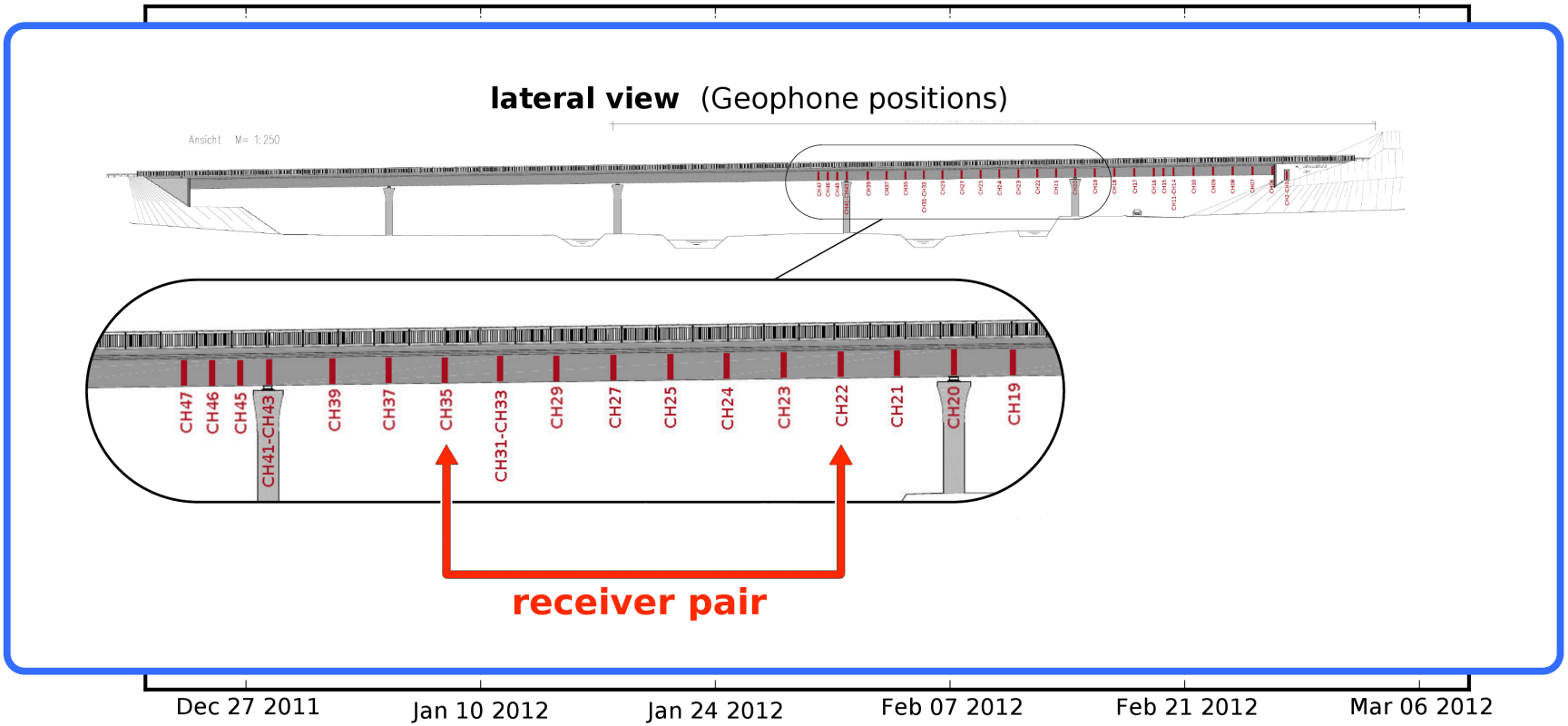
Observed Results

Velocity variation $\frac{\Delta v}{v}$



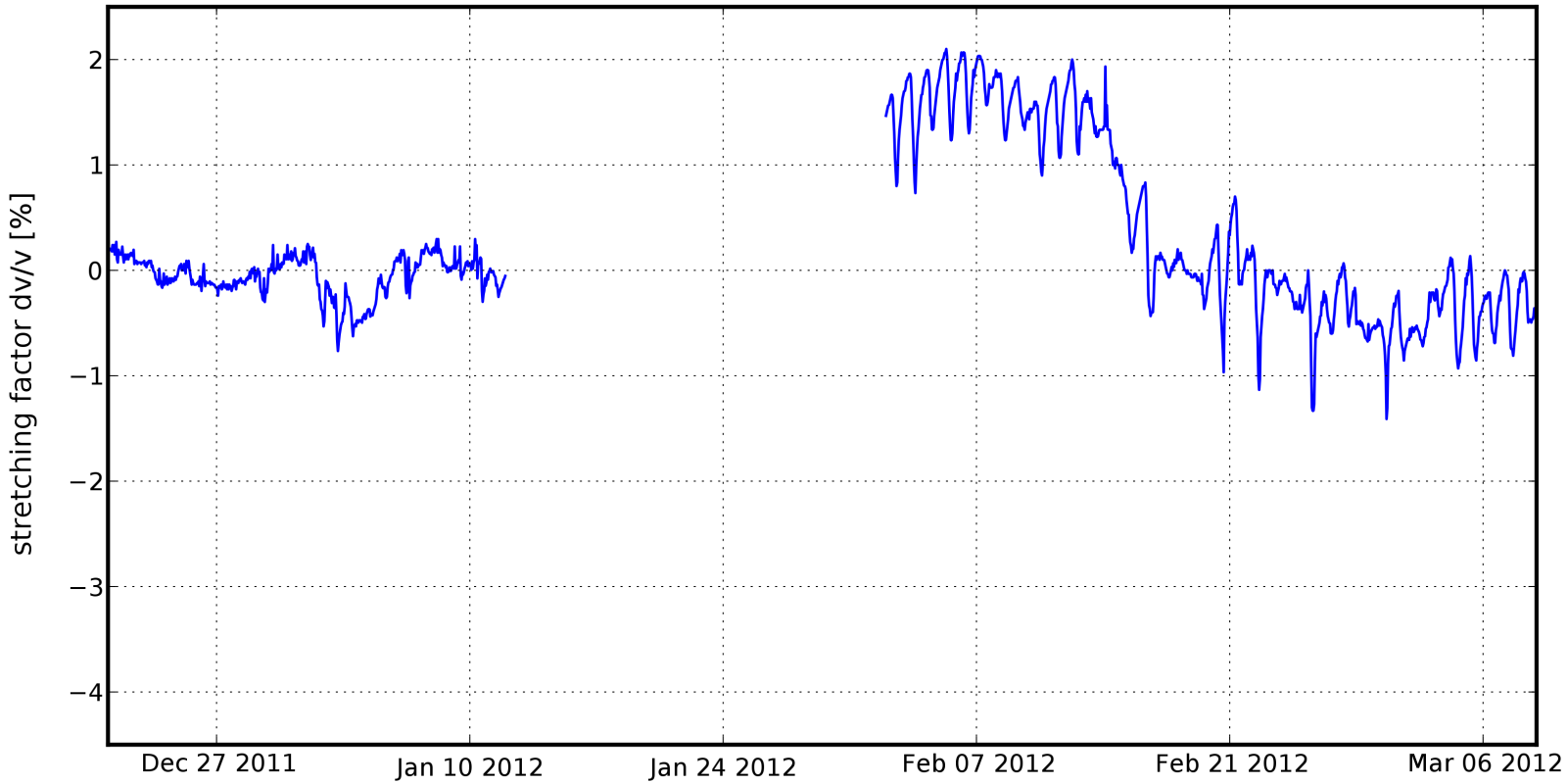
Observed Results

Velocity variation $\frac{\Delta v}{v}$



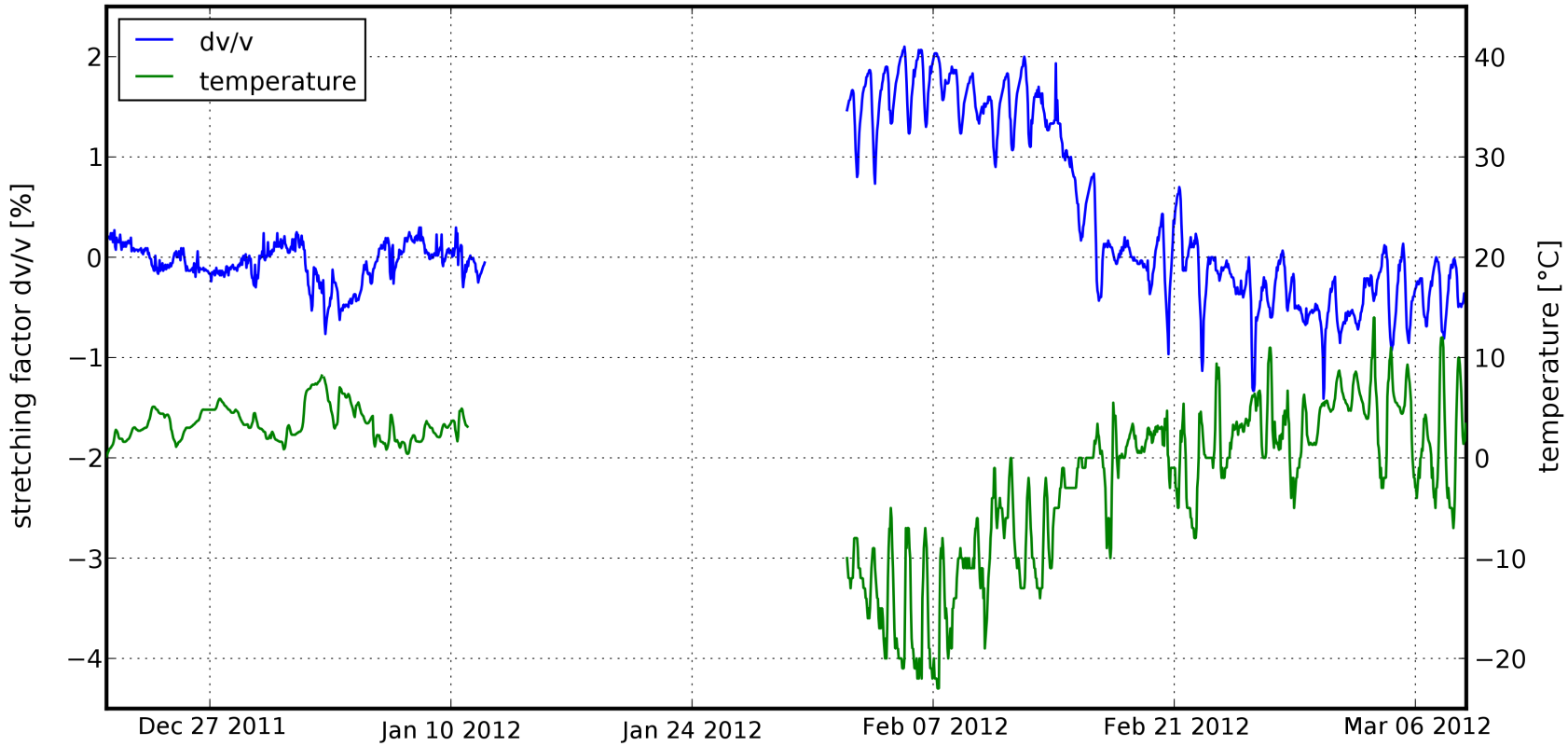
Observed Results

Velocity variation $\frac{\Delta v}{v}$



