Recording the song of the city with fibre-optic cables

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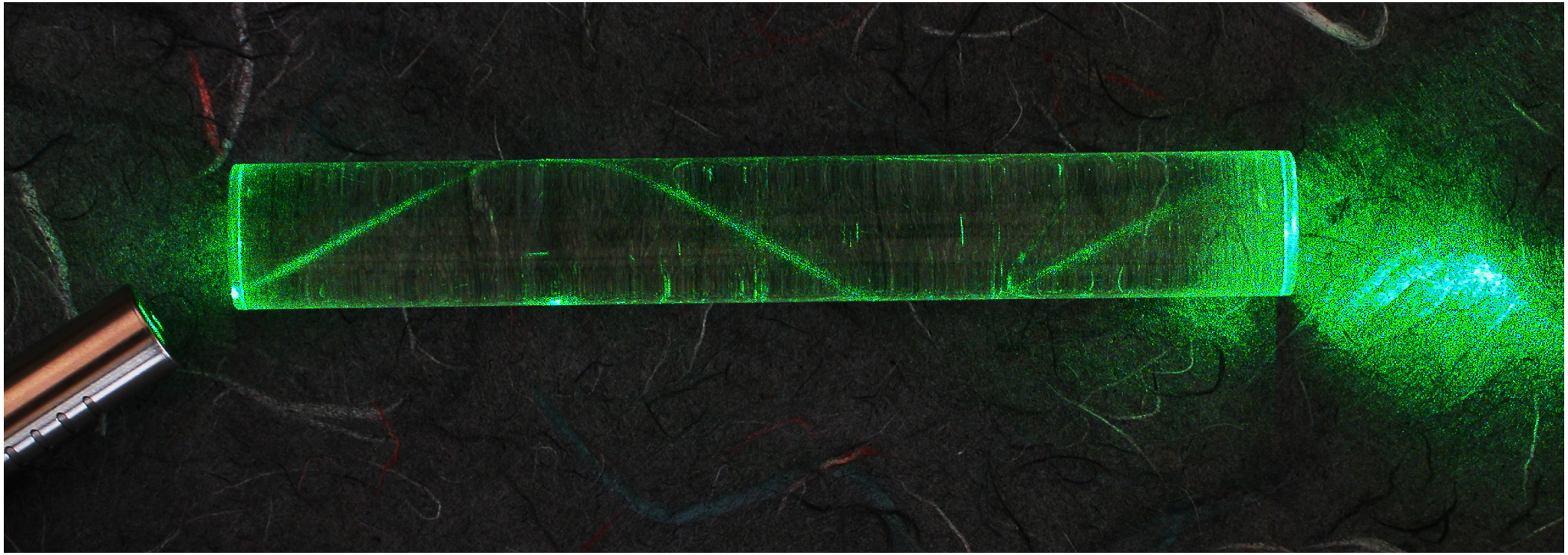
Earth Submarine Fiber Optic Cable Network

Network Stylized for Clarity—Actual Physical Routes Not Shown

Created with rayrender (www.rayrender.net)
Data: github.com/telegeography/www.submarinecablemap.com

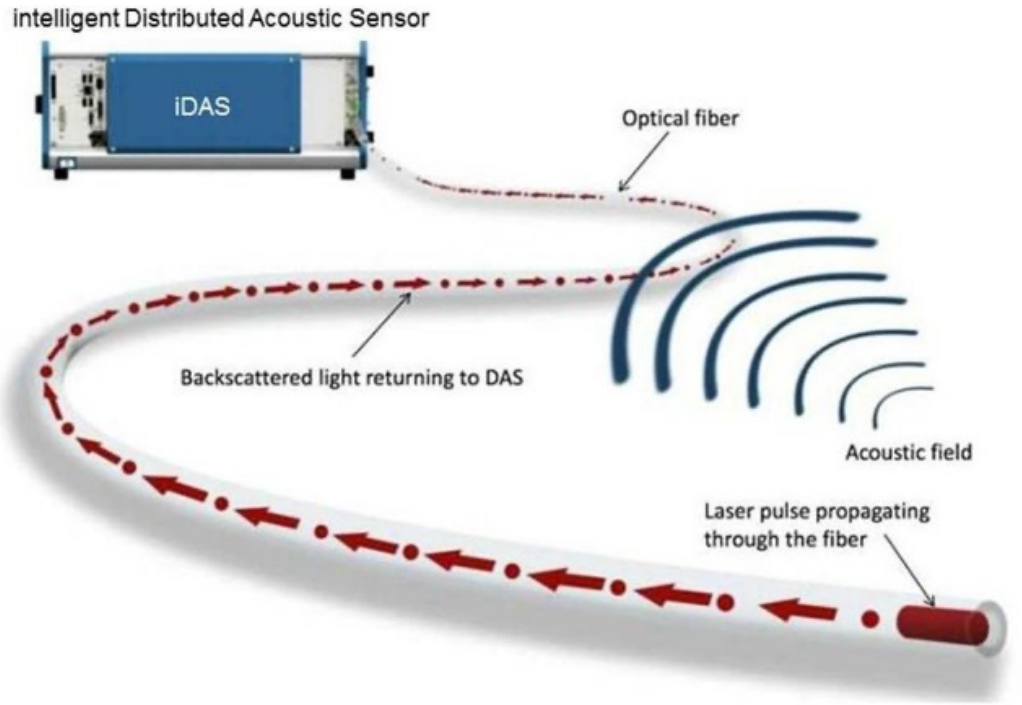
Twitter: @tylermorganwall

Fibre-optic sensing



Fibre-optic sensing

- Independent measurements every few metres (~1-10 m)
- Simultaneous recording at > 1 kHz
- Total range: >100 km



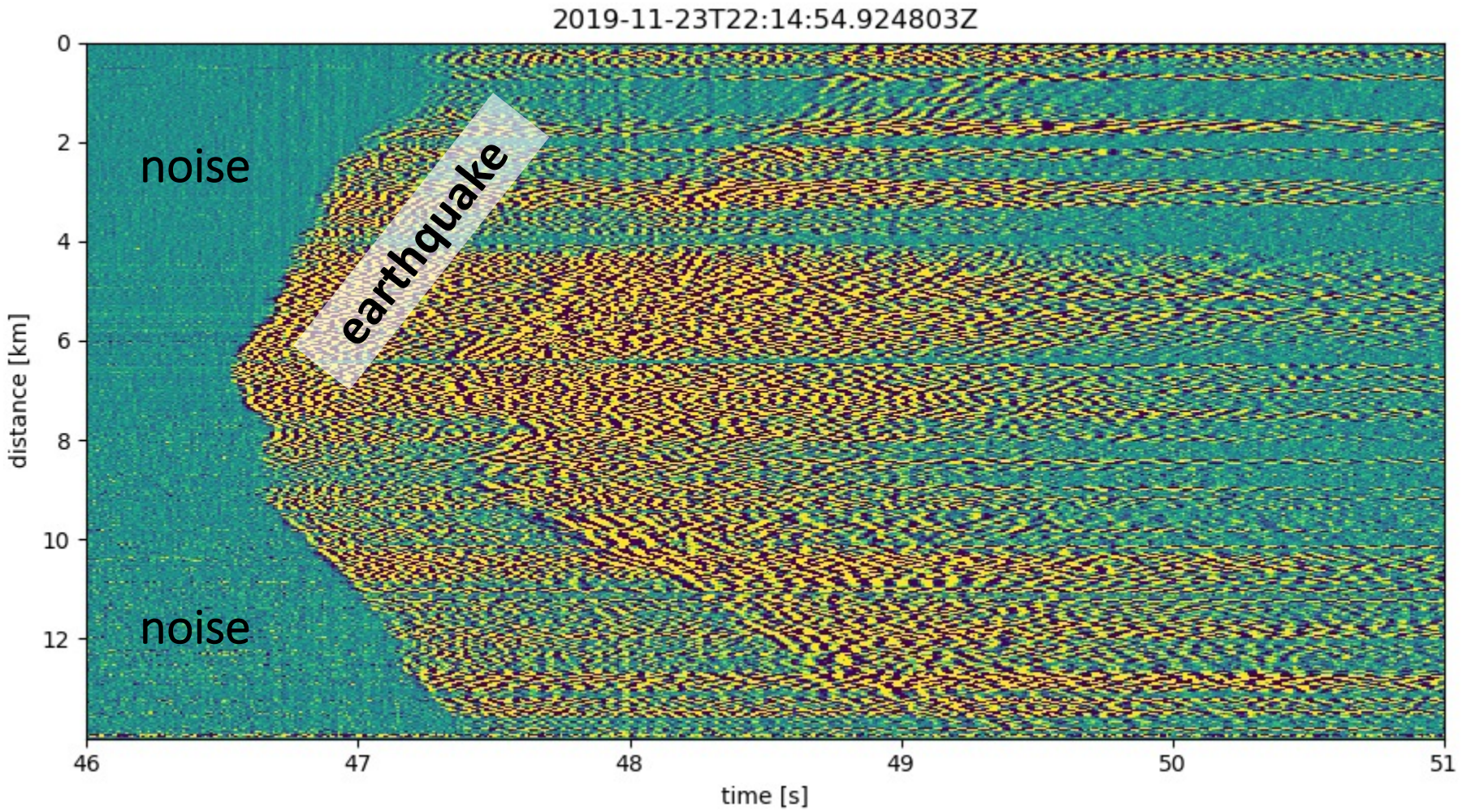
© Silixa

Diverse deployment scenarios

Sources of vibrations

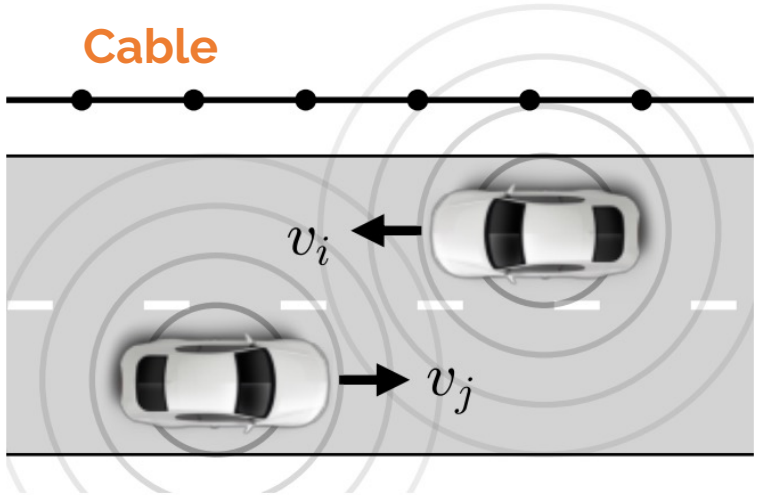
- Fluid flows (water, air)
- Swaying and resonance of high-rise structures
- Earthquakes, landslides, rock falls, avalanches
- Cars, trains, pedestrians, boats
- Whales, weevils

