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OSPP contest

Deep learning for laboratory earthquake prediction and autoregressive forecasting of fault zone stress

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Outline

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- Topic introduction
- Neural Network features and models
- Results I: prediction
- Results II: forecasting
- Conclusions

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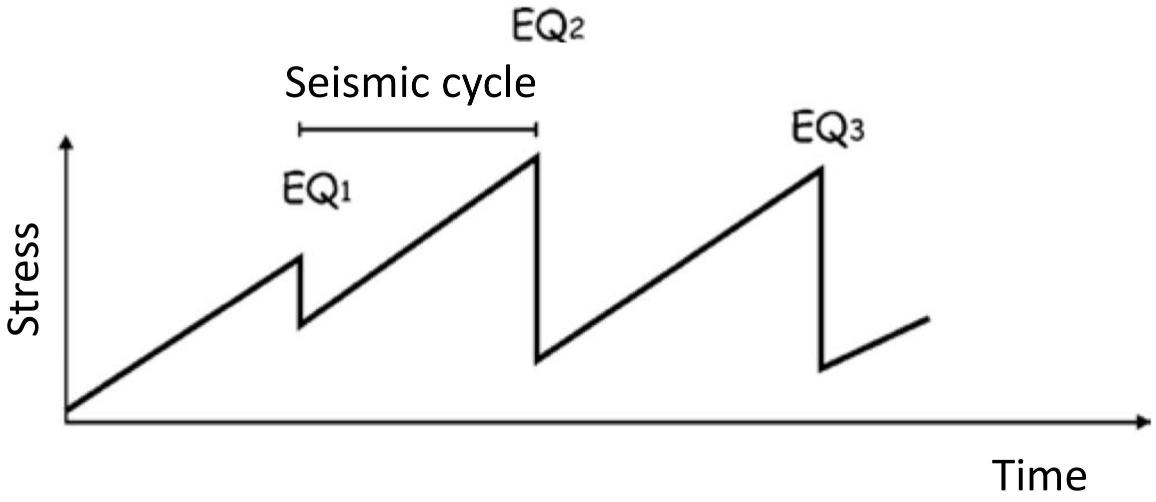