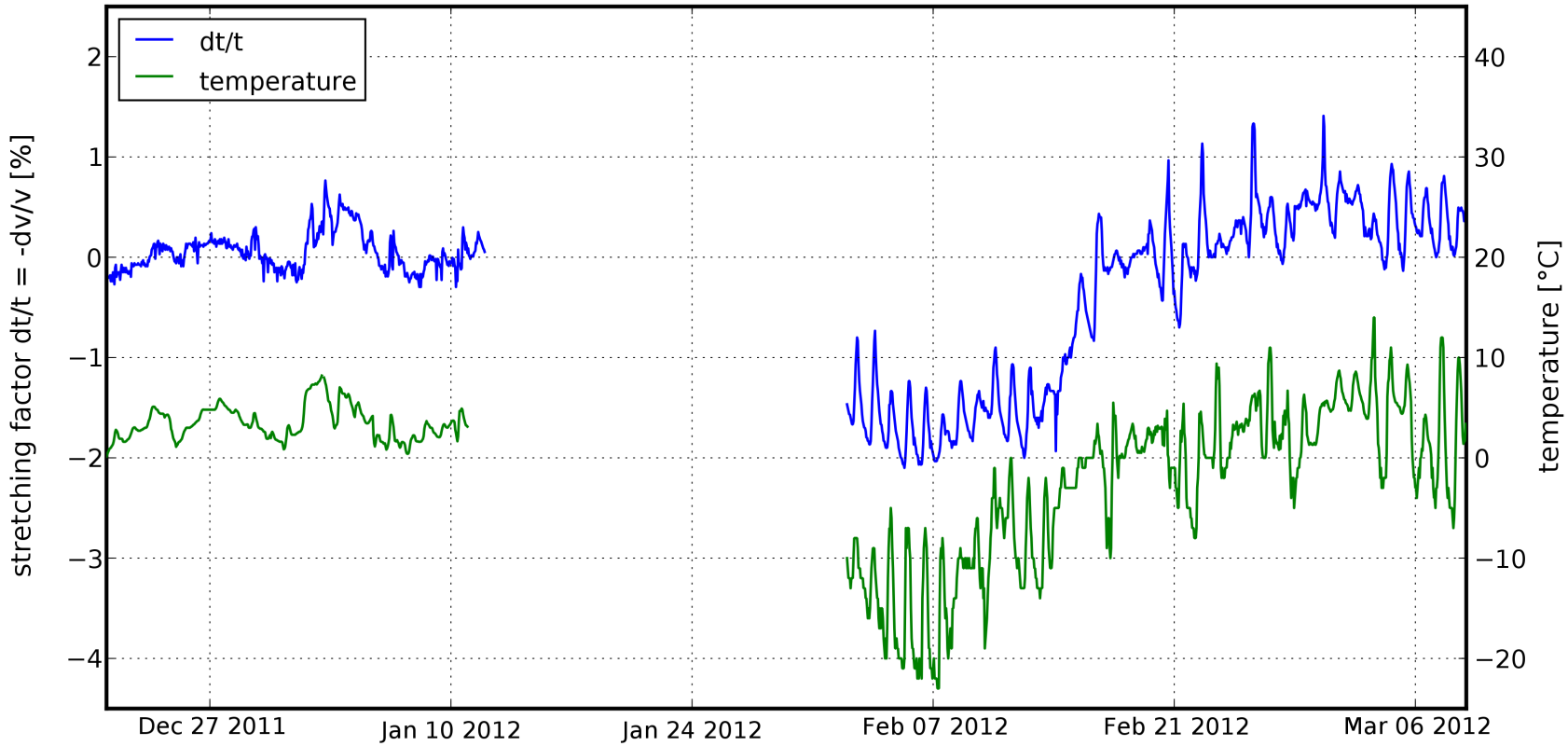
Observed Results

Velocity variation $\frac{\Delta v}{v}$ **Temperature**



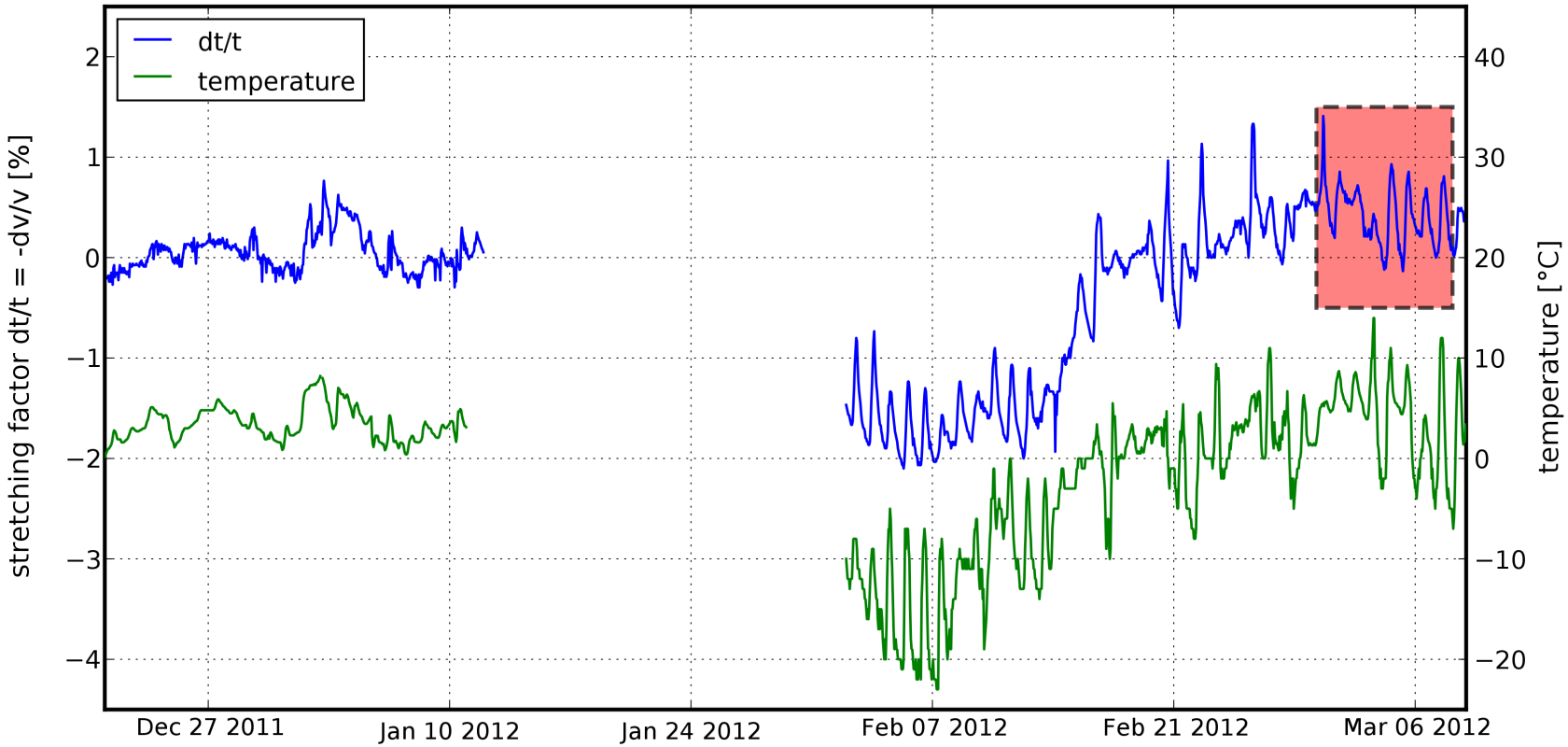
Observed Results

Velocity variation $\frac{\Delta t}{t}$ **Temperature**



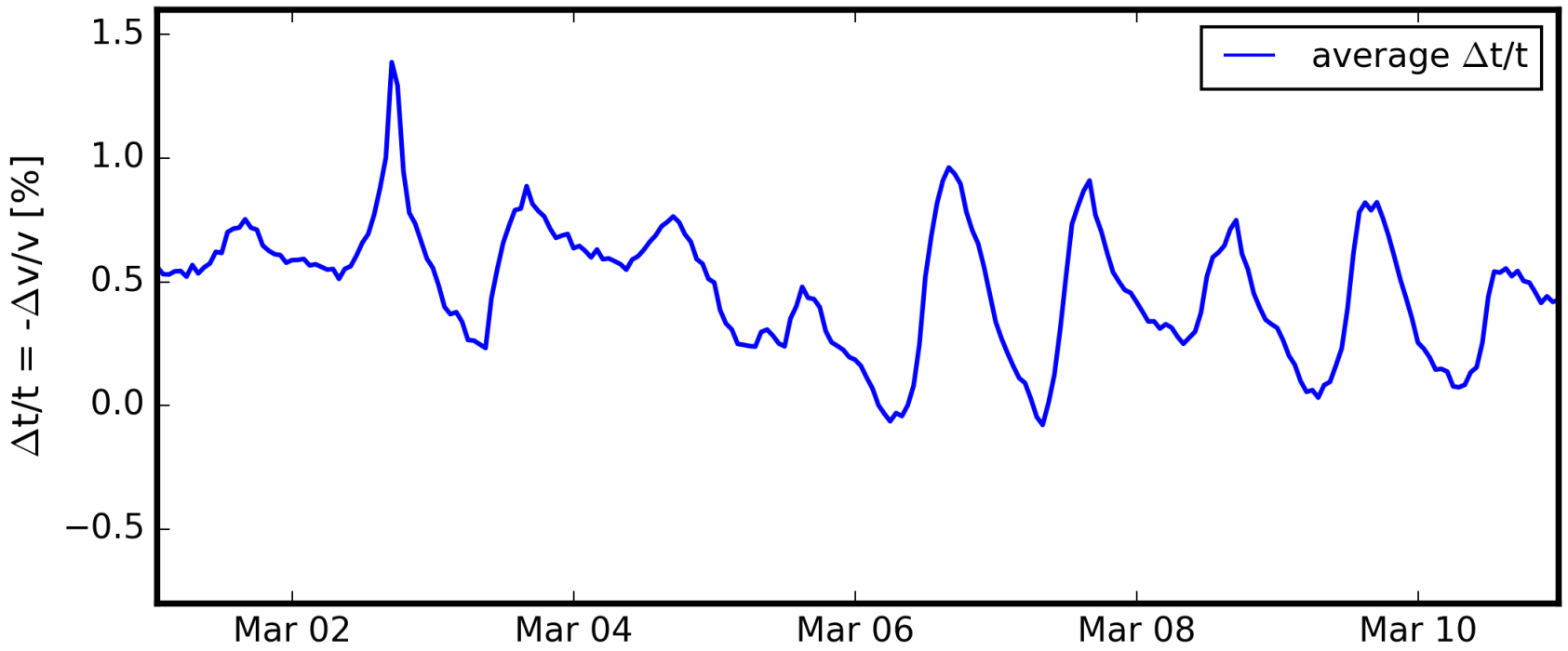
Observed Results

Velocity variation $\frac{\Delta t}{t}$ **Temperature**