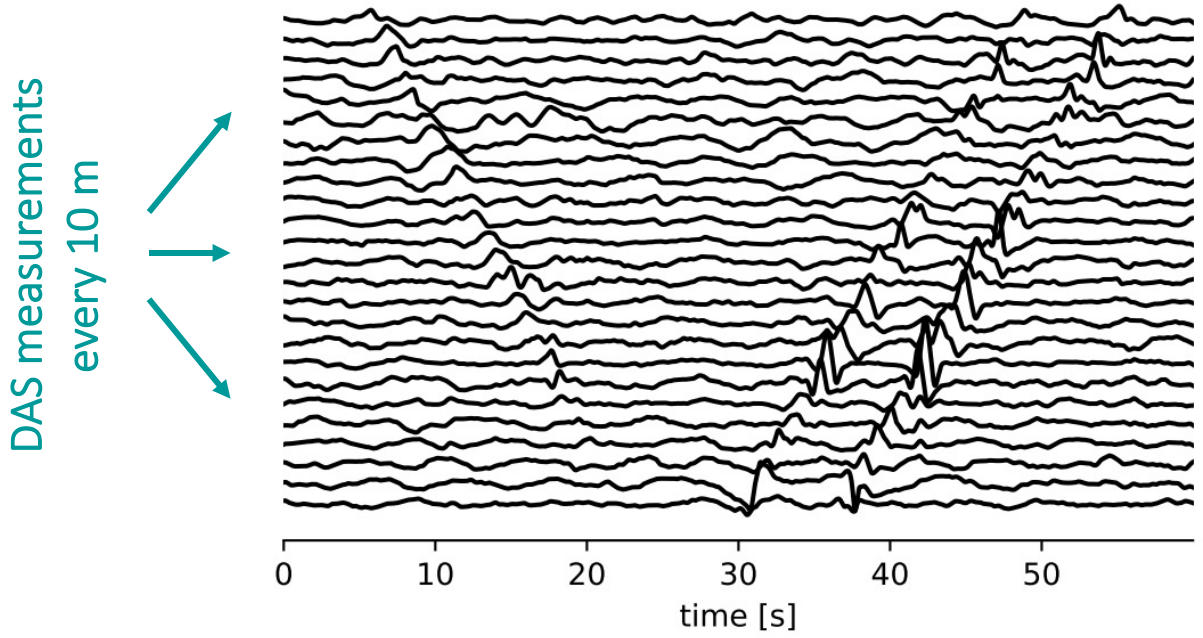
Example: earthquake



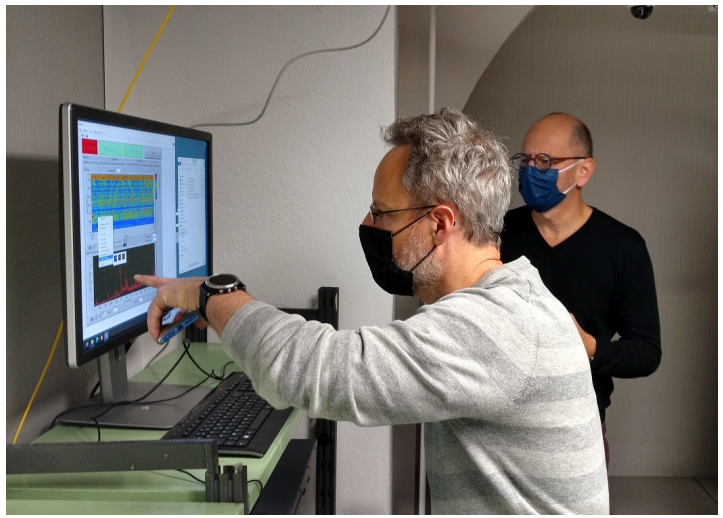
Roadside DAS

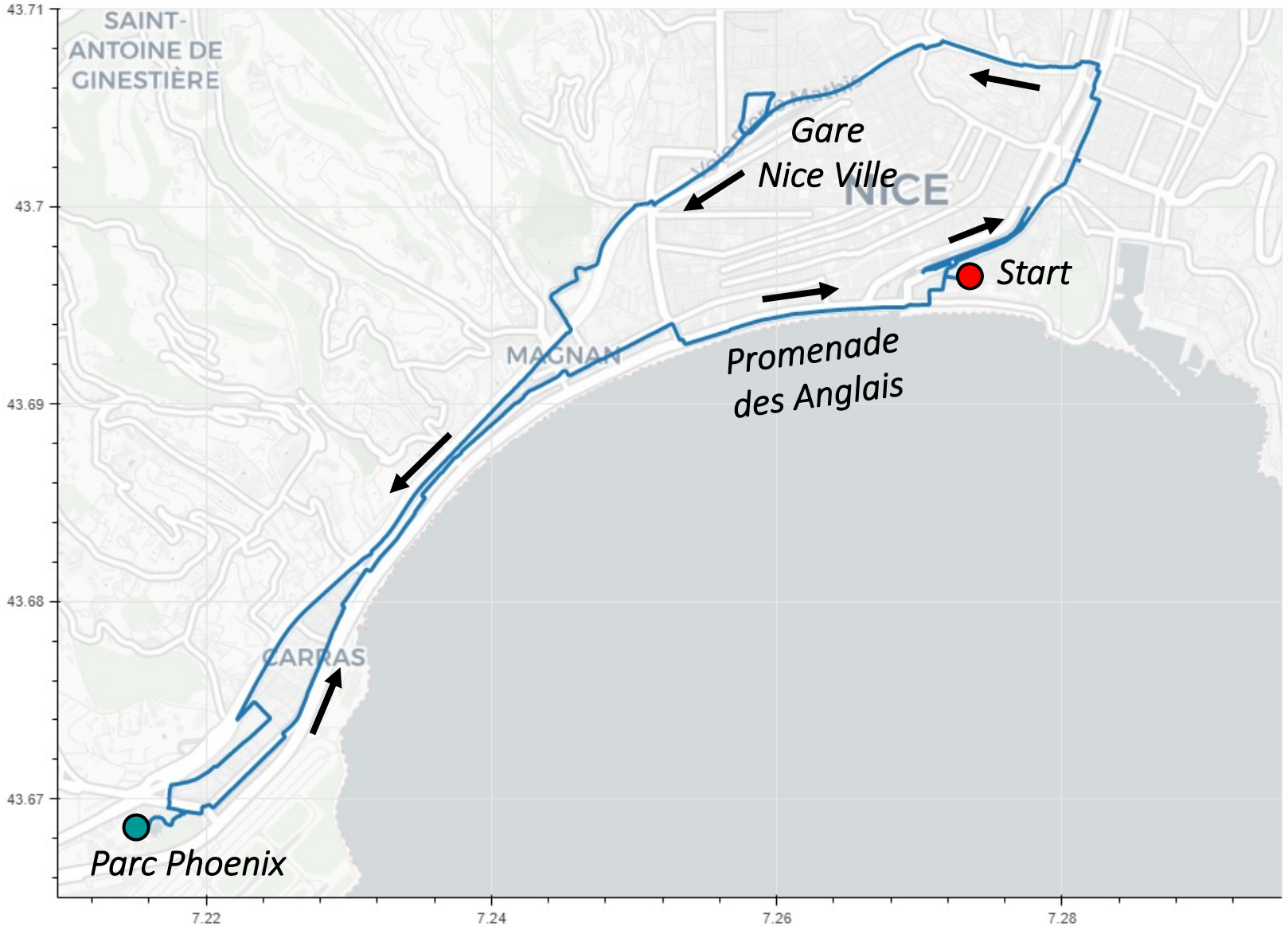
- Commercial telecom fibre deployed alongside streets in Nice, France
- Independent measurements every 10m
- DAS system records deformation induced by cars



