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Sektor za meteorološko in oceanografsko modeliranje

FRI UNIVERSITY OF LJUBLJANA
Faculty of Computer and Information Science

ViCOS visualcognitive systemslab

HIDRA3: a Robust Deep-Learning Model for Multi-Point Ensemble Sea Level Forecasting

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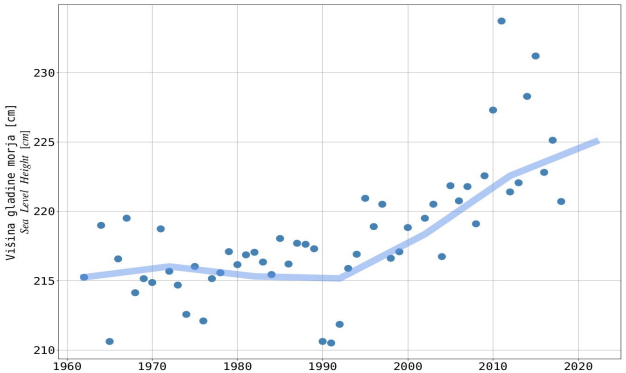
Sea Surface Height (SSH) Forecasting

Accurate sea level prediction several days ahead is crucial for protection of coastal communities, marine traffic and economy.



Mean sea level height in Koper from 1960 to 2020

Source: Slovenian Environment Agency ARSO

Koper, December 2008

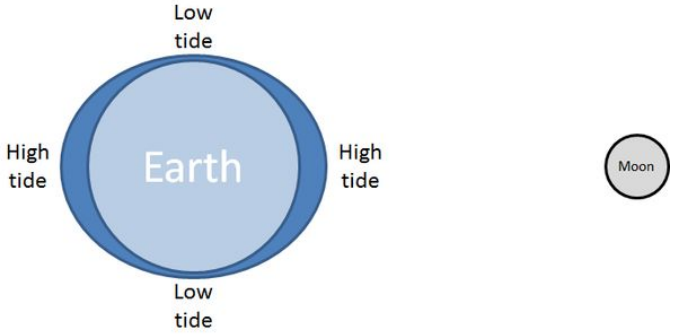
photo: Janez Polajnar, ARSO

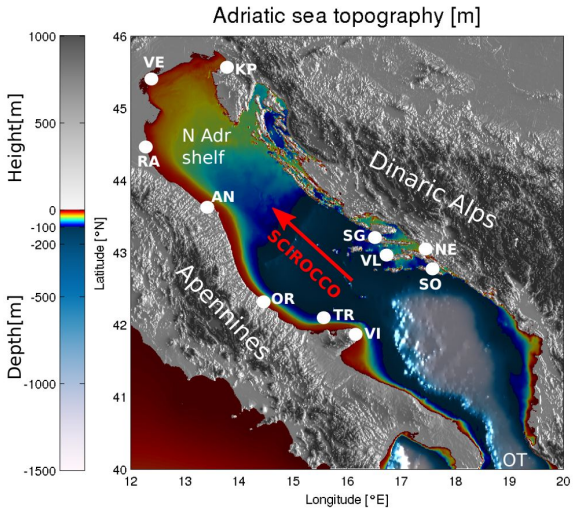
Piran, December 2008

photo: Janez Polajnar, ARSO

Sea Surface Height Forecasting

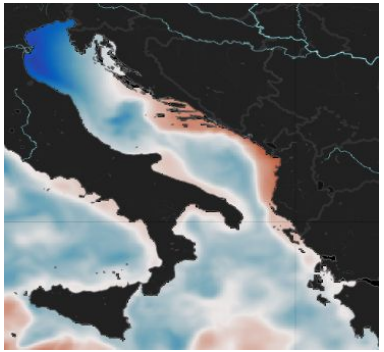
- Sea level height (SSH) dynamics:
  - gravitational forces cause tides (12 h, 24 h),
  - atmospheric forces cause seiches (22 h).
- Astronomical tide can be approximated using tidal models.
- Forecasting the final SSH is challenging.
  - Complex basin dynamics in the Adriatic.
  - Sensitivity to phase difference between seiches and tides.