March 2012

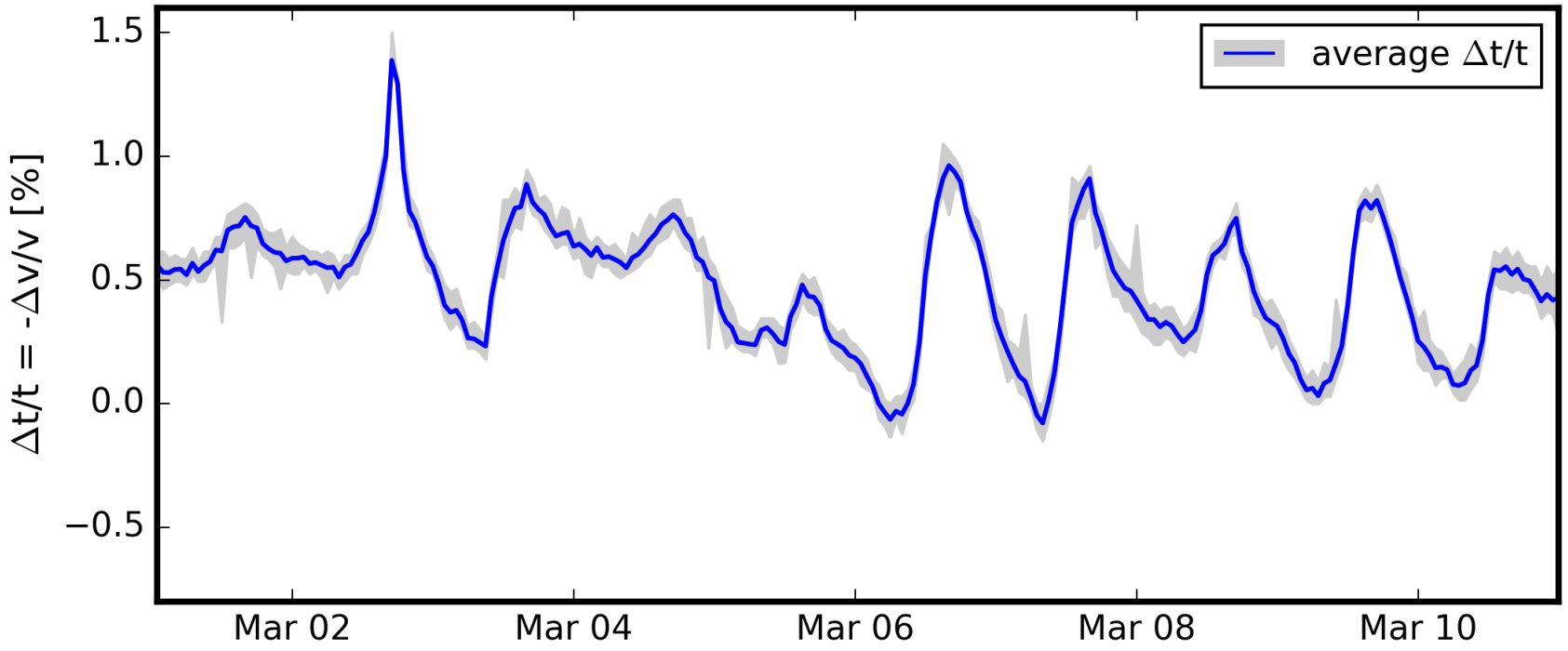
Velocity variation $\frac{\Delta t}{t}$



March 2012

Velocity variation $\frac{\Delta t}{t}$

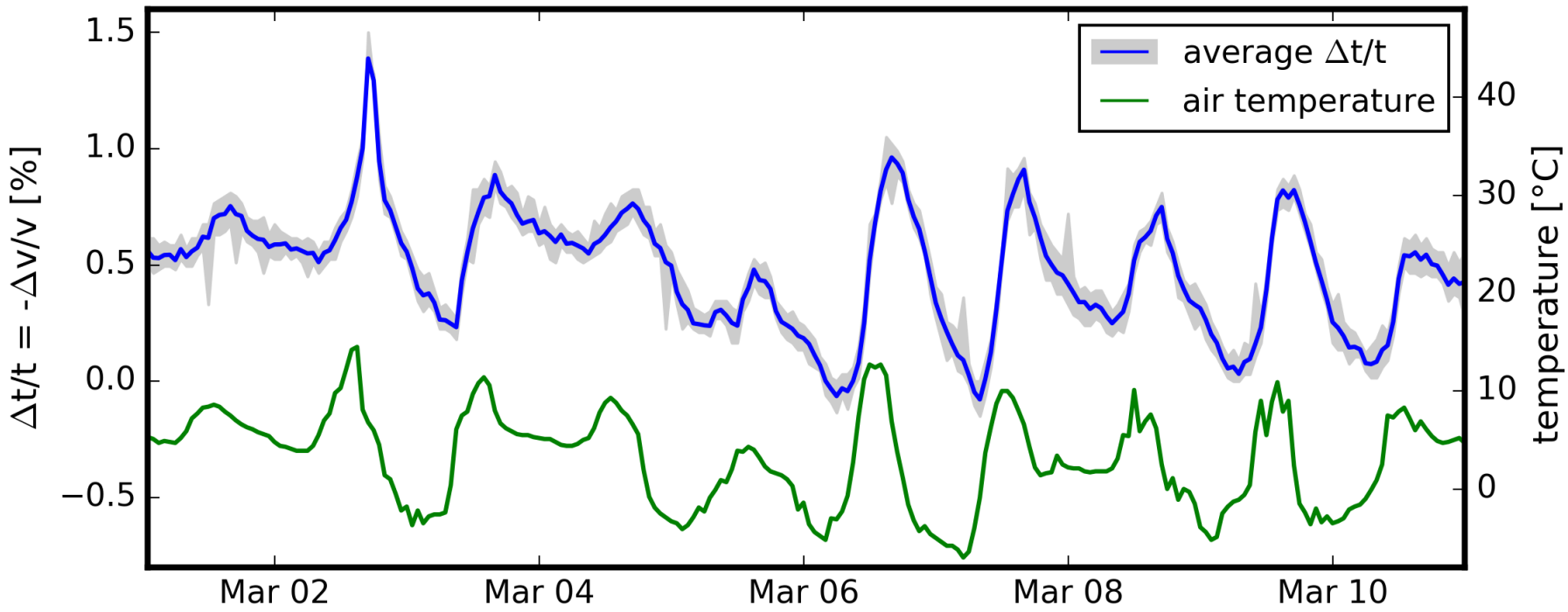
Deviation (32 receiver pairs)



March 2012

Velocity variation $\frac{\Delta t}{t}$ **Temperature**