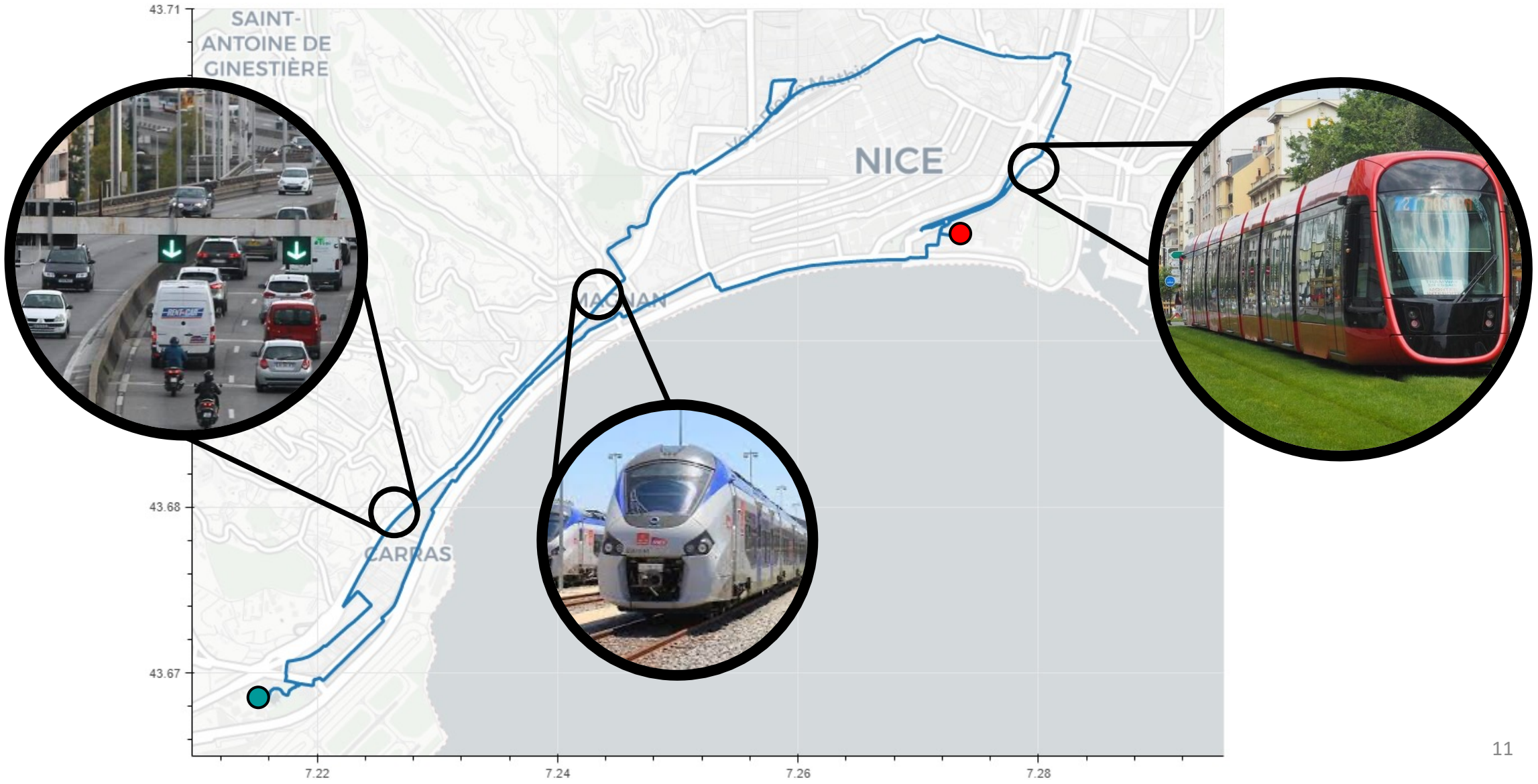


Nice experiment

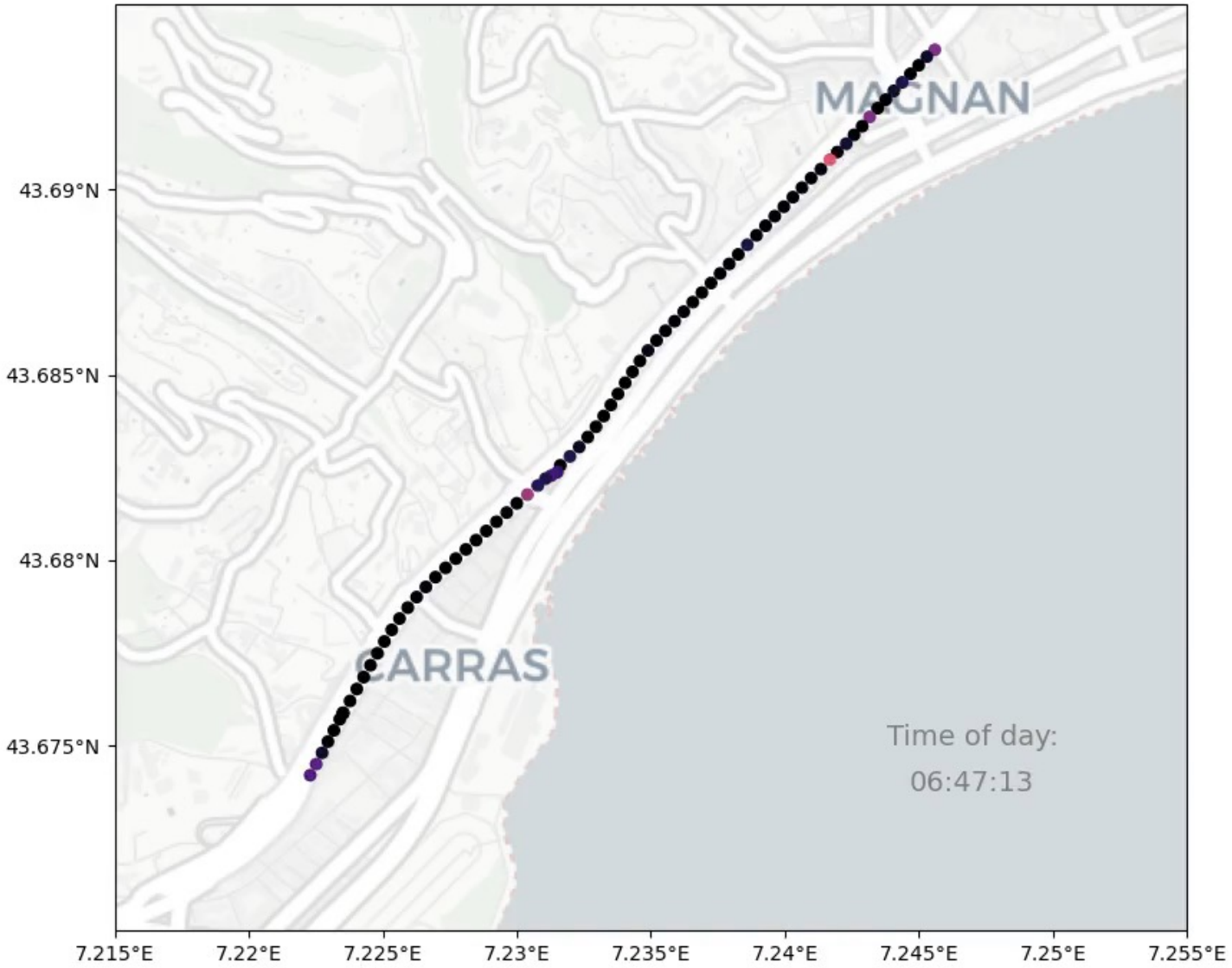




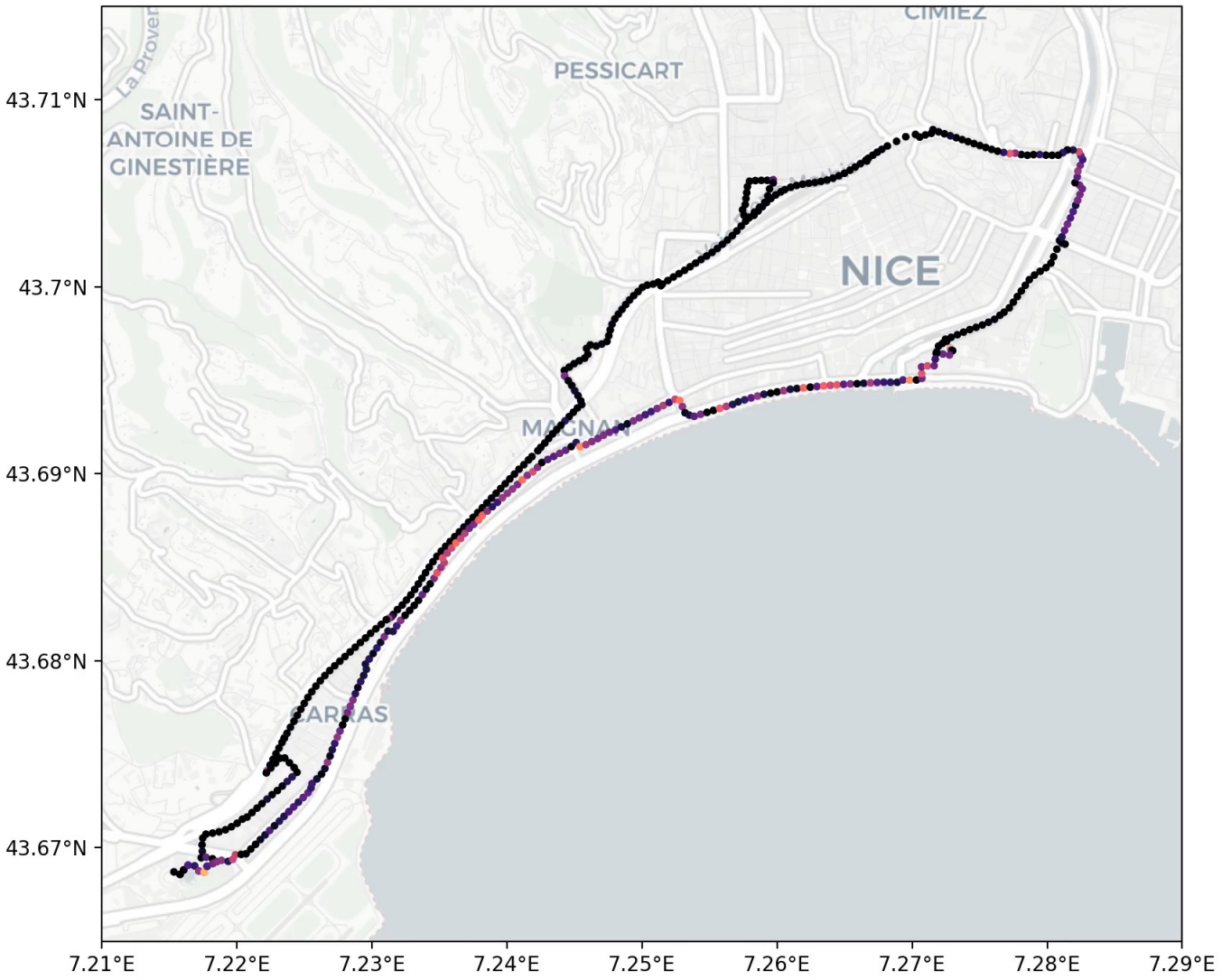
Nice experiment



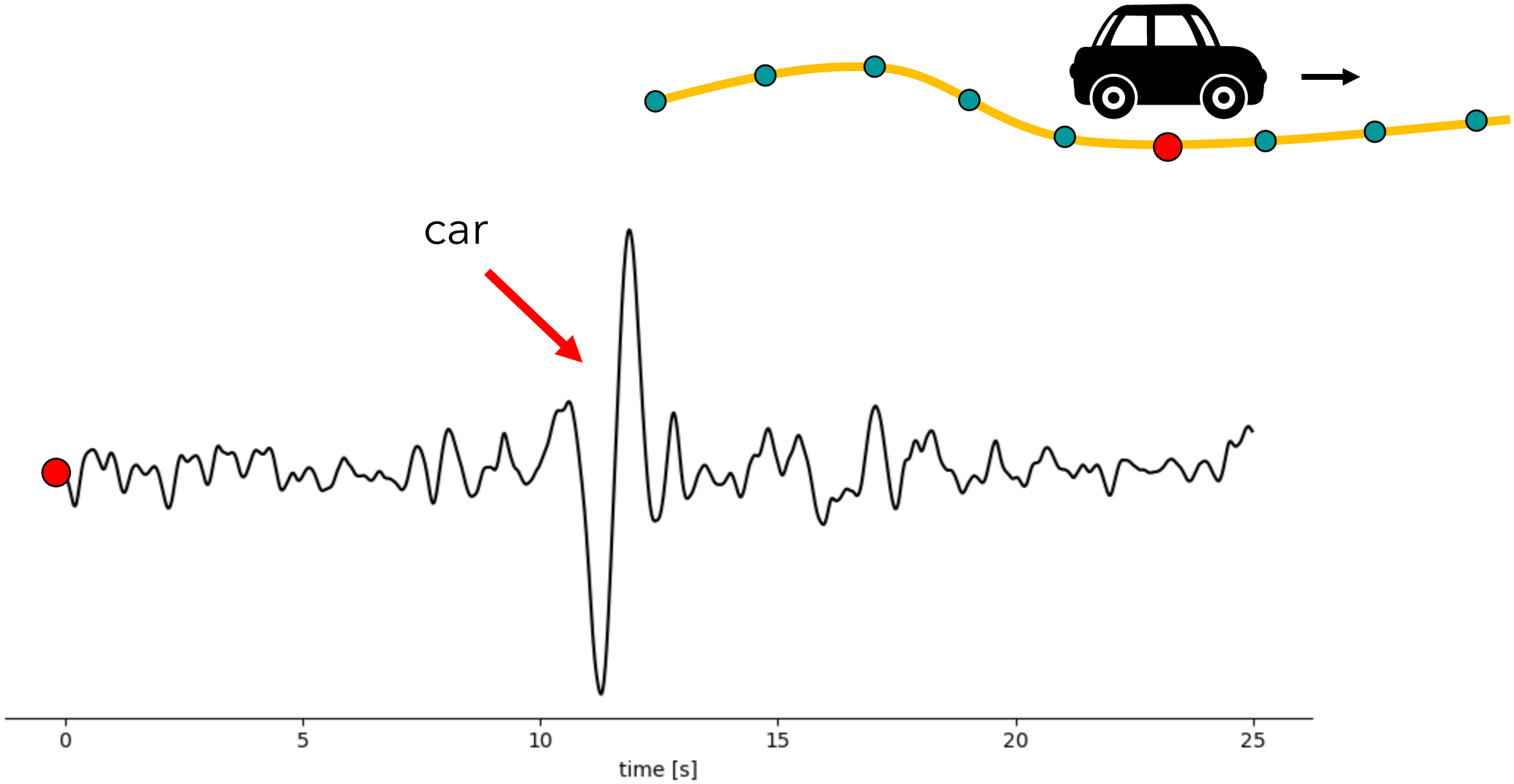
Tracking cars



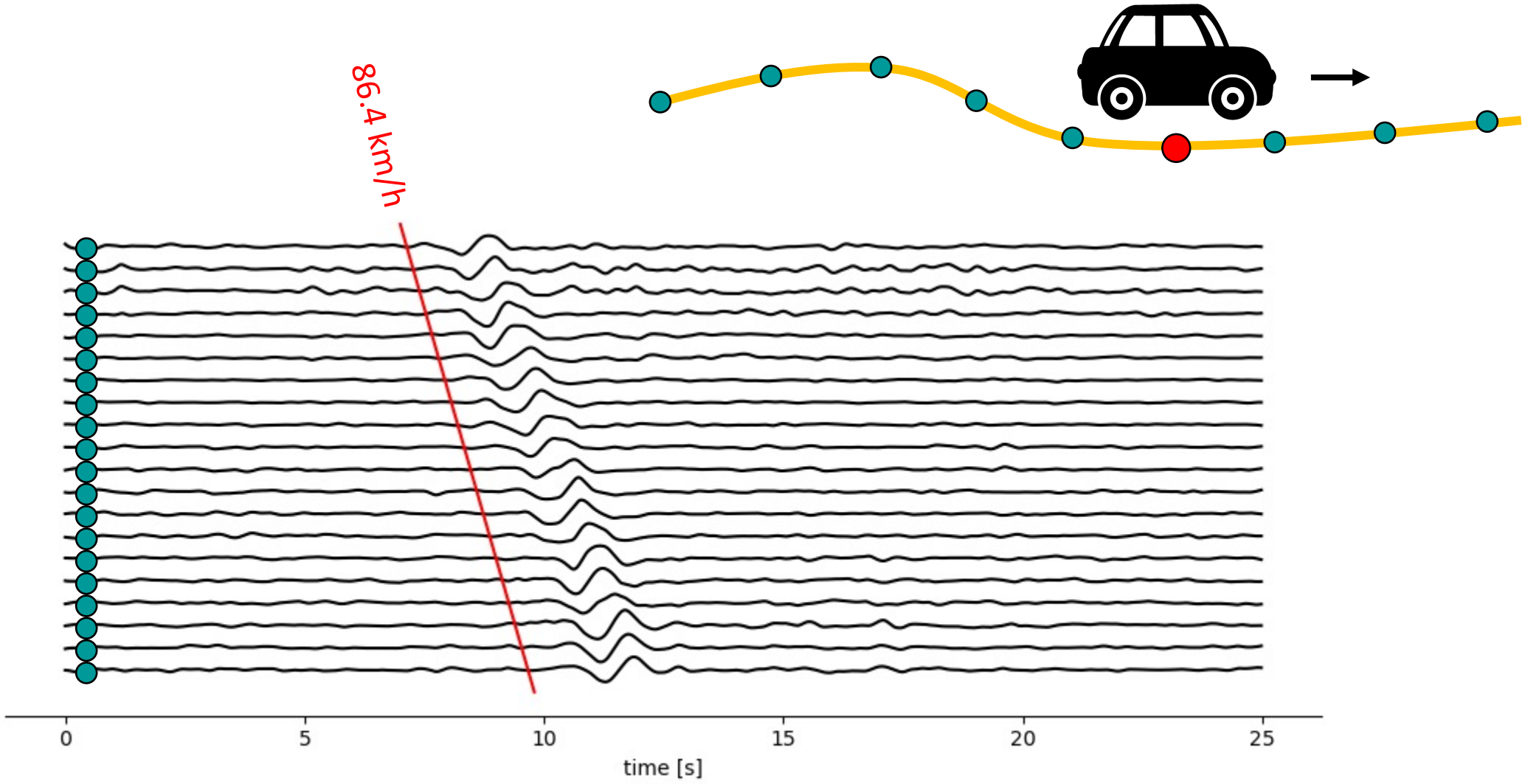
Heartbeat of a city