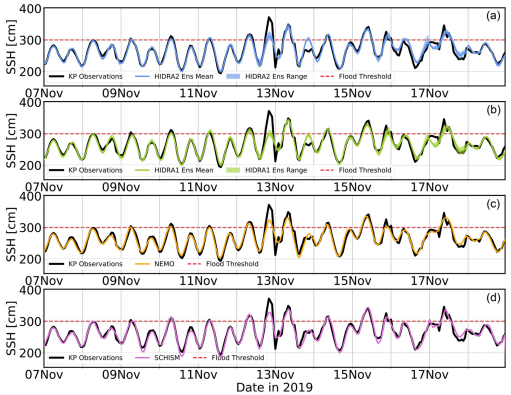


Approaches to SSH Forecasting

- Numerical ocean model setup
  - NEMO [1], SCHISM [2]
  - **Spatially-dense** sea map.
  - Computationally expensive.
  - Currently operational at many meteorological stations.



- Machine learning approach
  - HIDRA1 [3], HIDRA2 [4], HIDRA-T [5]
  - **Single-point** forecasting.
  - Computationally cheap
  - 25 % lower MAE on storm surge events (in Koper 2019–2020).



[1] Madec, Gurvan, et al. "NEMO ocean engine." (2017).
[2] Zhang, Yinglong J., et al. "Seamless cross-scale modeling with SCHISM." Ocean Modelling 102 (2016): 64-81.
[3] Žust, Lojze, et al. "HIDRA 1.0: deep-learning-based ensemble sea level forecasting in the northern Adriatic." Geoscientific Model Development 14.4 (2021): 2057-2074.
[4] Rus, Marko, et al. "HIDRA2: deep-learning ensemble sea level and storm tide forecasting in the presence of seiches–the case of the northern Adriatic." Geoscientific Model Development 16.1 (2023): 271-288.
[5] Rus, Marko, et al. "HIDRA-T – A Transformer-Based Sea Level Forecasting Method." International Electrotechnical and Computer Science Conference (ERK), 2023.