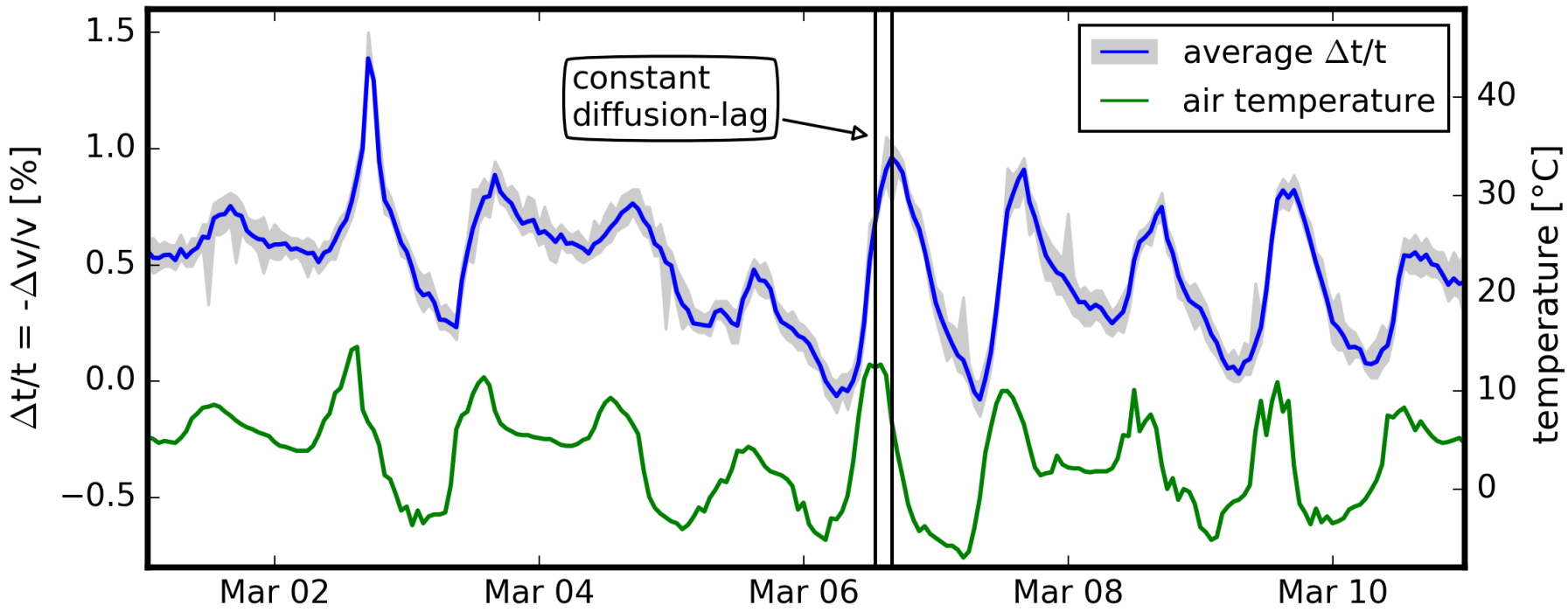
Deviation
(32 receiver pairs)



March 2012

Velocity variation $\frac{\Delta t}{t}$ **Temperature**

Deviation
(32 receiver pairs)



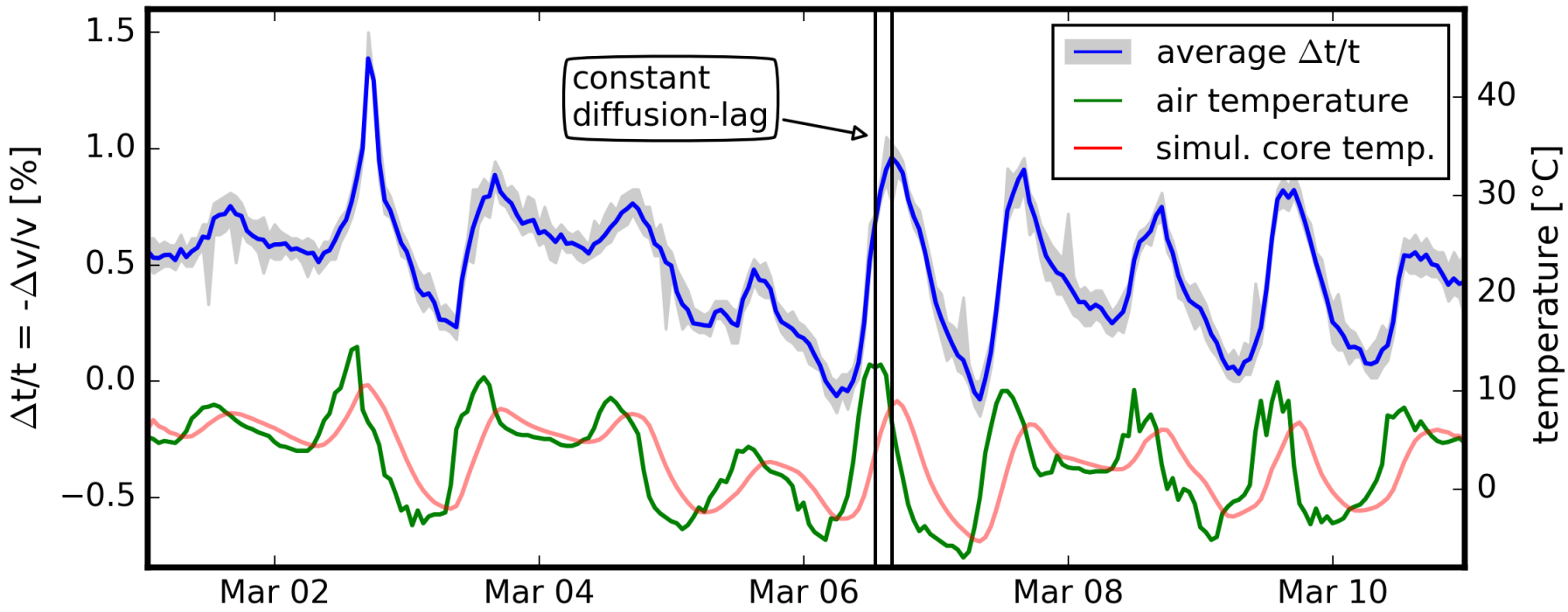
March 2012

Velocity variation $\frac{\Delta t}{t}$

Temperature

Simulated core temperature

Deviation (32 receiver pairs)