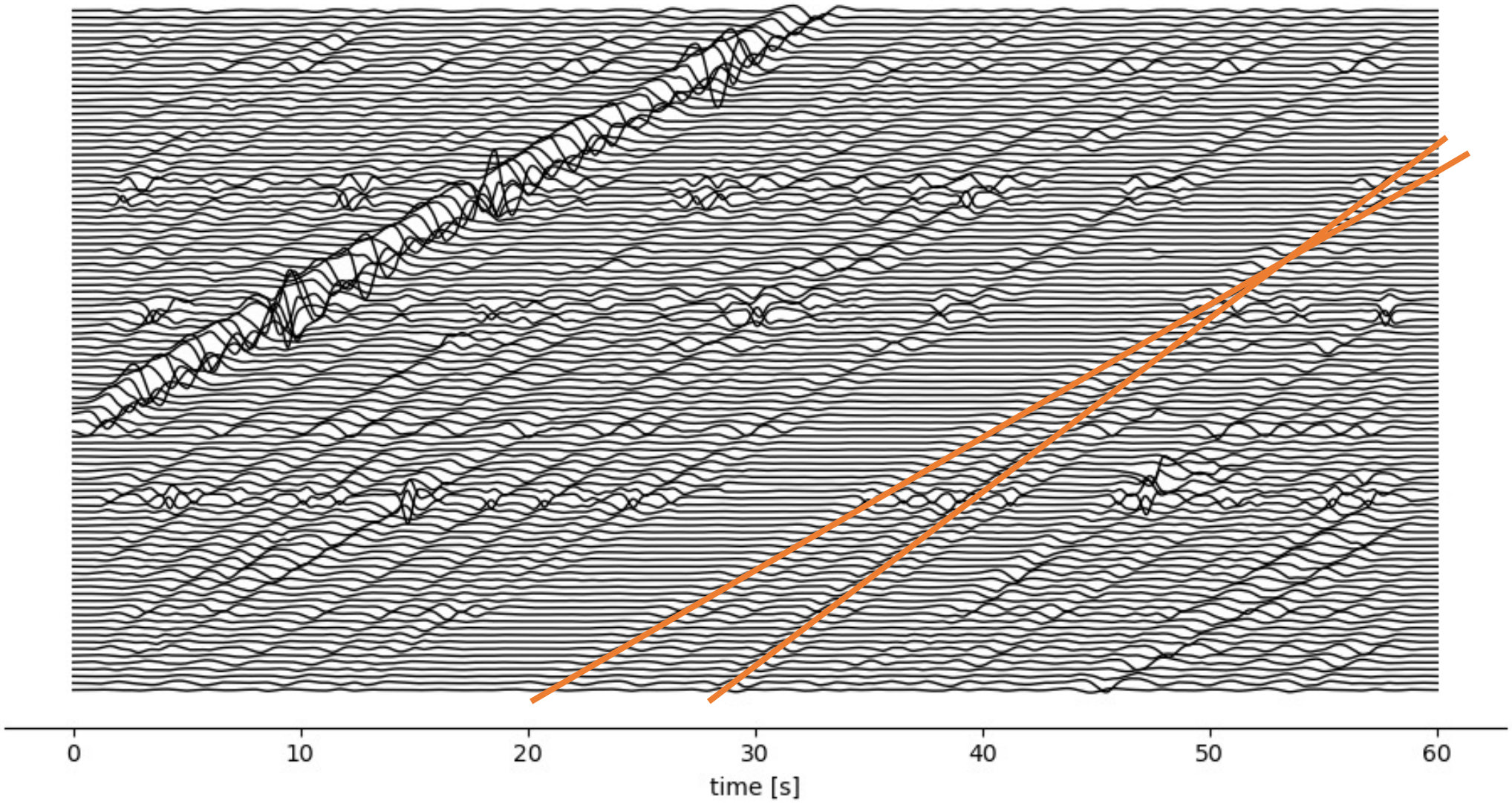
Measurements of cars



Measurements of cars

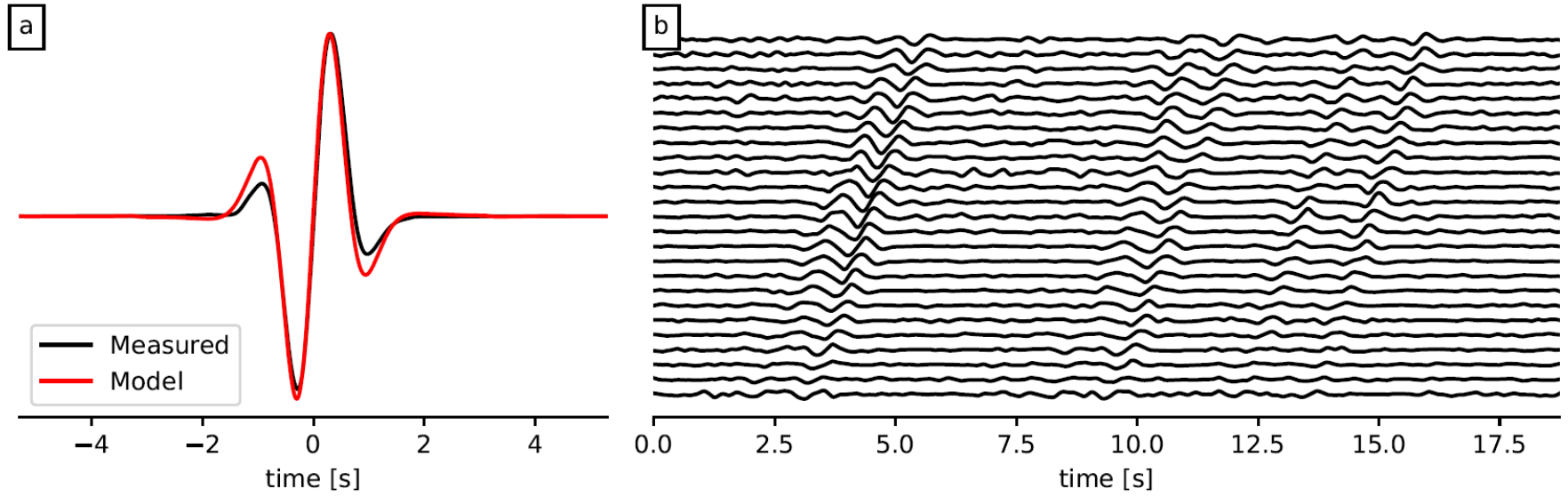


Lots of measurements of cars…

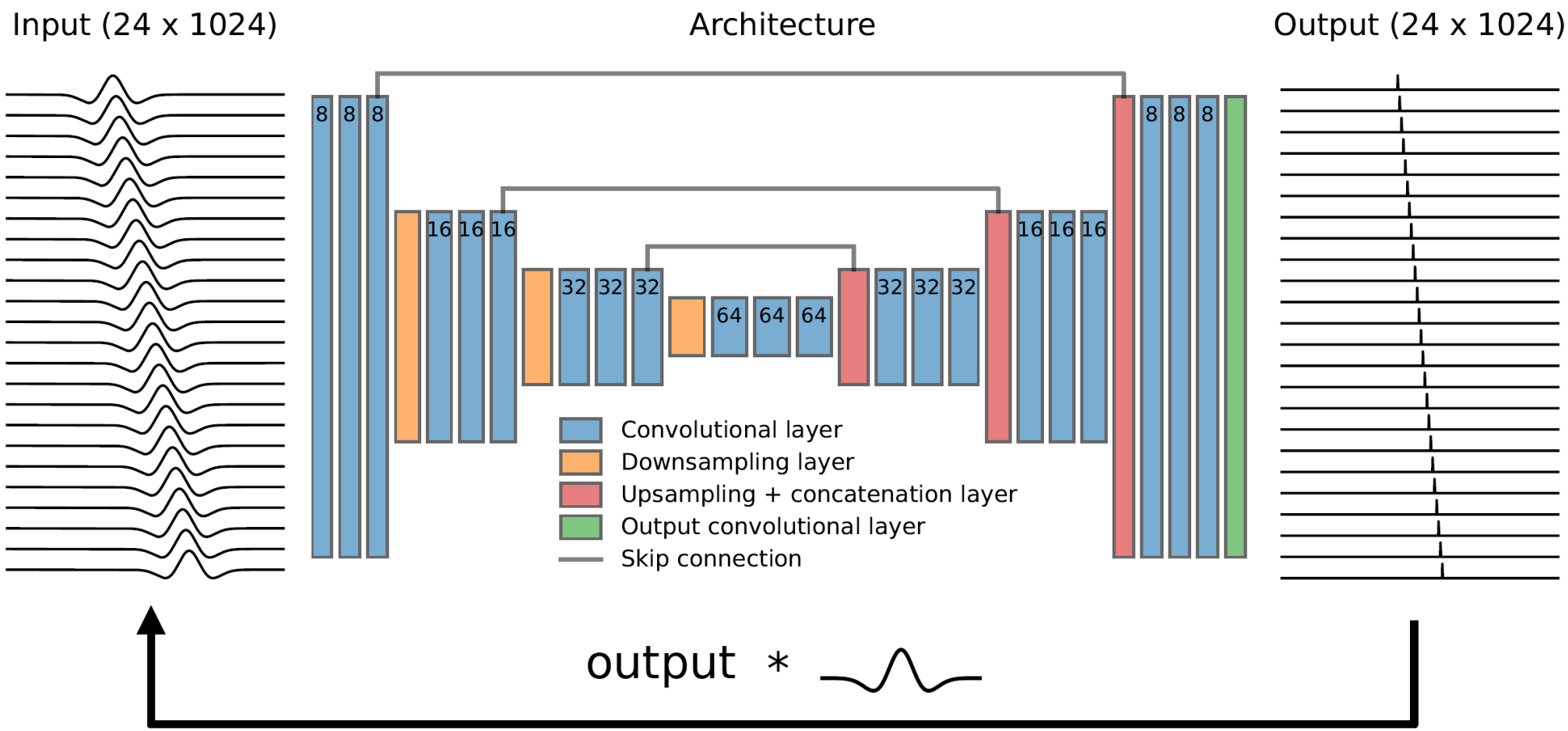


Exploiting similarity

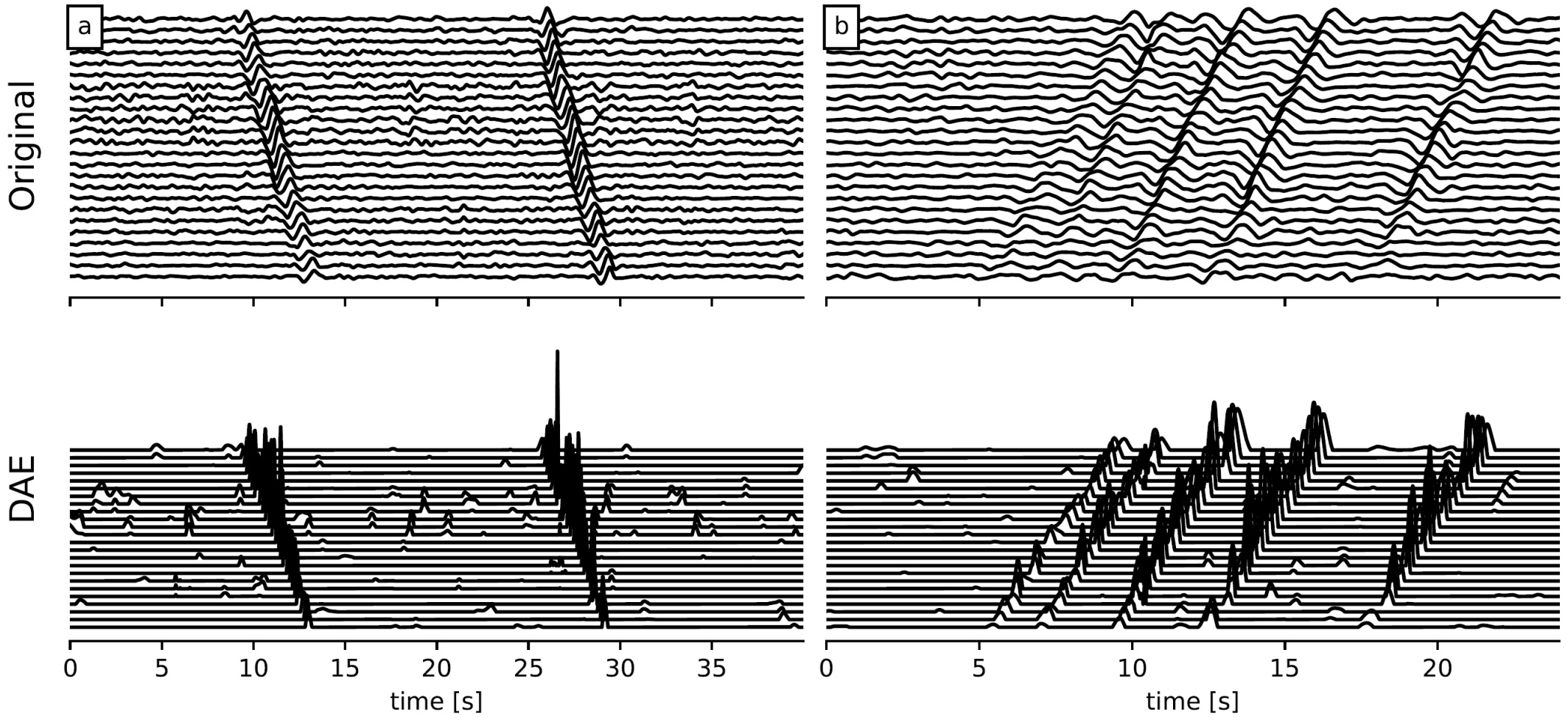