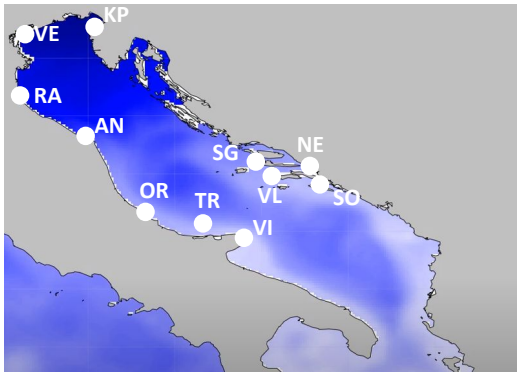
Challenges

1. Tide gauge failure
2. Limited historical SSH measurements at a tide gauge

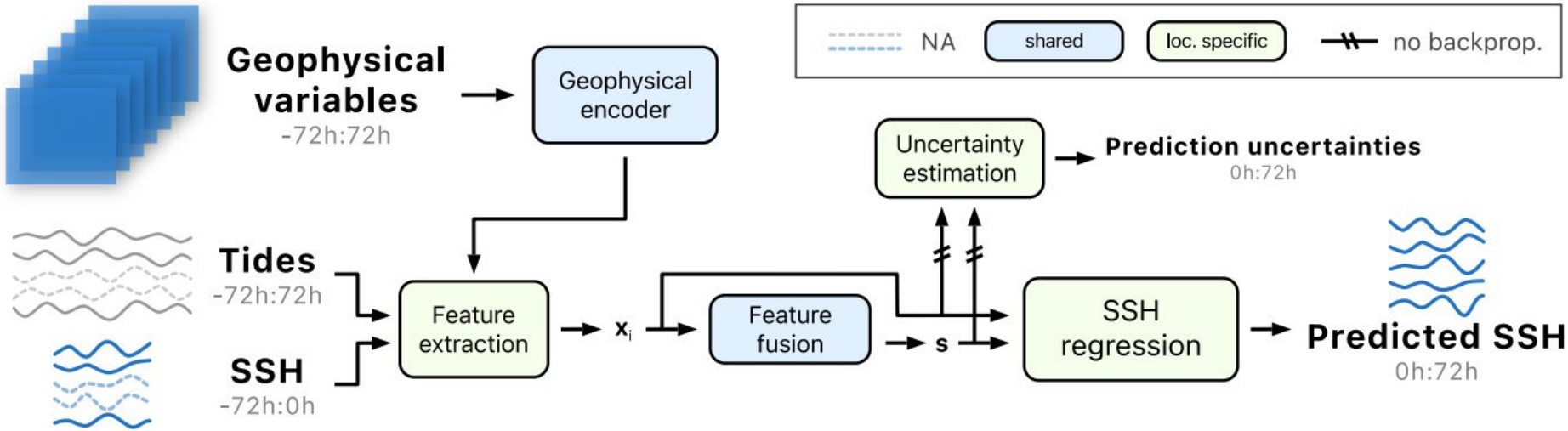
Solution: ***simultaneous prediction at multiple locations***

Benefits:

- In case of tide-gauge failures, predictions can still be calculated for all locations.
- Improved performance on tide gauges with limited historical training data.
- Information from one station can benefit predictions at the other station.