March 2012

Velocity variation $\frac{\Delta t}{t}$

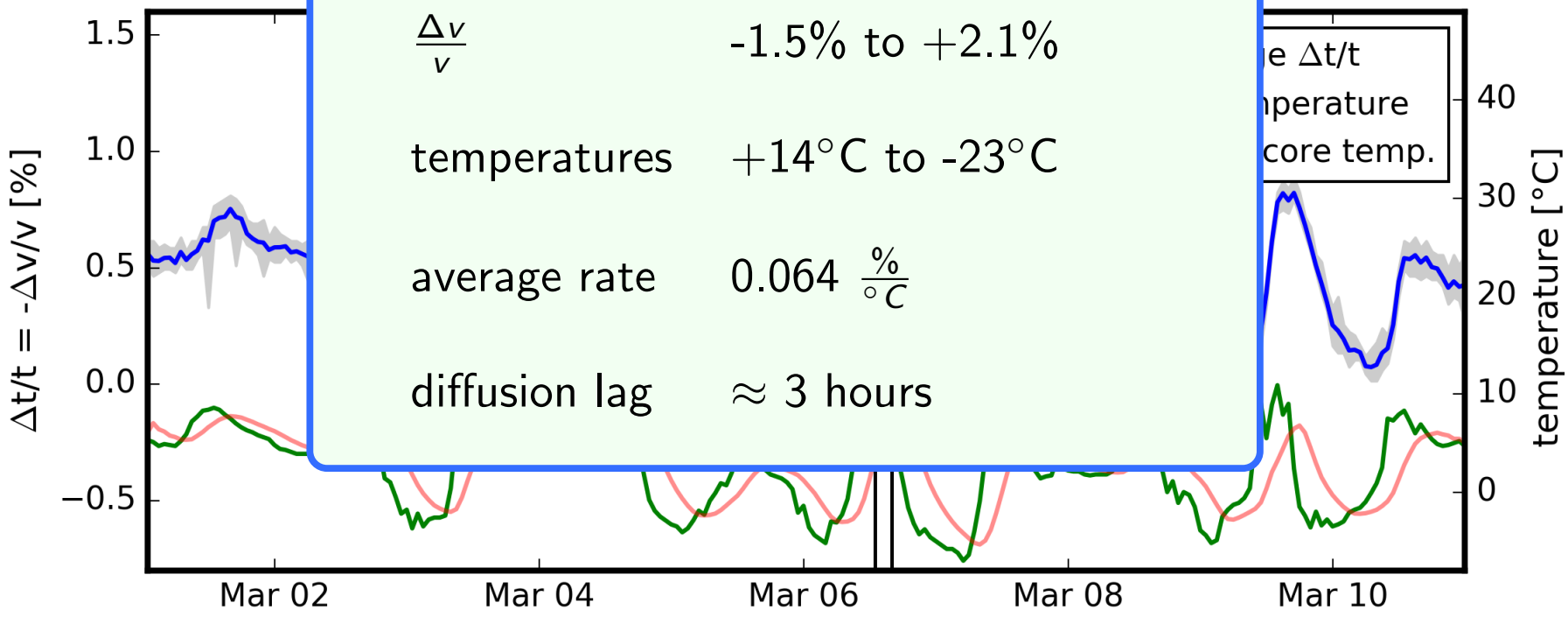
Temperature

Simulated core temperature

Deviation (32 receiver pa

Overall Results

$\frac{\Delta v}{v}$	-1.5% to +2.1%
temperatures	+14°C to -23°C
average rate	0.064 $\frac{\%}{°C}$
diffusion lag	≈ 3 hours



Reliability Tests

Thermal expansion

Expansion/Contraction of the bridge

Instrument stability

Temperature dependence of geophones

Msmt range

-1.5 to +2.3 %

Reliability Tests

Thermal expansion

Expansion/Contraction of the bridge
$\Rightarrow$ Effect in the order of $\mathbf{6\text{-}14 \cdot 10^{-4}}$ $\frac{\%}{^\circ C}$ for steel-reinforced concrete

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Msmt range

-1.5 to +2.3 %

Instrument stability

Temperature dependence of geophones

Reliability Tests

Thermal expansion

Expansion/Contraction of the bridge
$\Rightarrow$ Effect in the order of **6-14** $\cdot \mathbf{10^{-4}}$ $\frac{\%}{^\circ C}$ for steel-reinforced concrete

Instrument stability

Temperature dependence of geophones
$\Rightarrow$ Apparent delay of max. **0.52 %** for extreme shifts in corner frequency.

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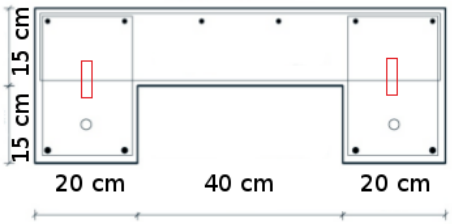
$<$