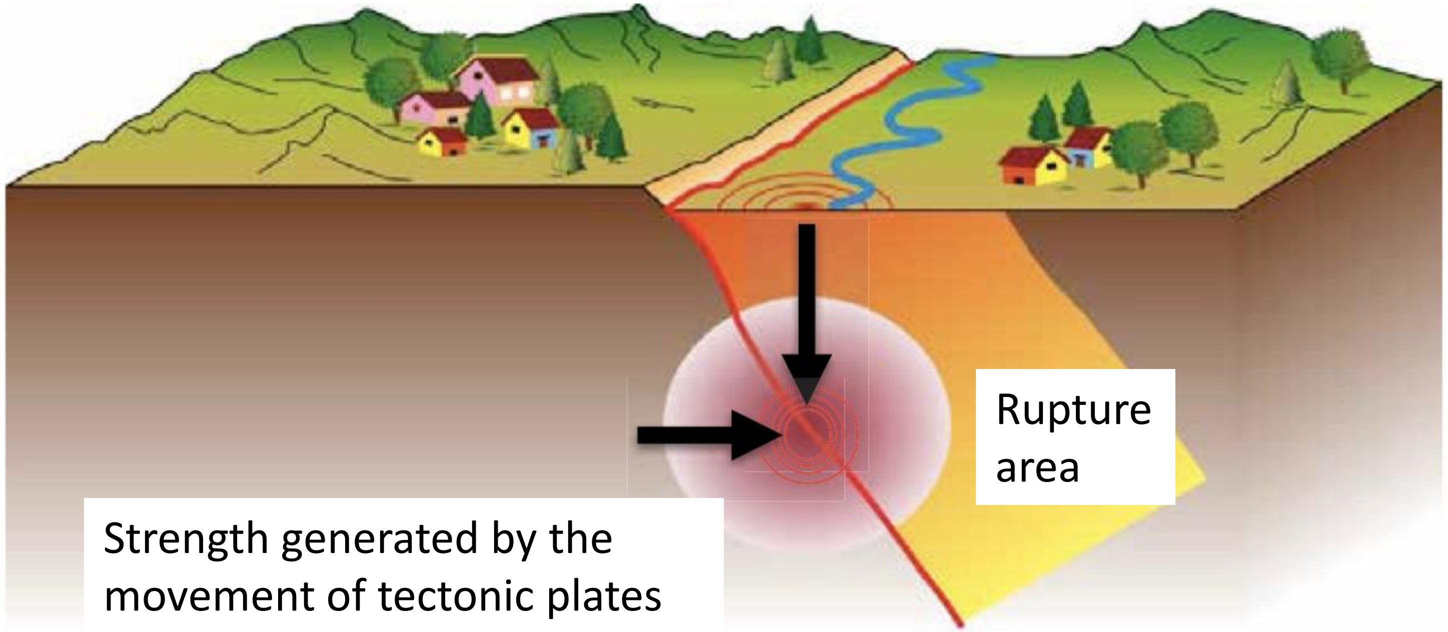

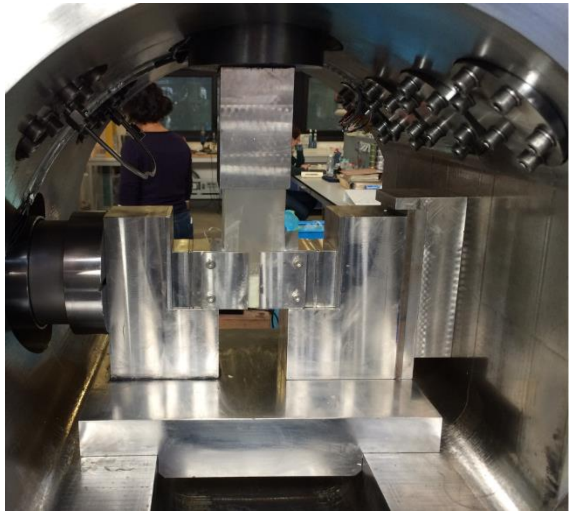

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Holy grail:
- when will the next event occur?
- Is it possible to know the state of stress of the faults?

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Problem definition

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Use Machine Learning to

Predict

Predict a quantity x (target) at the time t using a variable (input) at the same time.
The ML model can be trained to learn how the quantities of interest (input and target) are related to each other, to be able to estimate each present time of the target quantity given an input value.

Forecast

Forecast a quantity in future times *t+1,…,t+n*. based on time-series data about the past times *t-m,…t-1,t.*
The ML model can be trained to learn a variable in the past and to understand how it could evolve in the future.