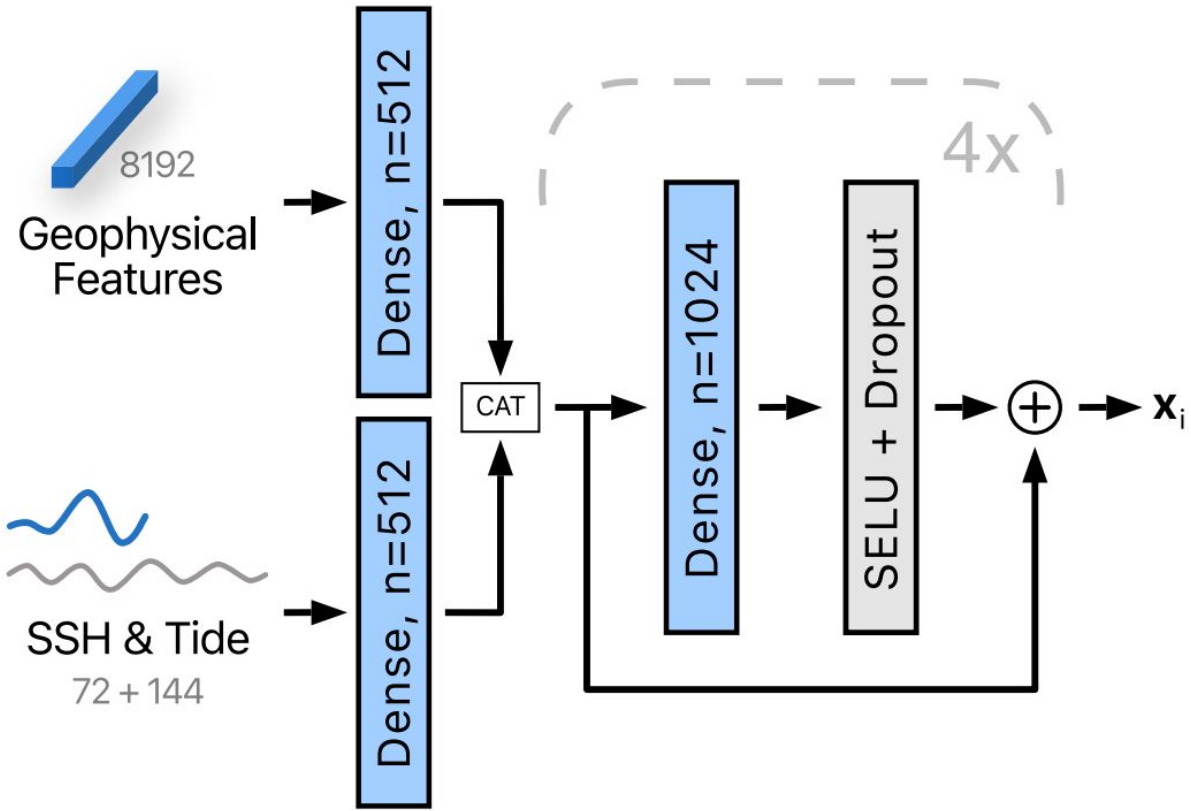


HIDRA3: Forecasting at Multiple Locations



SSH (sea surface height) = **tide** (gravitational forces) + **residual** (atmospheric forces)
Geophysical variables: atm pressure, wind, sst, waves (period, height, direction)