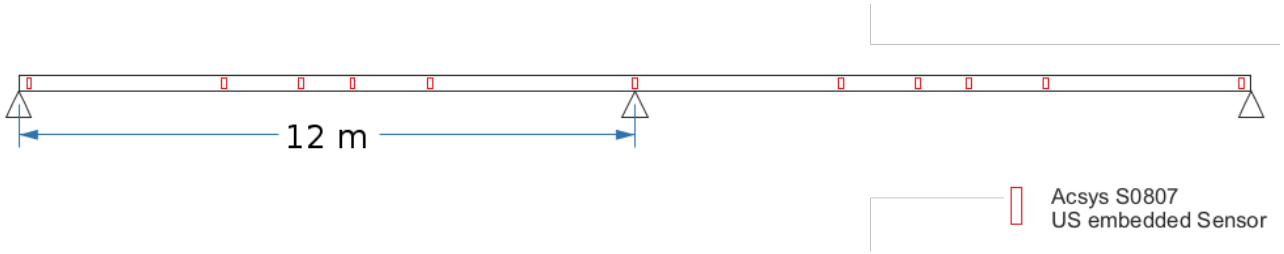
Msmt range

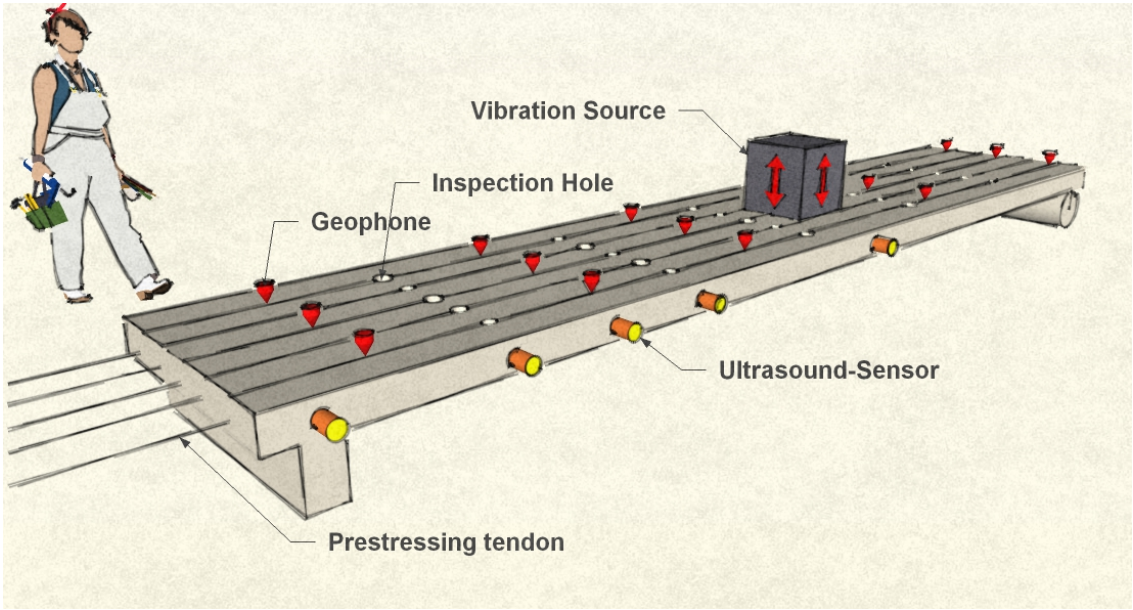
-1.5 to +2.3 %

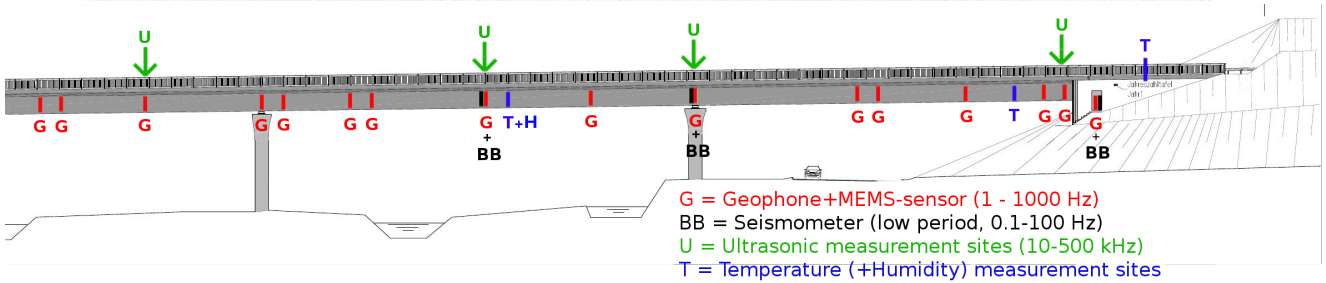
Conclusions

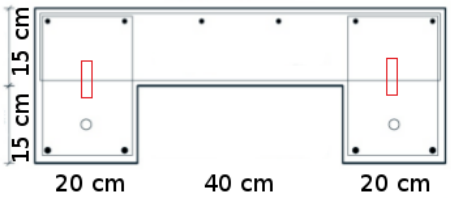
- Resolution of velocity variations is possible via cross-correlations from ambient traffic noise on a bridge
- Captured small velocity variations caused by temperature fluctuations:
  relative velocity $\frac{\Delta v}{v}$: -1.5% to +2.1%
  temperature range: +14°C to -23°C
- Strong correlation between temperature and $\frac{\Delta v}{v}$ series
- Advantages: high temporal resolution, high accuracy, low logistical effort

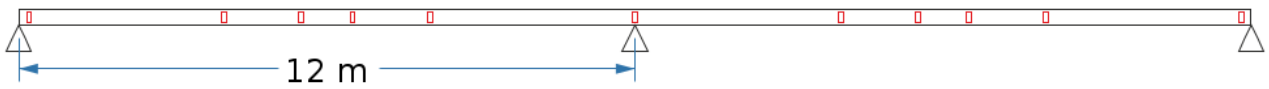

15 cm
15 cm
20 cm
40 cm
20 cm


12 m
Acsys S0807
US embedded Sensor


Vibration Source
Inspection Hole
Geophone
Ultrasound-Sensor
Prestressing tendon


U
G G
G
G G
G G
G T+H
BB
G
G
BB
G G
G
T
G G
T
G
BB
G = Geophone+MEMS-sensor (1 - 1000 Hz)
BB = Seismometer (low period, 0.1-100 Hz)
U = Ultrasonic measurement sites (10-500 kHz)
T = Temperature (+Humidity) measurement sites





Perspective - aspired project

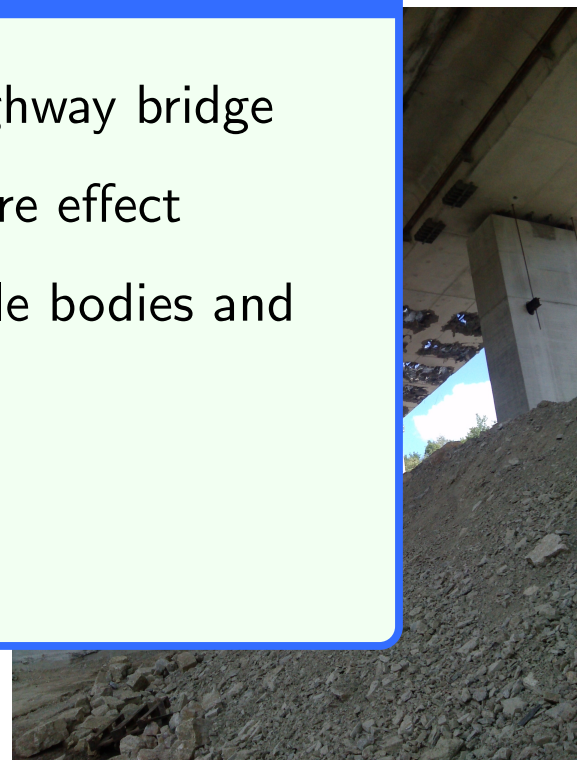
- Long-term ($>$ 1 year) monitoring of a highway bridge

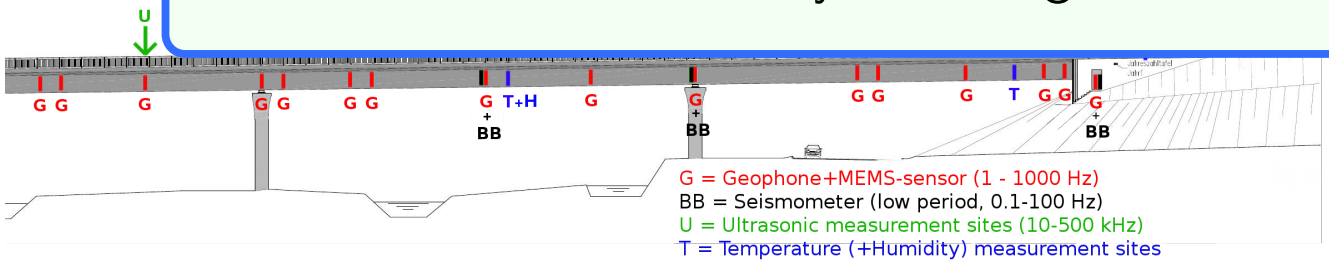
  $\Rightarrow$ improve characterization of temperature effect

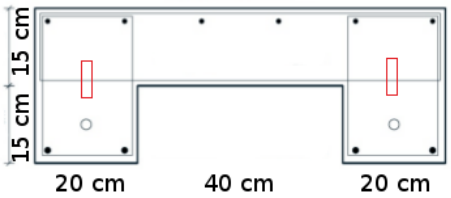
- Extensive damage-scenario tests on sample bodies and expired structures