- Characteristic signature of a car recorded at a given location is the same for each car (up to a proportionality constant)
- Make measurements of cars more “compact” by deconvolving this characteristic signature from the DAS data



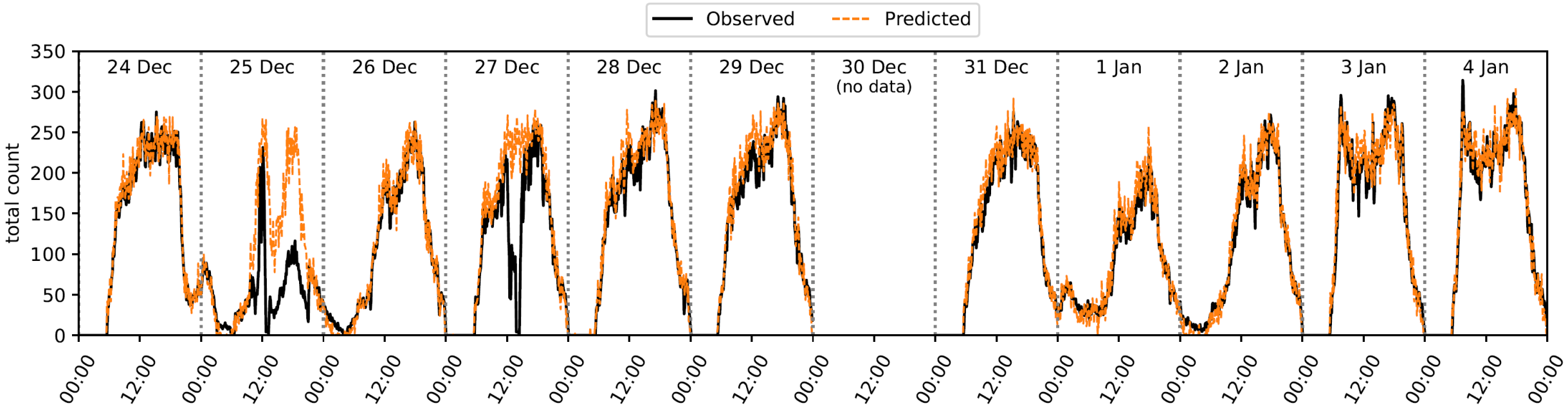
Deconvolution Auto-Encoder (DAE)