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Laboratory earthquakes

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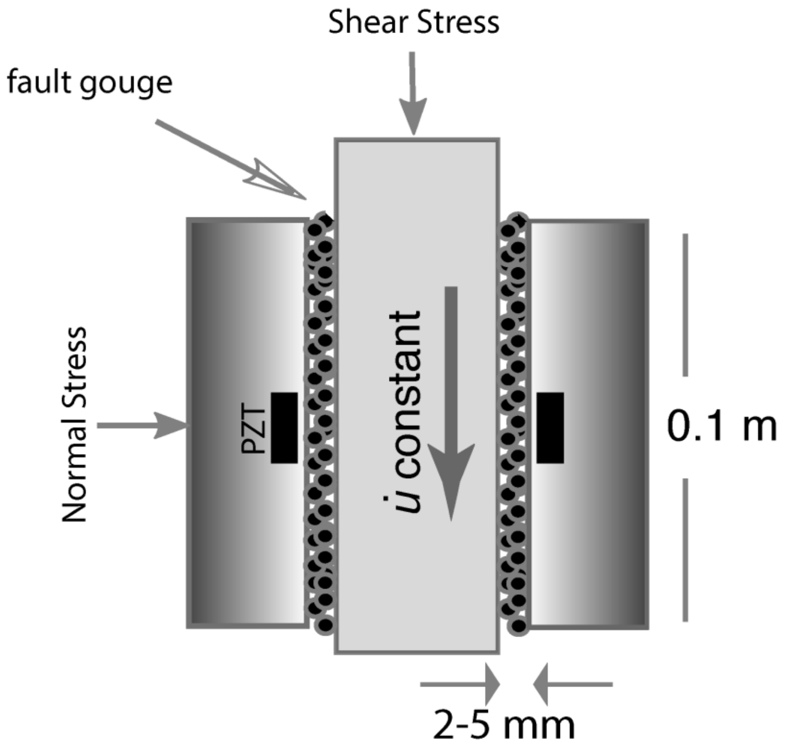
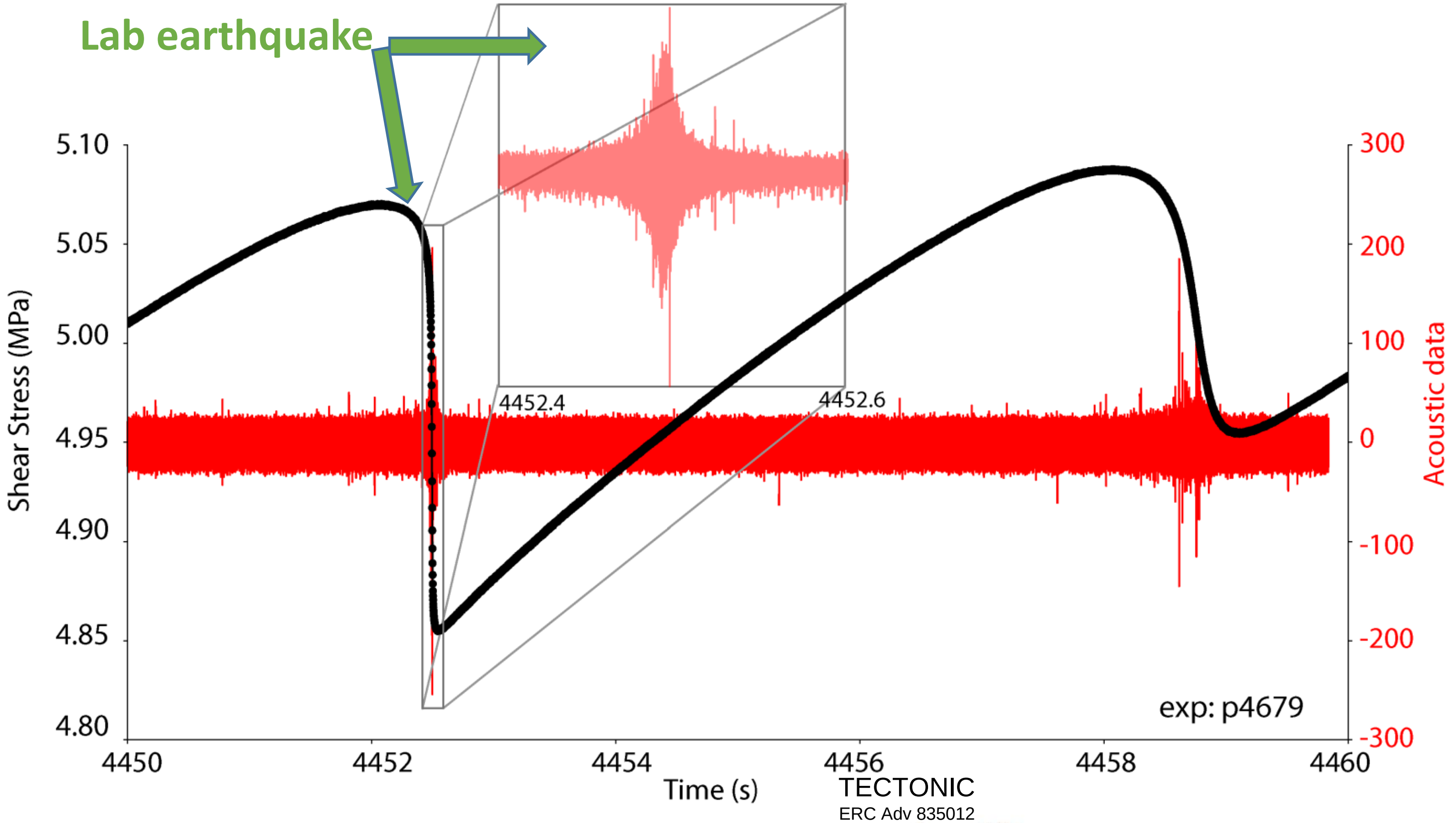
Recorded quantities of interest: Shear Stress, Acoustic Emissions (lab foreshocks)

Goal: fault zone stress state.





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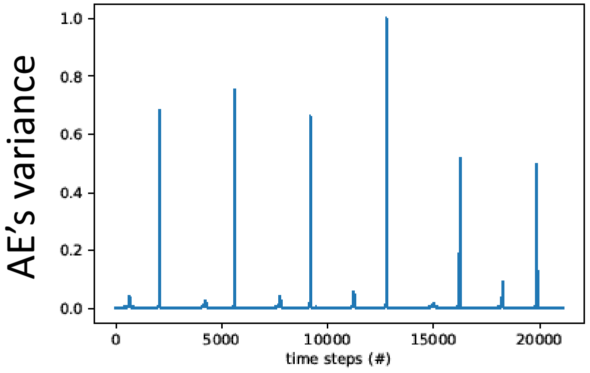
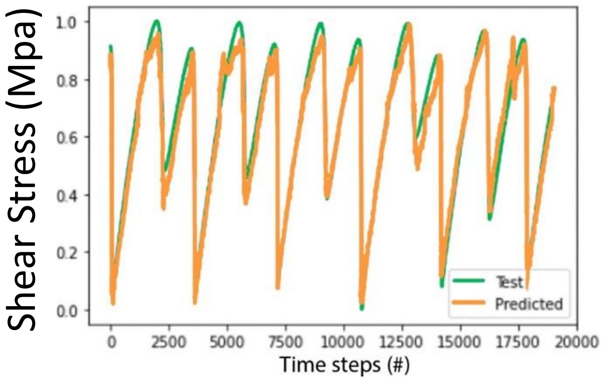
NN models for…