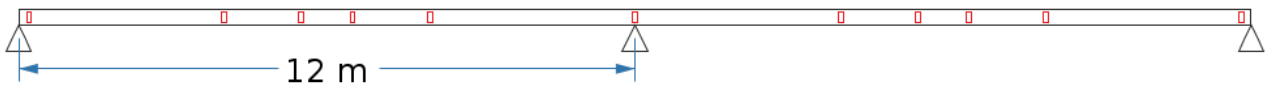
- Numerical simulations

  $\Rightarrow$ confirm reliability of damage detection







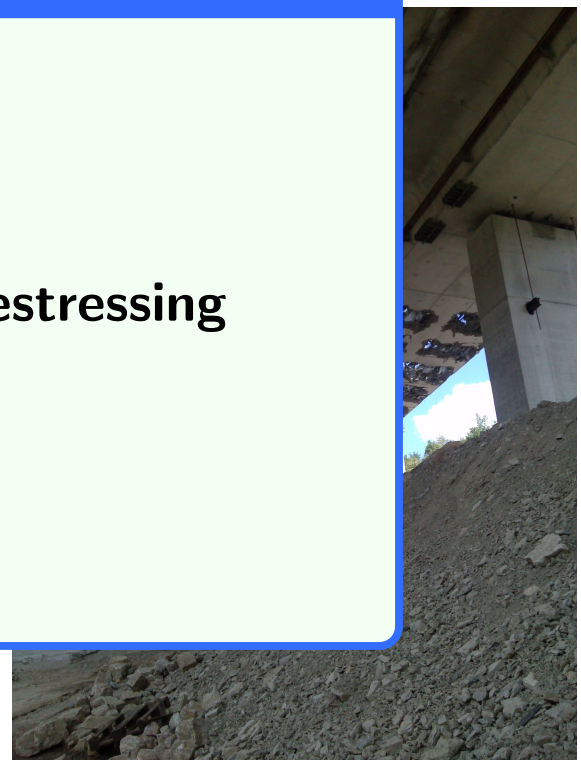


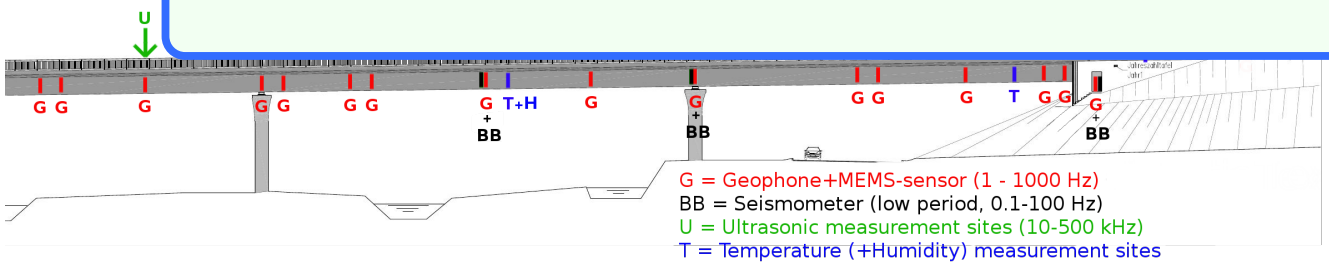
Acsys S0807
US embedded Sensor

Perspective - aspired project

Aim

Detect corrosion-induced **decrease in prestressing** and associated **concrete crack** evolution

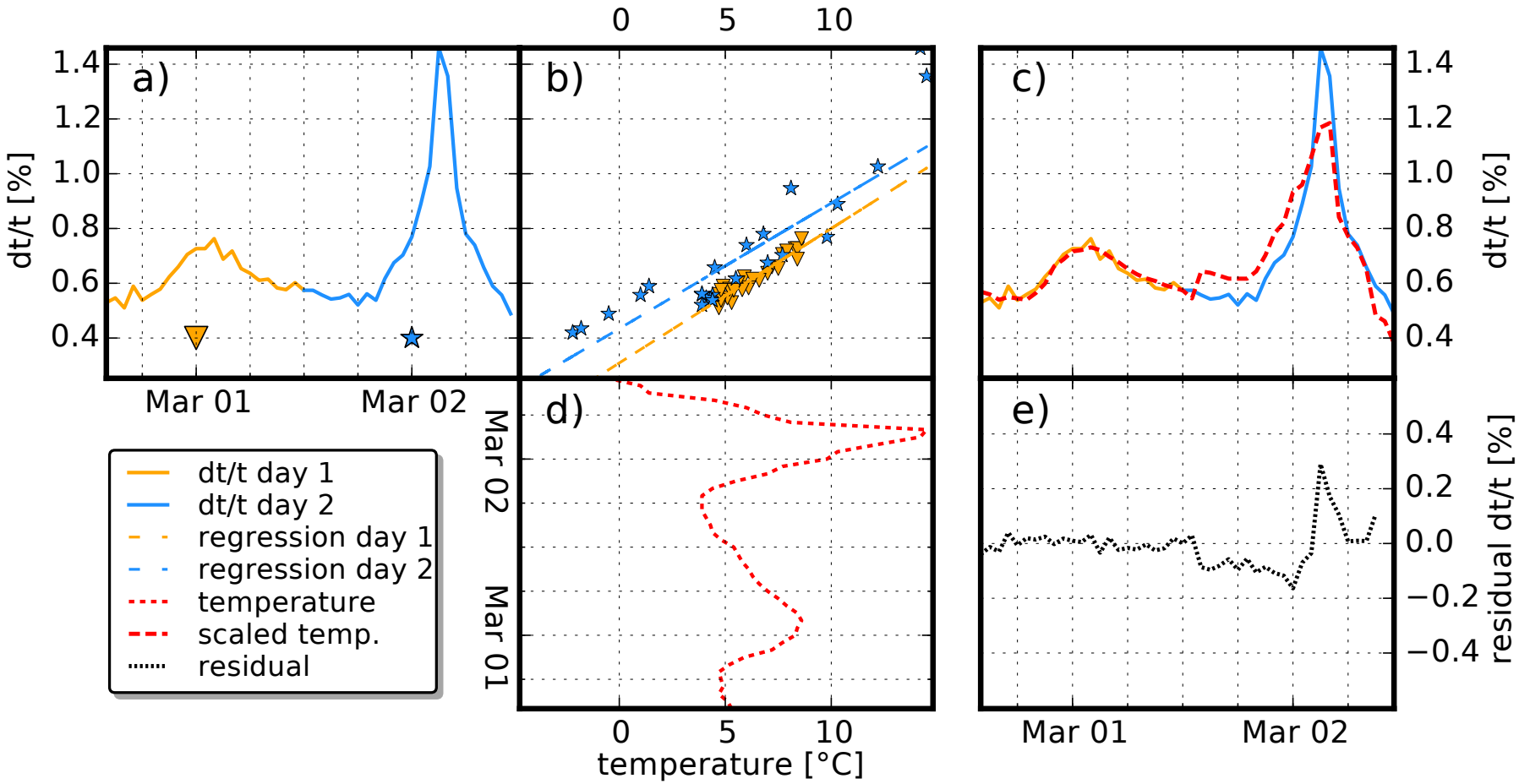




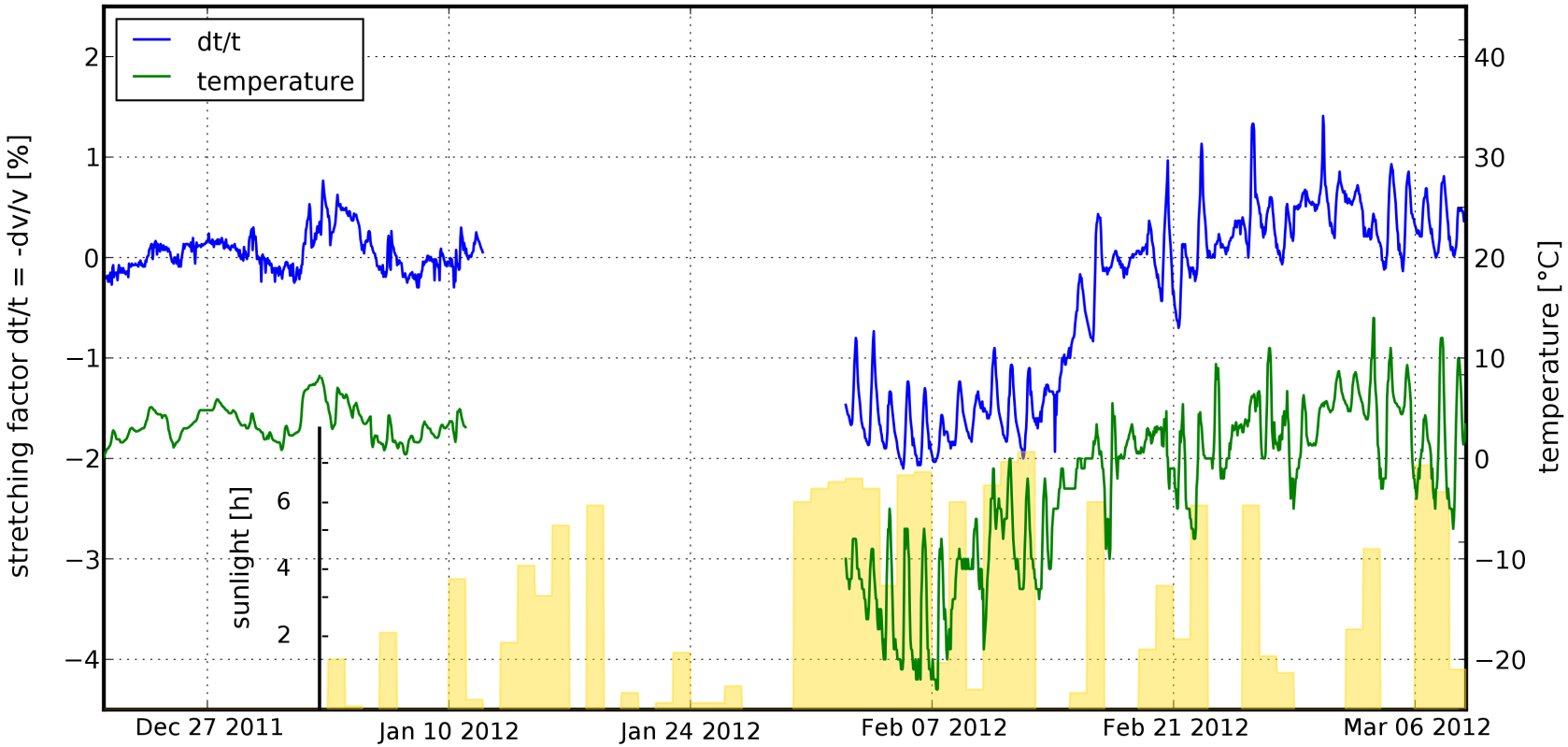
Questions

Thank you!