Deconvolution results

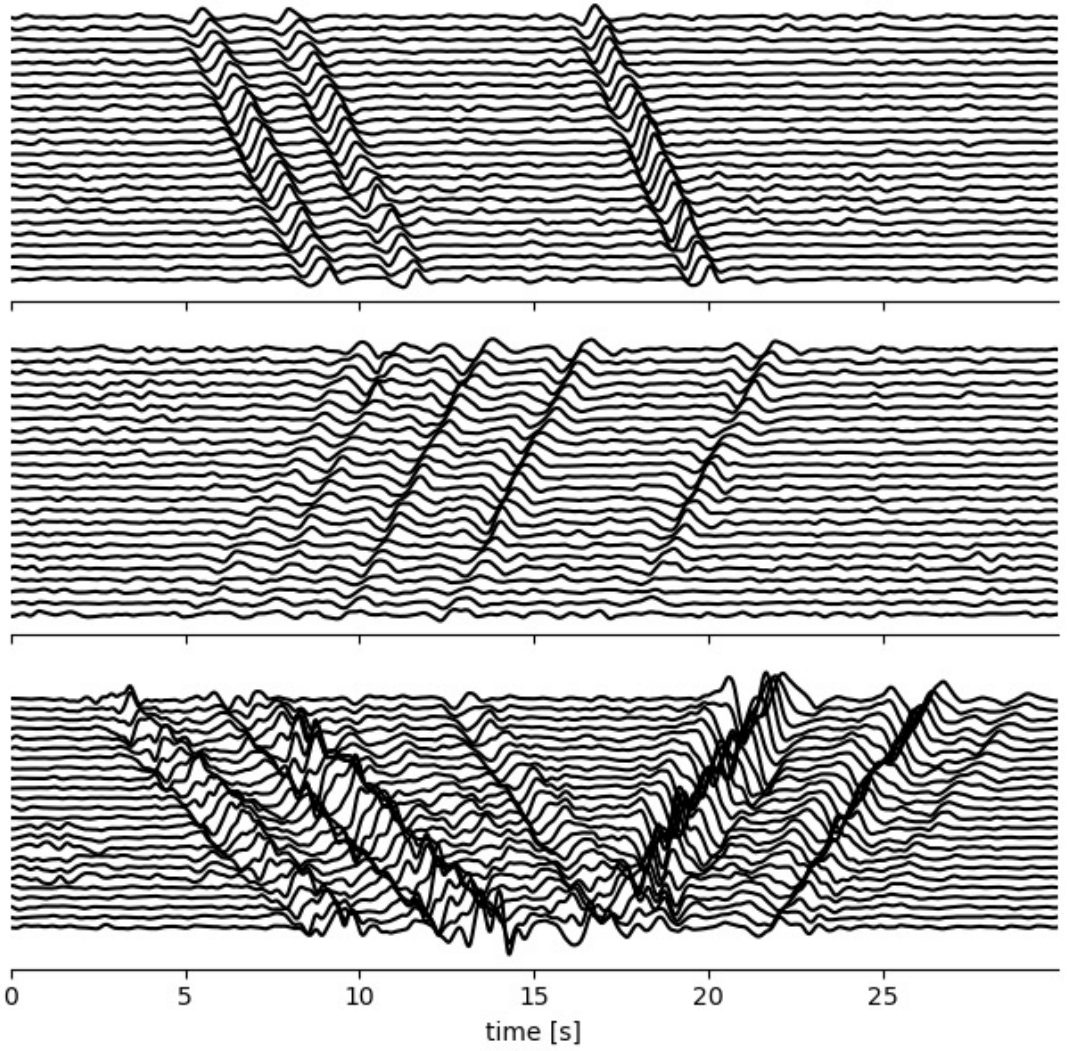


Counting cars

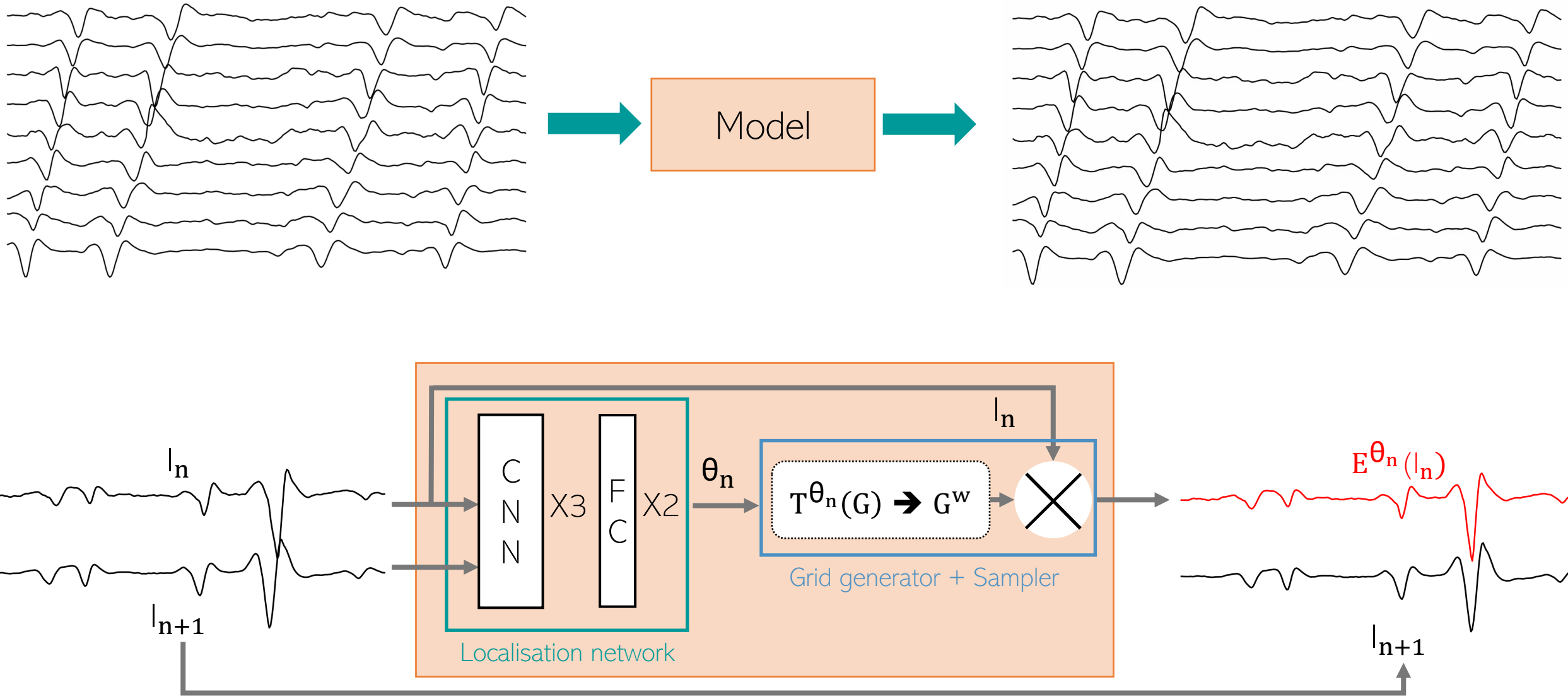


DAS beamforming

- Cars are identified as coherent waveforms propagating at a constant speed
- DAS is an array of sensors: ideally suited for beamforming analysis

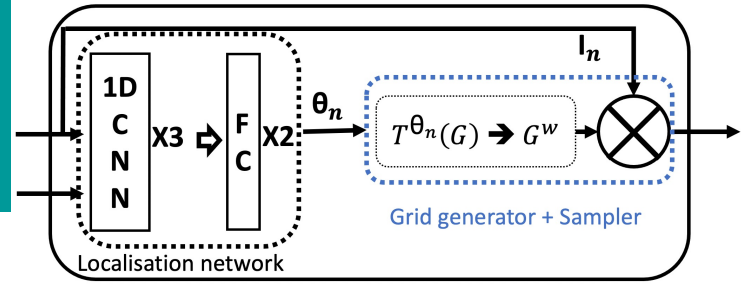


Model architecture

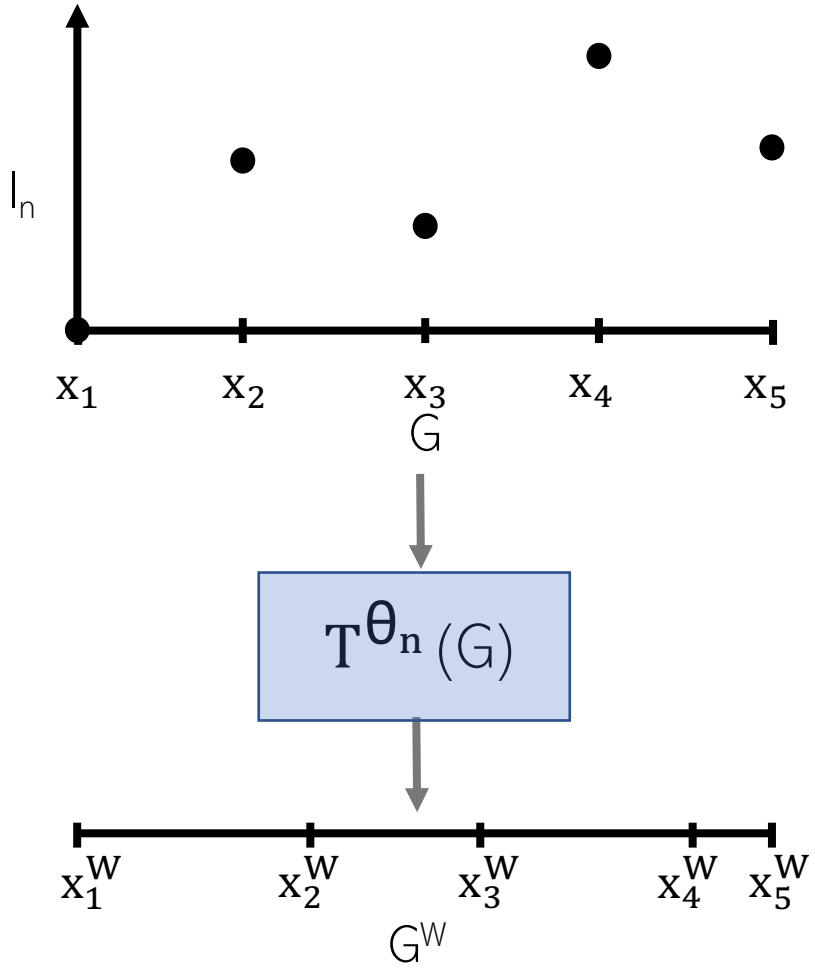


[1] Shapira Weber, Ron A., et al. "Diffeomorphic temporal alignment nets." Advances in Neural Information Processing Systems 32 (2019).

Model architecture

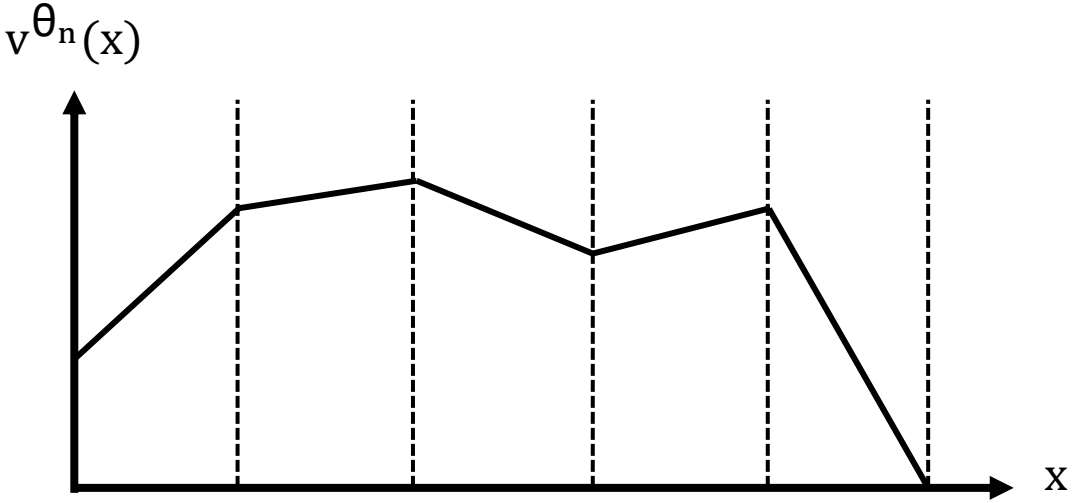


Grid generator (toy example)



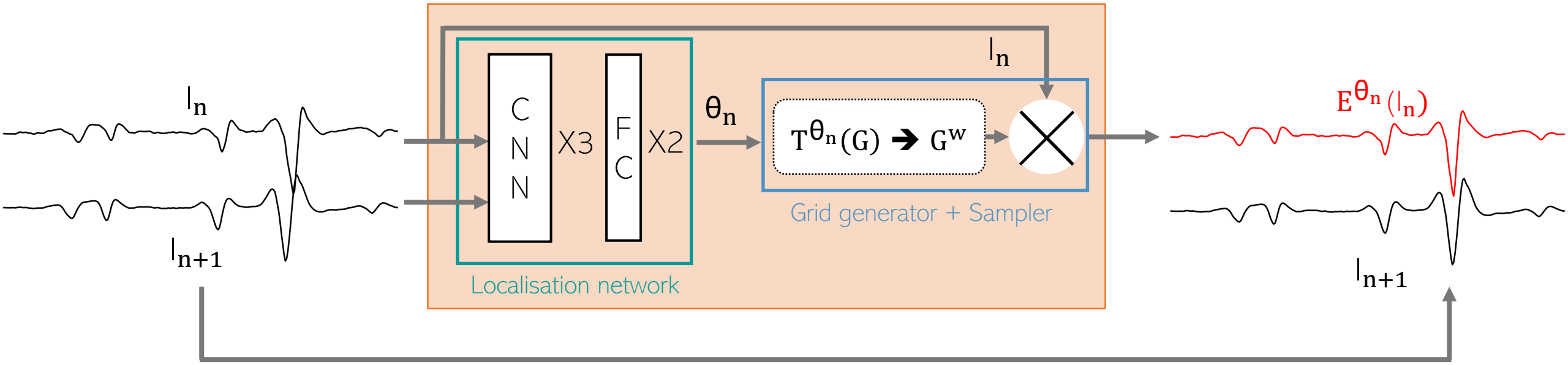
T^{θ_n} is a Continuous Piecewise-Affine Based (CPAB) transformation

$$T^{\theta_n}(x) = x + \int_0^1 v^{\theta_n}\left(\phi^{\theta_n}(x,\tau)\right) d\tau$$



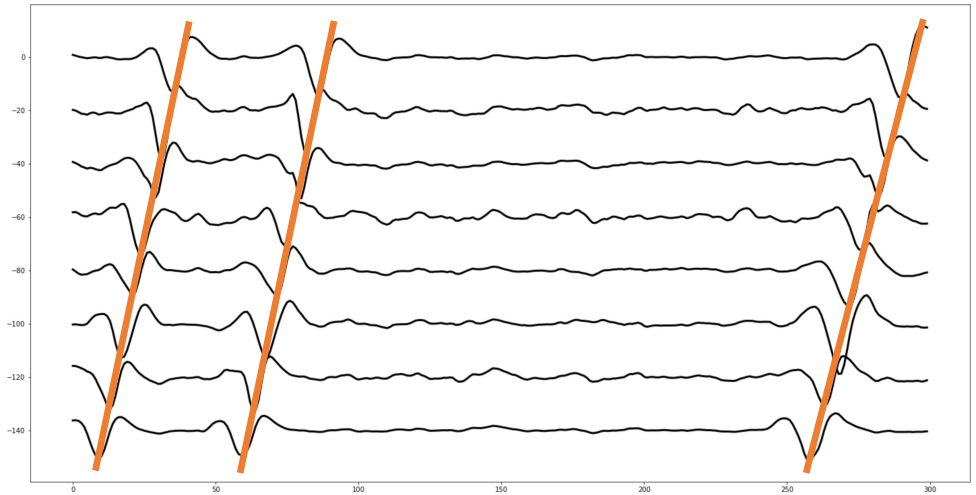
Freifeld, Oren, et al. "Transformations based on continuous piecewise-affine velocity fields."