(1) Prediction





Input= Acoustic Emission's variance

Output= shear stress

Adopted MODEL:

- **LSTM+CNN**

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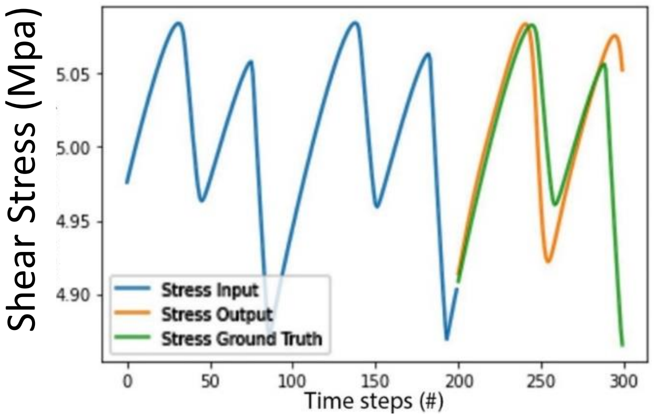
(2) Forecasting



Input= past shear stress (20 seconds)

Output= future shear stress (10 seconds)

Adopted MODELS:

- **LSTM**
- **TCN**
- **Transformer**

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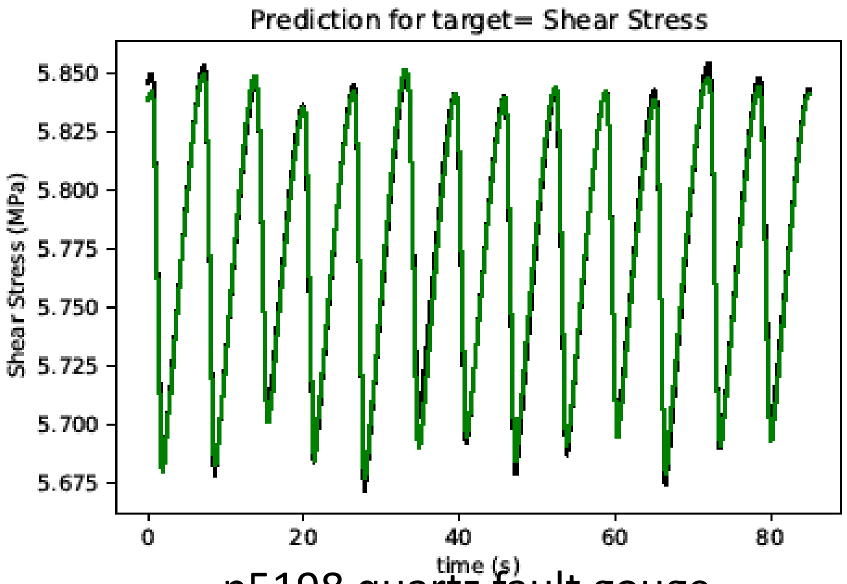
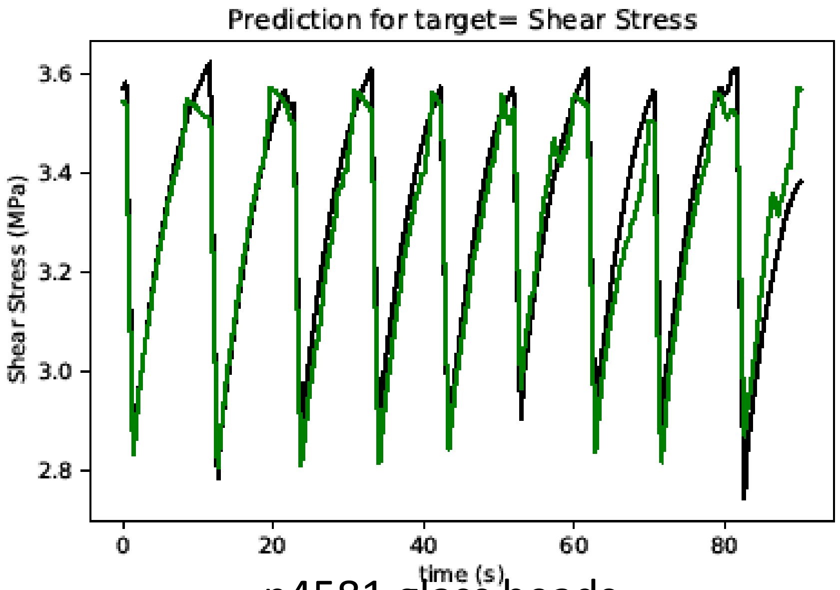
Prediction