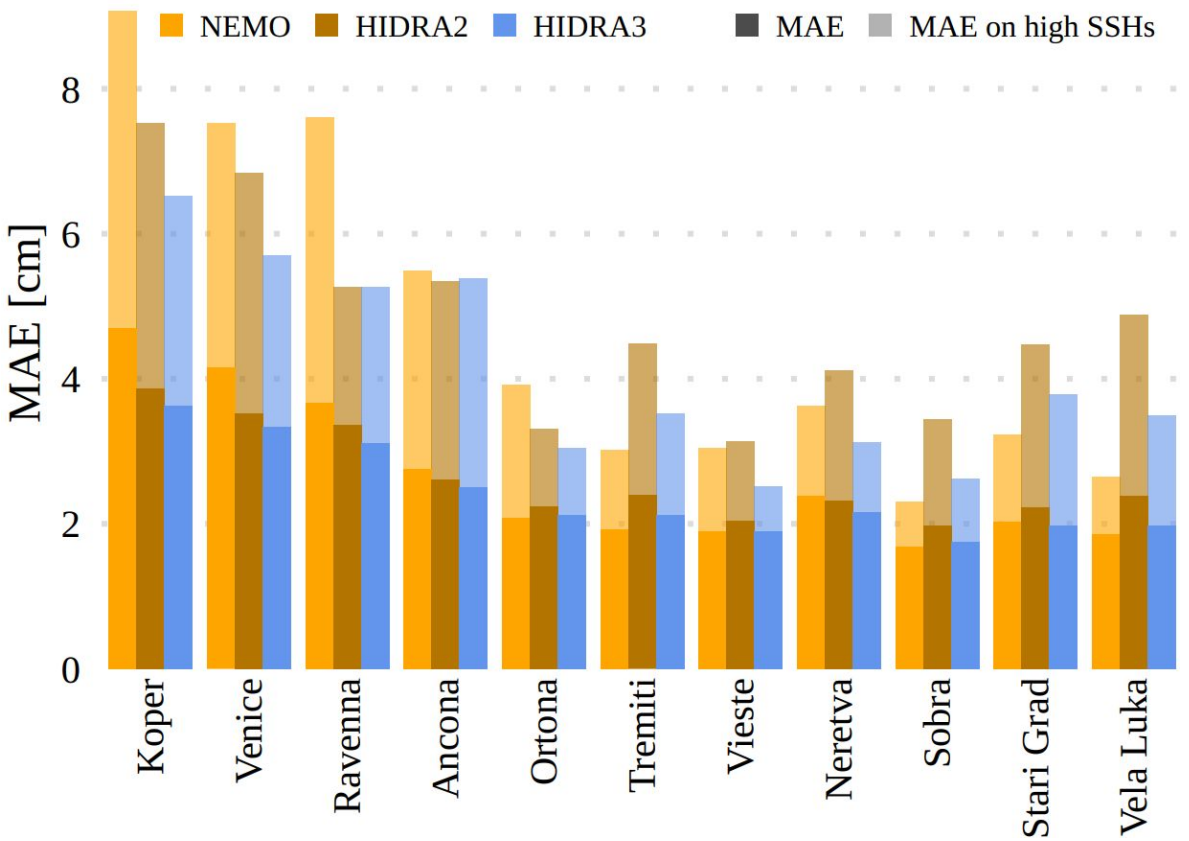
HIDRA3: Feature Extraction Module



Average MAE

Past SSH available	Model	MAE	MAE_h
✓	NEMO	2.65	4.68
✓	HIDRA2	2.63	4.80
✓	HIDRA3	**2.42**	**4.09**
✗	$NEMO_0$	3.26	5.12
✗	HIDRA3	**2.61**	**4.45**