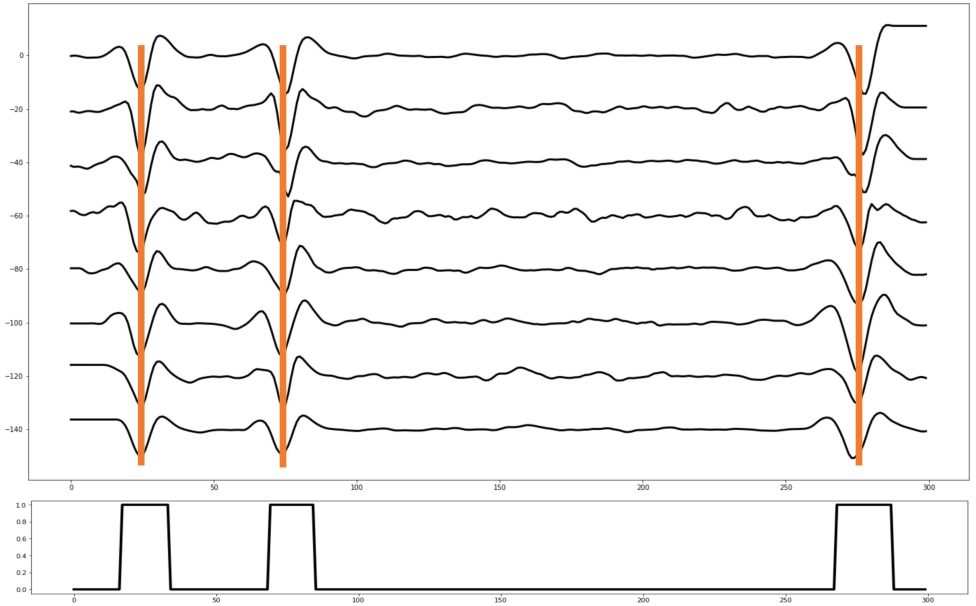
Self-supervised training



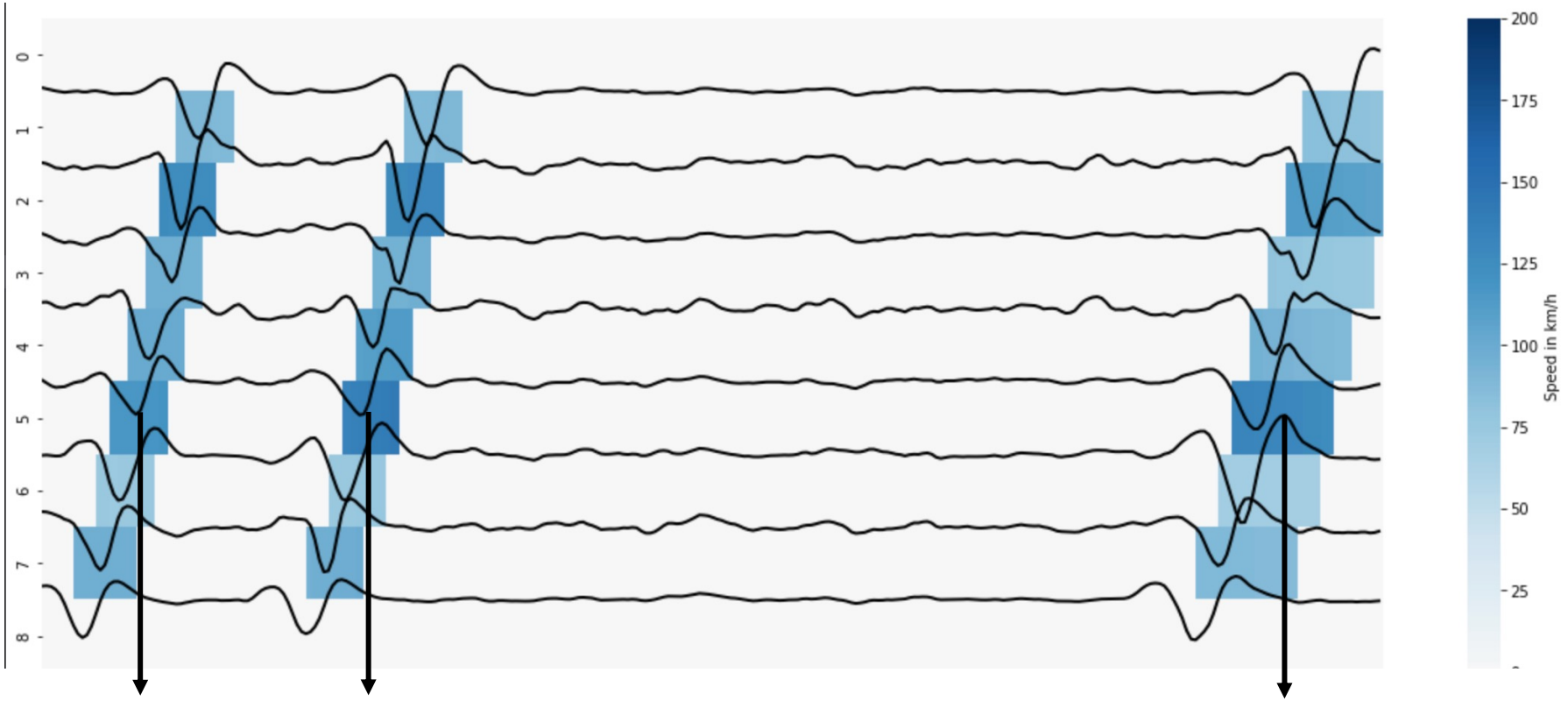
$$\text{Loss} = \sum_{n=0}^{Nch-1} \left\| E^{\theta_n}(I_n) - I_{n+1} \right\|_{l2}^2 + \alpha \sum_{n=0}^{Nch-1} \|\theta_n\|_{\Sigma_{CPA}^{-1}}$$