p5198 quartz fault gouge



p4581 glass beads

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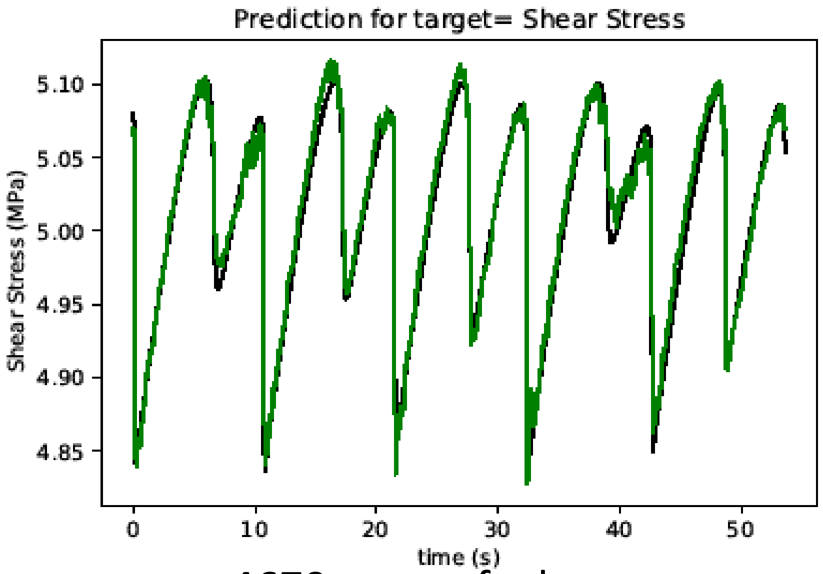

p4679 quartz fault gouge

Target	Performance	**LSTM+CNN**
p5198	R^2	0.98844
	RMSE	0.03049
p4581	R^2	0.92538
	RMSE	0.06703
p4679	R^2	0.95737
	RMSE	0.05191

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Forecasting: Autoregressive procedure

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In the second part of this work the goal is to actually **forecast** the future, with an autoregressive (AR) procedure. This is the **first work of its kind in seismology!**

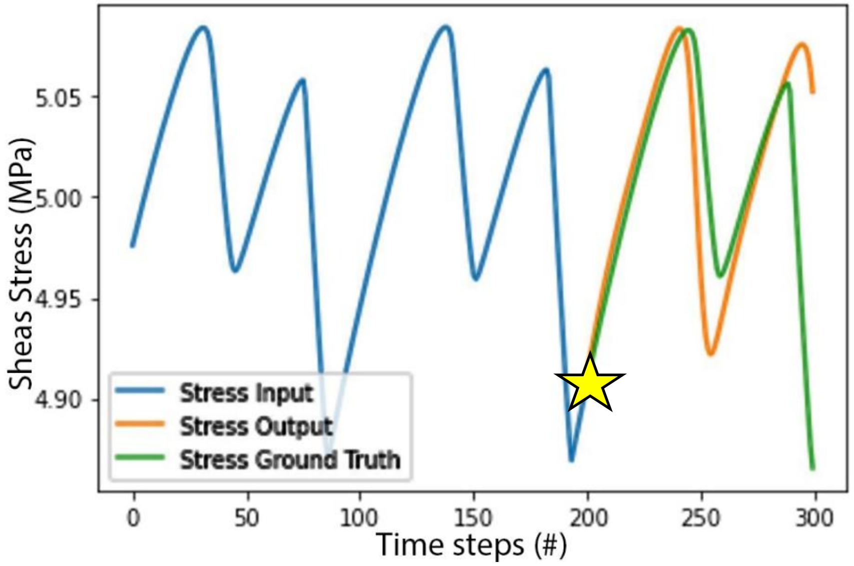
Adopted models: **LSTM, Temporal Convolution Network, Transformer Network**

☆ Present time

Target variable in the past

Target Ground Truth

Target estimate (forecasting)



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Forecasting in p5198, fault gouge