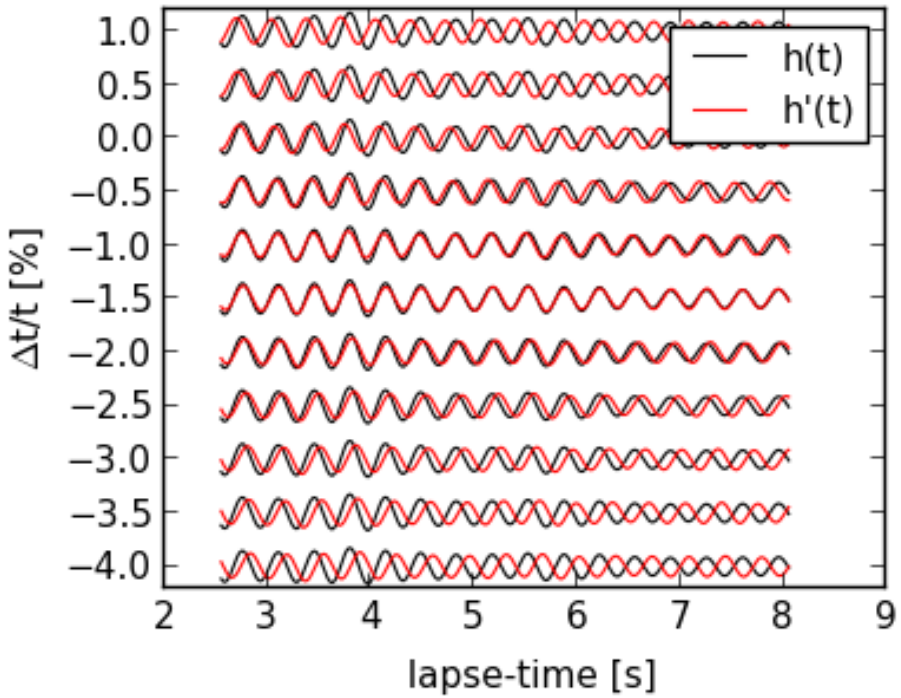
Temperature reduction

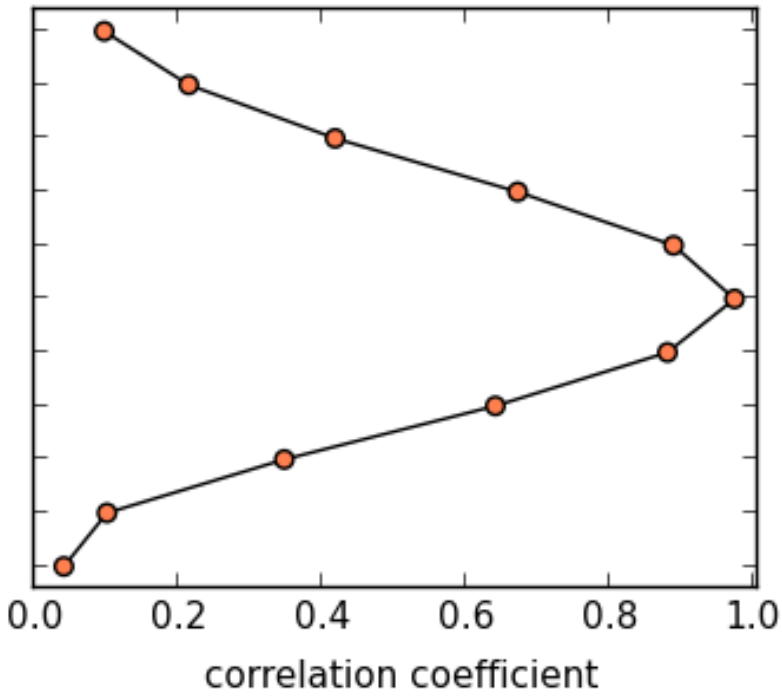


Daily Sunlight

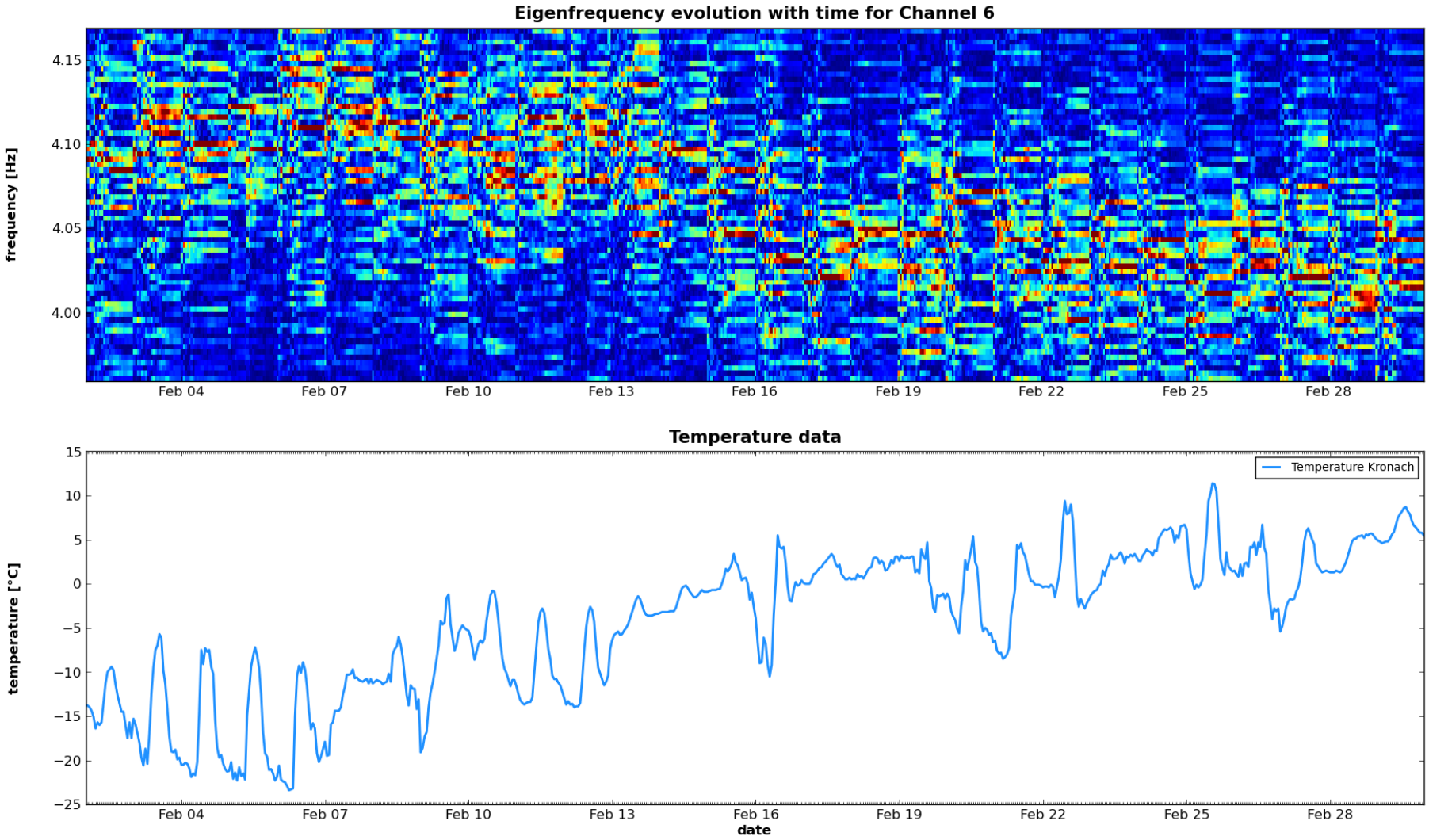


Stretching Method





Eigenfrequency Evolution



Instrument Stability Test