Velocity estimation



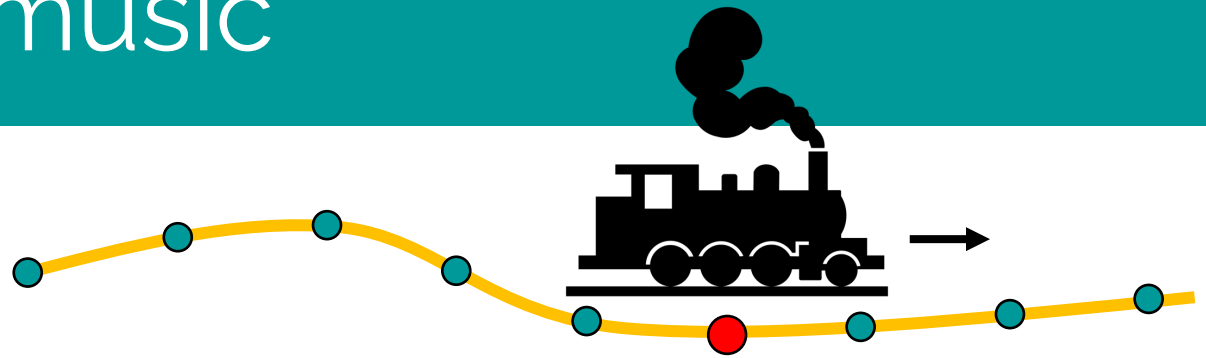


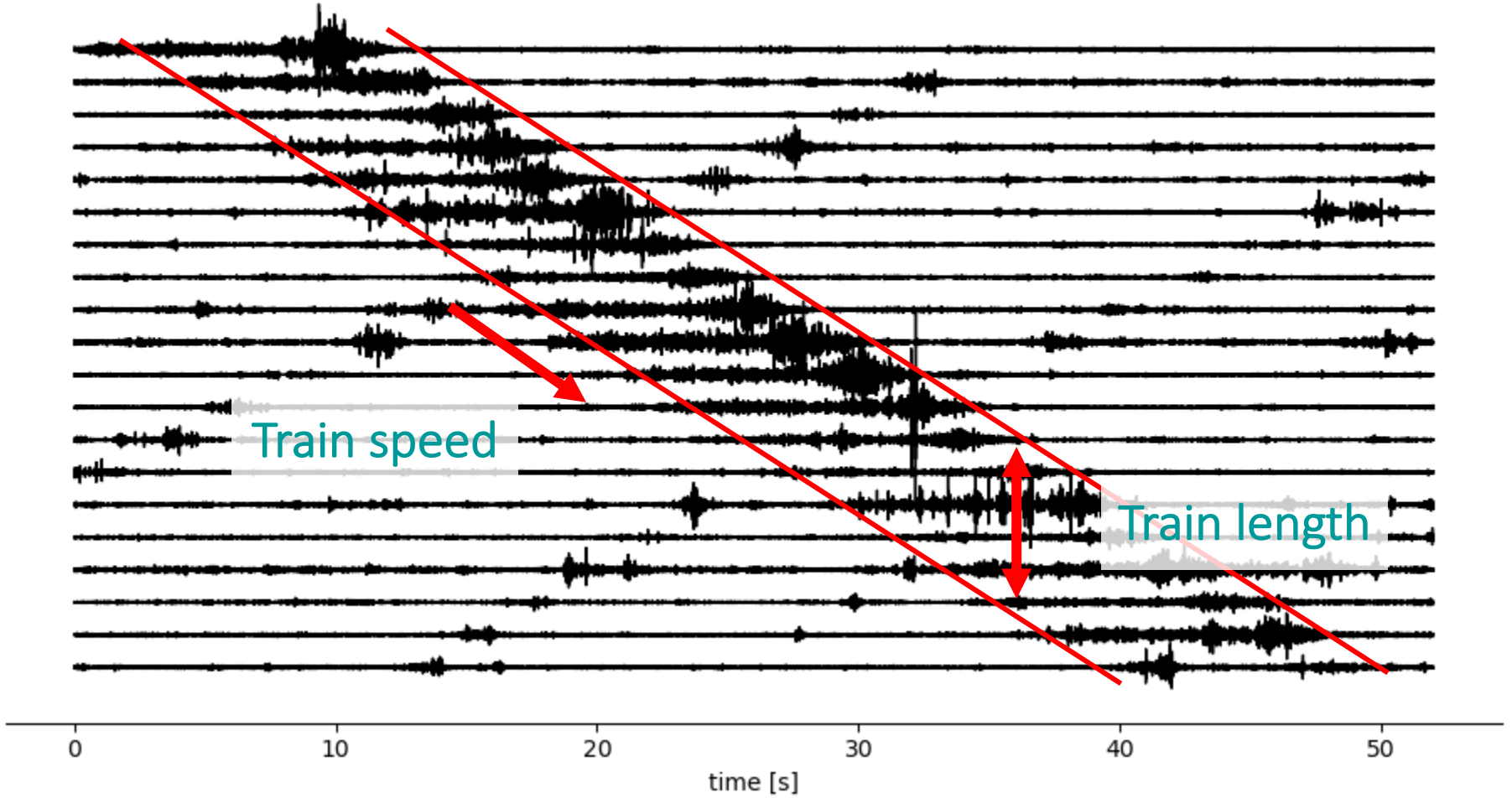
Velocity estimation



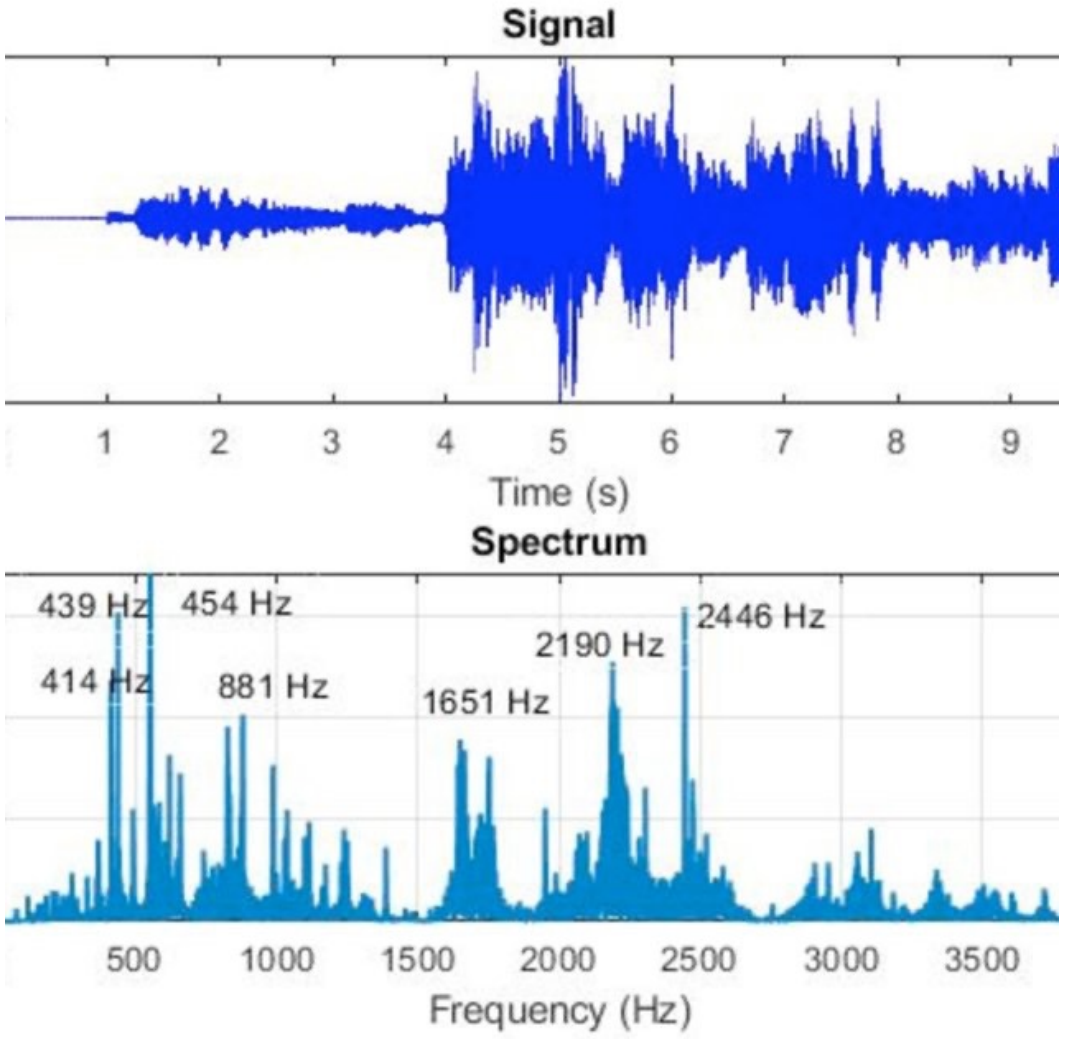
Window average speed:
97 km/h

Train music

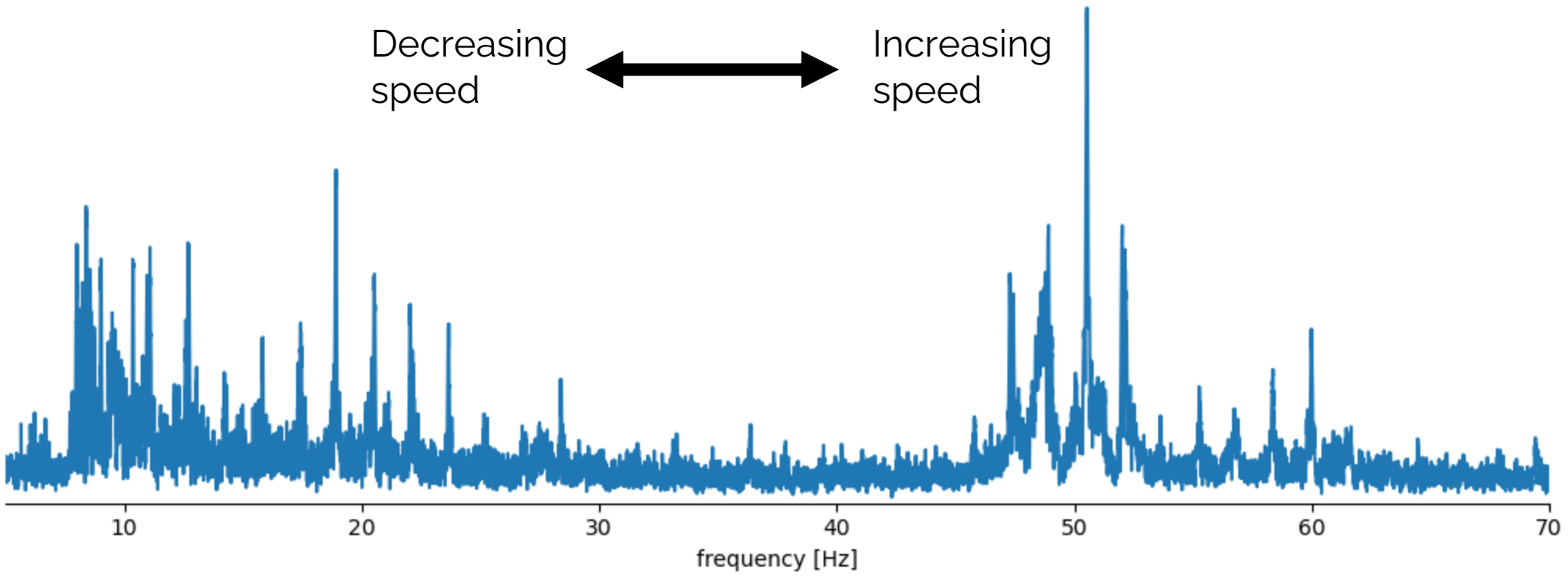


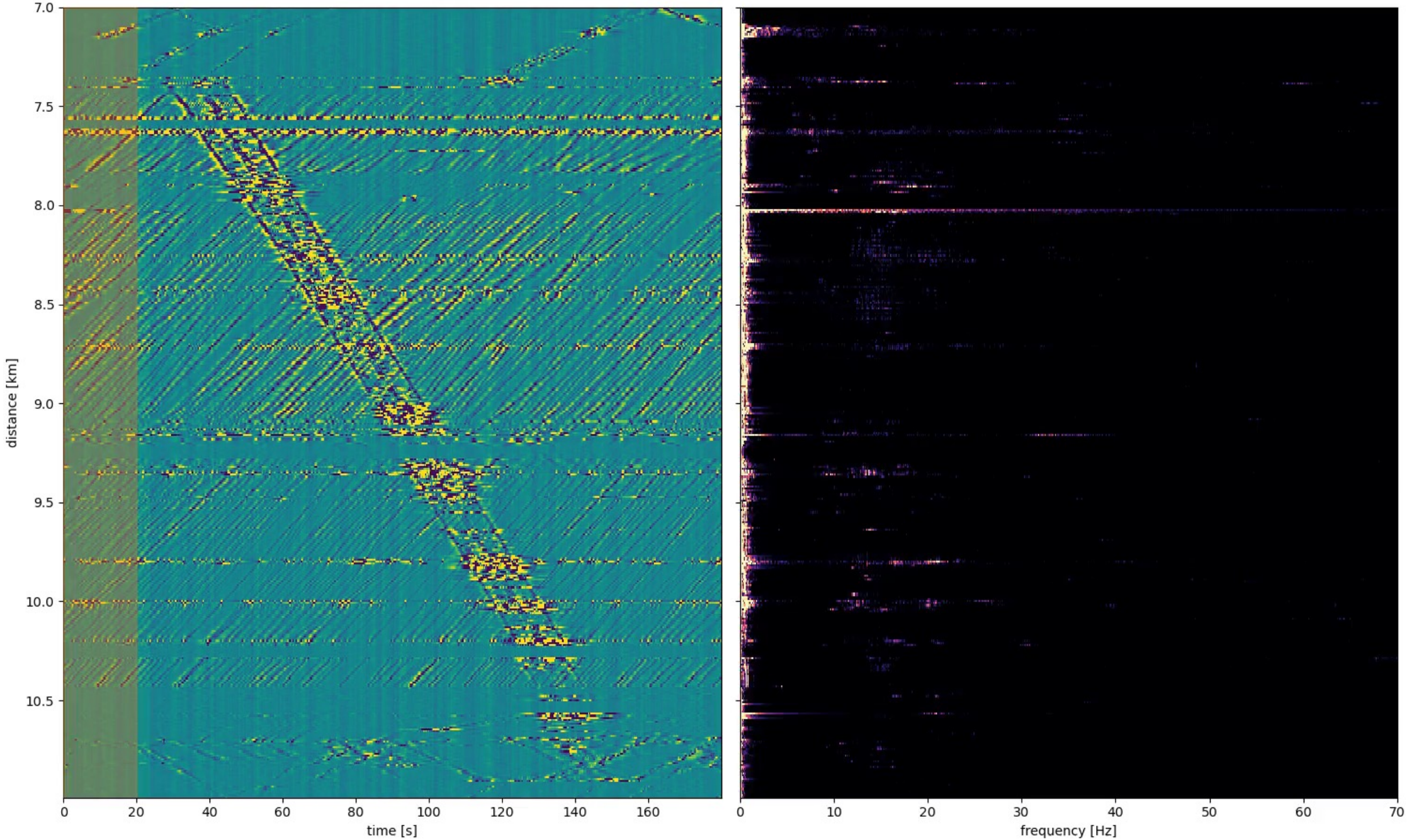


Train music


Signal
1
2
3
4
5
6
7
8
9
Time (s)
Spectrum
439 Hz
454 Hz
414 Hz
881 Hz
1651 Hz
2190 Hz
2446 Hz
500
1000
1500
2000
2500
3000
3500
Frequency (Hz)

Train music

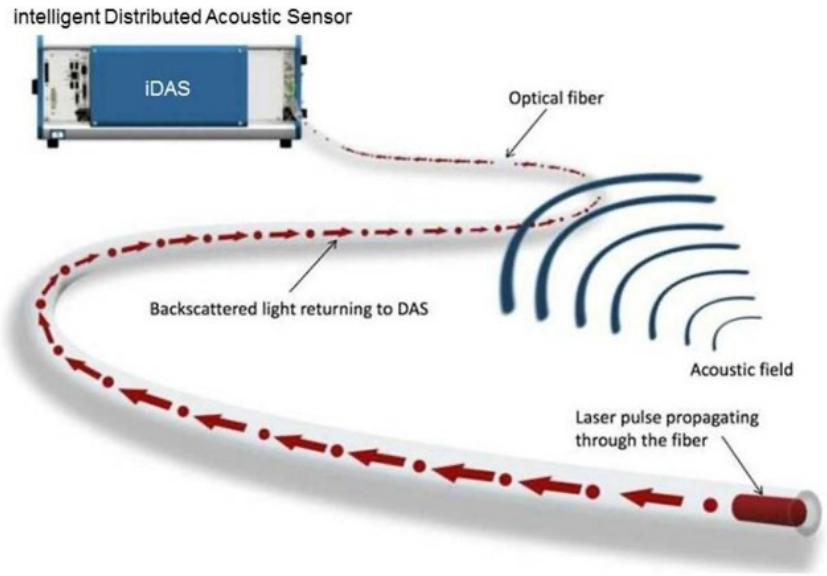

Decreasing speed
Increasing speed
10
20
30
40
50
60
70
frequency [Hz]


distance [km]
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
0
20
40
60
80
100
120
140
160
time [s]
0
10
20
30
40
50
60
70
frequency [Hz]

Ongoing researches and perspectives

Traffic analysis

Vehicle speed
Number of vehicles
Weight of trucks



Railway monitoring

Train speed
Railroad quality
Safety assessment

Subsurface imaging

Water table monitoring (droughts/rainfall)
Landslides

Offshore activities

Tracking of ships
Identification of marine mammals
Protection of *Marine Protected Areas*

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Papers and codes available online.