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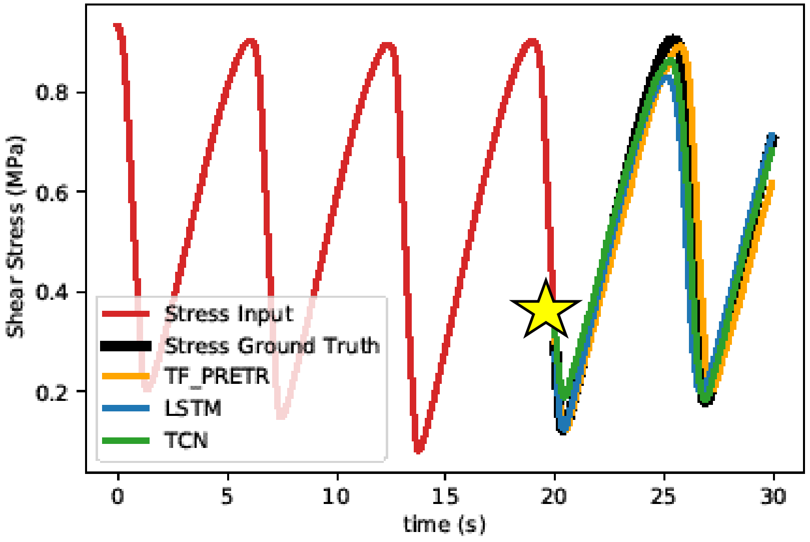
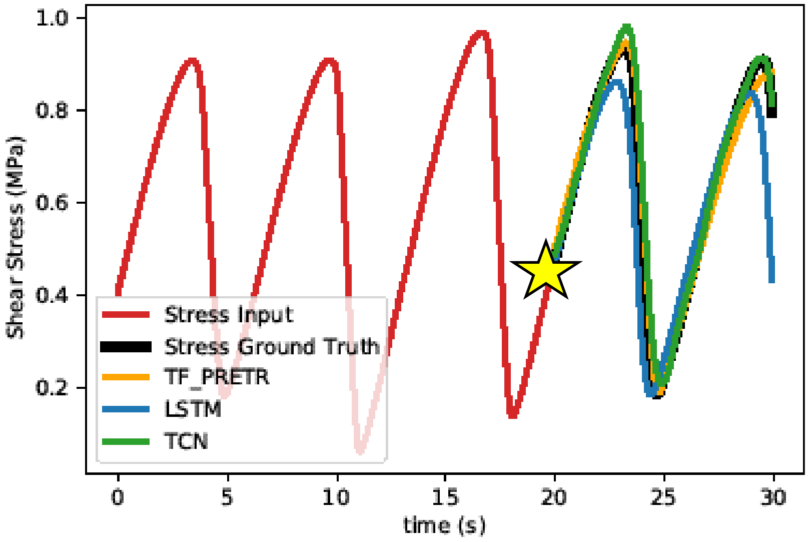
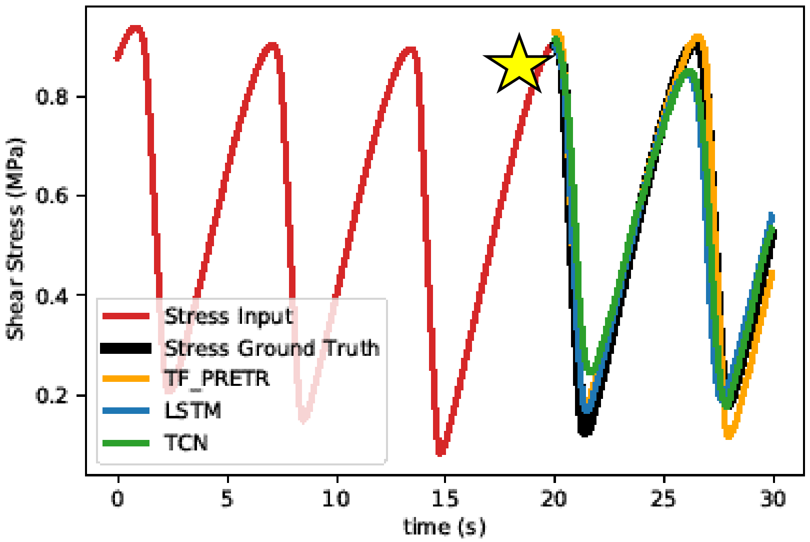


Example of 3 windows showing different times during the experiment.

With this experiment the performance is really good for TCN and TF.

TCN	R^2	**0.9419**
	RMSE	**0.0549**
LSTM	R^2	0.8021
	RMSE	0.0904
Transformer	R^2	0.8914
	RMSE	0.0707





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Forecasting in p4581 glass beads