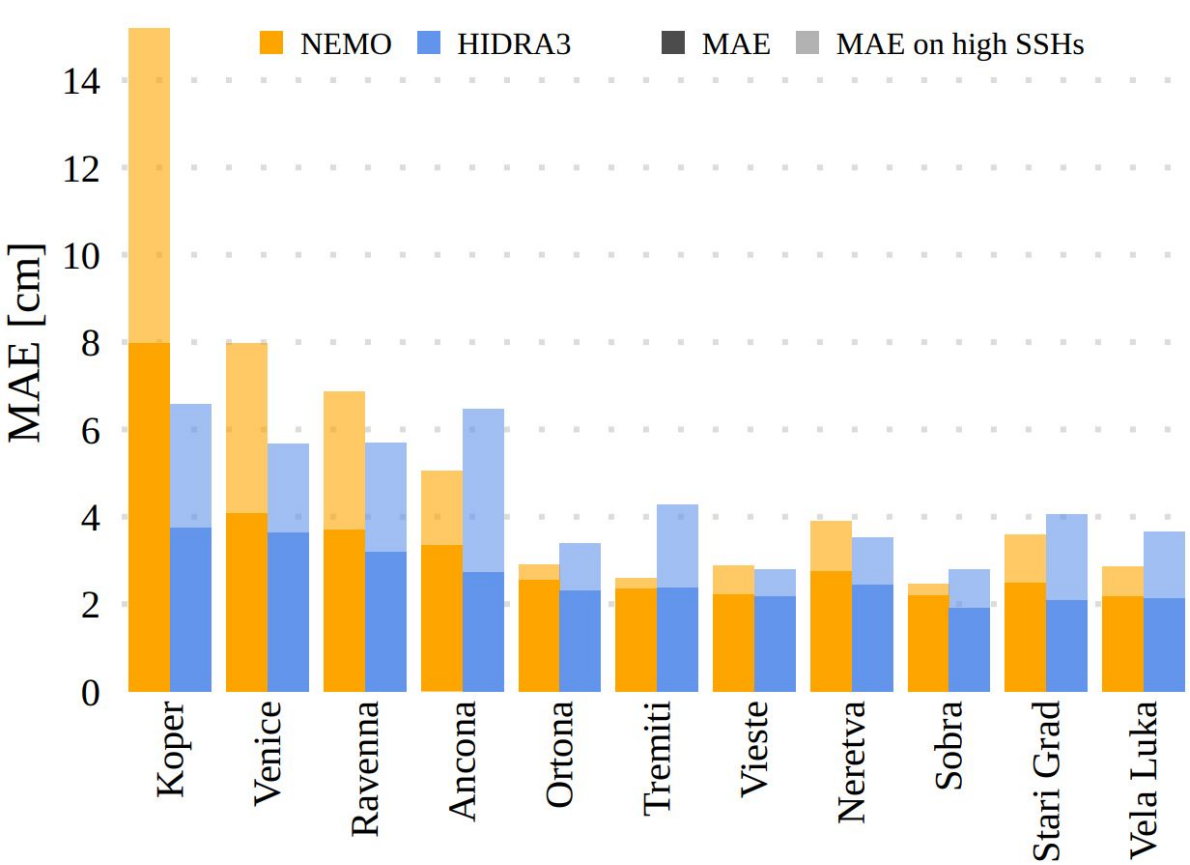
HIDRA3 MAE



- HIDRA3 outperforms HIDRA2 at all locations.
- HIDRA3 has much lower error than NEMO at the locations in the northern Adriatic, but not in the south!

train: 2000–2018
test: 2019–2020
Data from Slovenia by ARSO, Koper
Data from Croatia by IOR, Split and DHMZ
Data from Italy by Commune di Venezia, ISPRA

MAE when Past SSH **is not** Available



- For every location, scores are calculated by omitting past SSH measurements.
- HIDRA3 has lower or equal overall MAE than NEMO (non-transparent bars).