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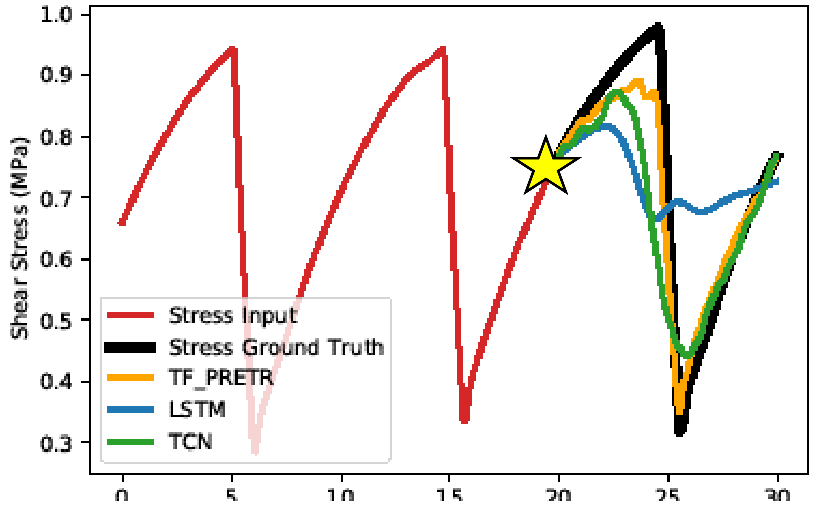
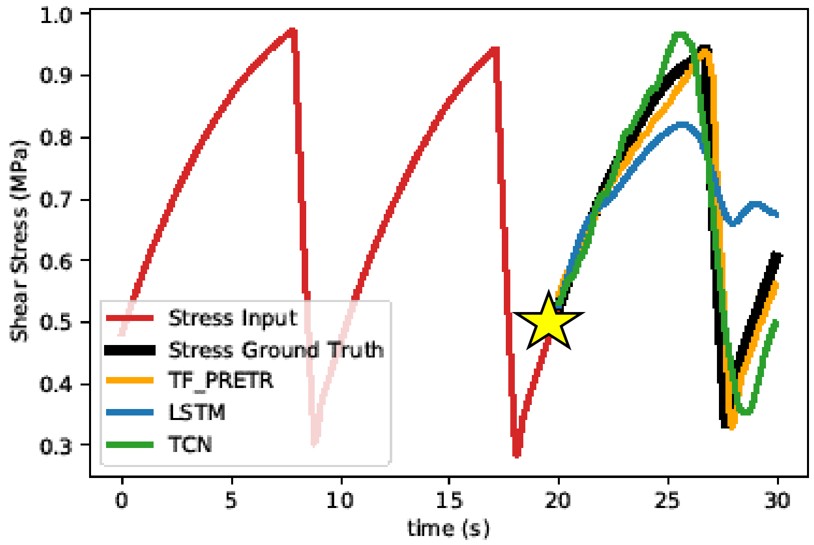
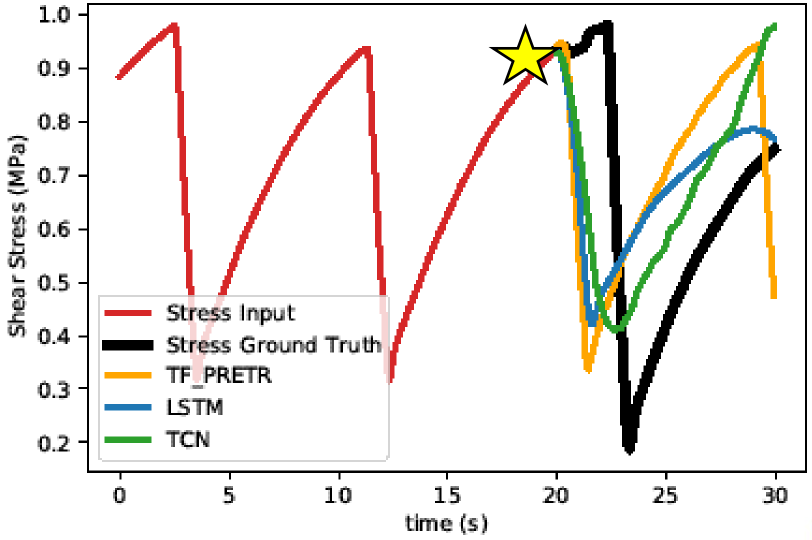


Example of 3 windows showing different times during the experiment.

The performance (in average) the worst among the tested experiments.
Analyzing many windows we understood that the problem is due to some «important noise» around the peak.





TCN	R^2	**0.3935**
	RMSE	**0.1245**
LSTM	R^2	-4.5193
	RMSE	0.1521
Transformer	R^2	0.1172
	RMSE	0.1460

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Forecasting in **p4679**, fault gouge

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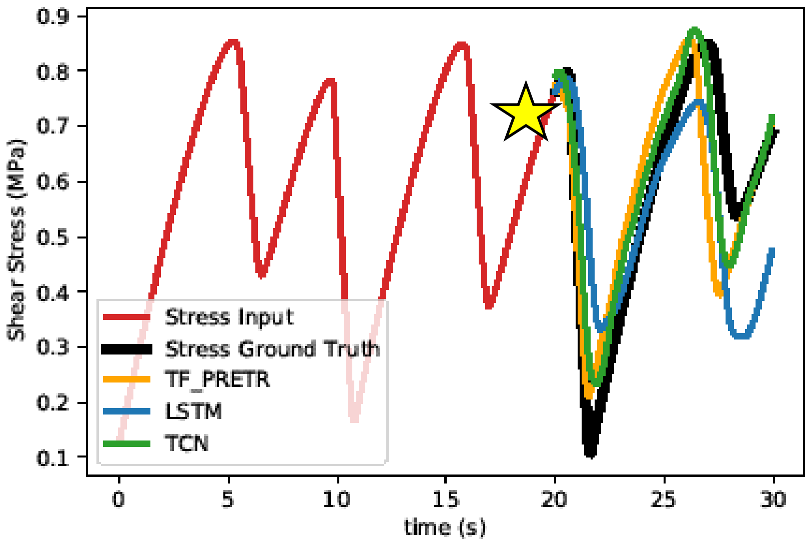
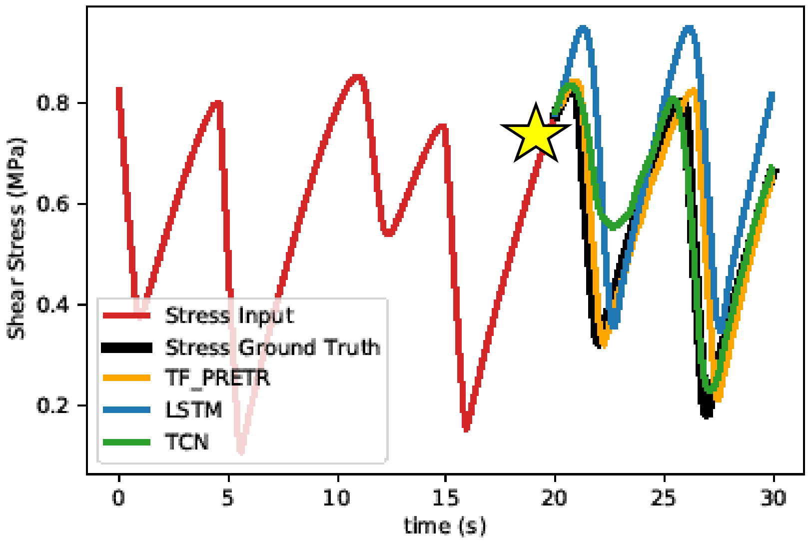
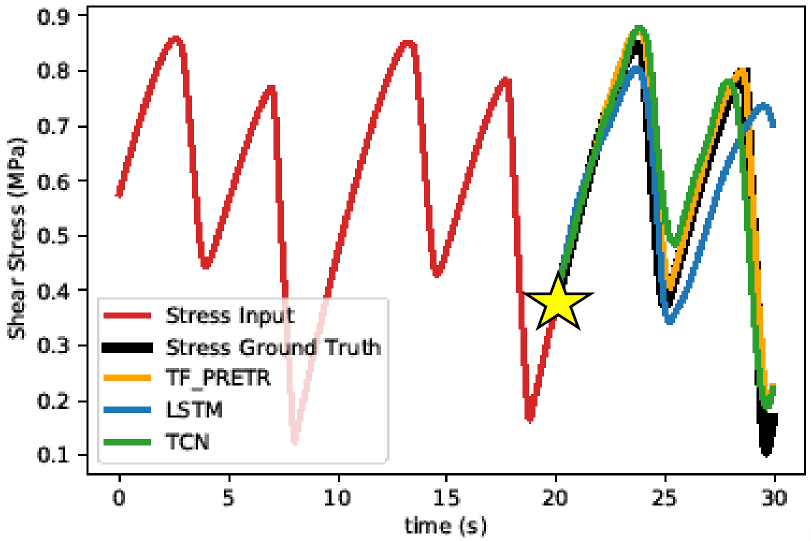


Example of 3 windows showing different times during the experiment.

With this experiment the best performance is with TCN, followed by Transformer.

TCN	R^2	**0.8273**
	RMSE	**0.0732**
LSTM	R^2	-0.2704
	RMSE	0.1634
Transformer	R^2	0.7940
	RMSE	0.0738





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Conclusions: Prediction **Results**

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- The LSTM+ CNN model works properly for all the tested experiments.
- The AE's variance is a good feature to predict the shear stress for all tested experiments.

Conclusions: Forecasting Results

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- Autoregressive procedure allows for predicting indefinitely in the future.
- The best models to forecast shear stress in the future is the TCN, followed by the Transformer. The worst is LSTM.
- Experiment p4581 with glass beads is very challenging for forecasting. Further investigations are needed (problems are perhaps related to lack of fault creep or noisy data).

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THANKS FOR YOUR ATTENTION!

For any questions you can email me at: laura.laurenti@uniroma1.it

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