train: 2000–2018
test: 2019–2020
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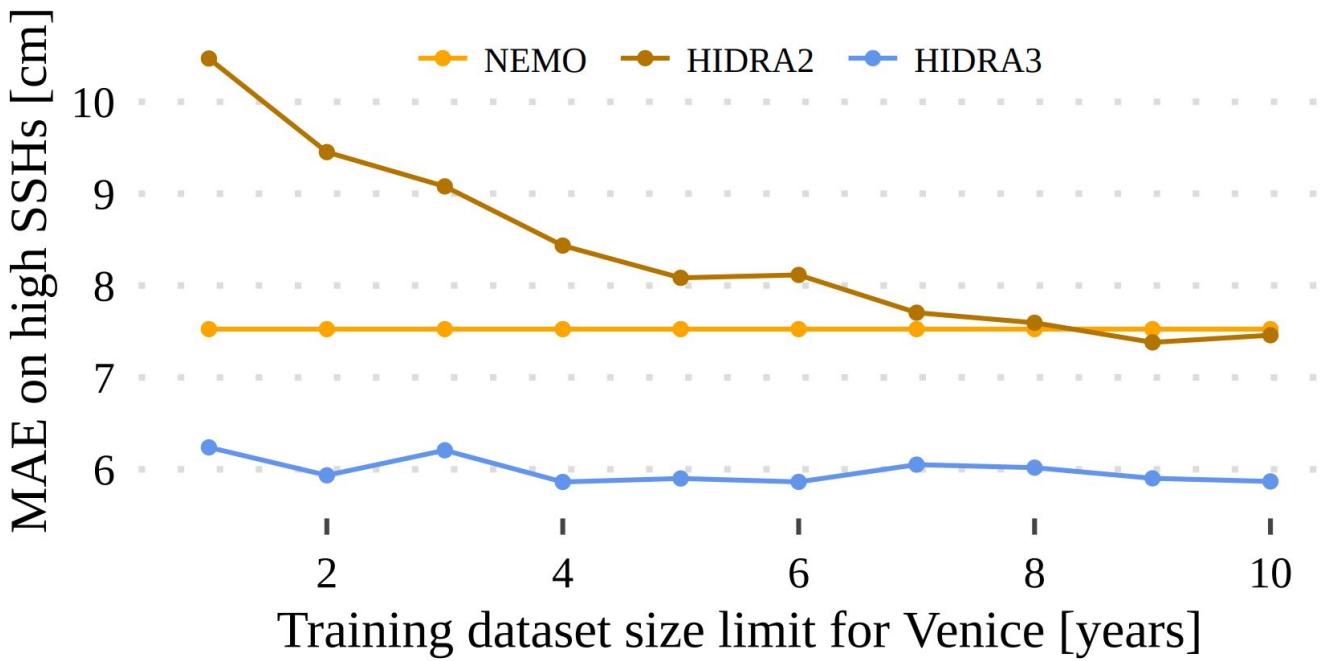
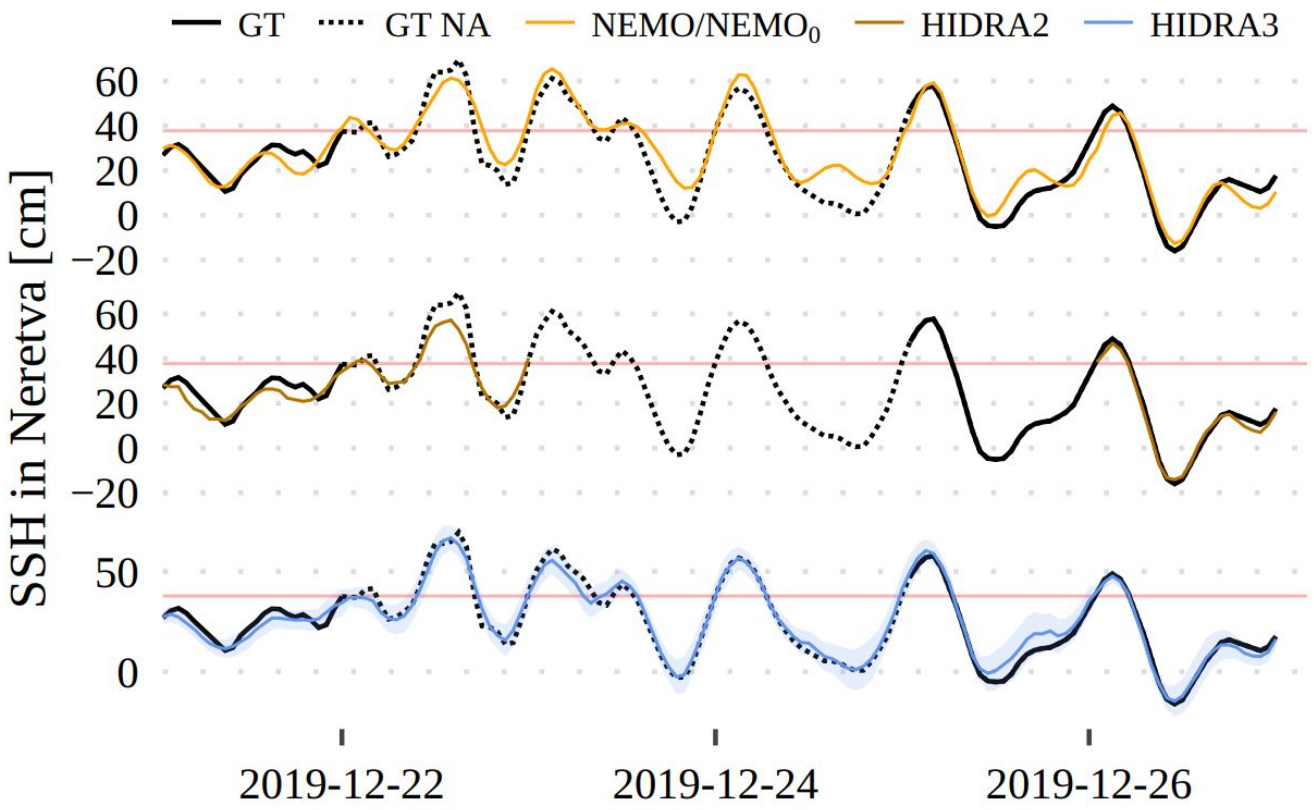
Limiting Training Dataset Size for Koper



Simulating a Tide Gauge Failure



Conclusions

- The new machine learning method for multi-point sea-level forecasting **HIDRA3** novelties:
  - Robust to tide-gauge failures (at inference as well as training time).
  - Exploits measurements from multiple tide gauges.
  - Requires less training data.
  - Outperforms single-point state-of-the-art.
- Current work:
  - Developing **spatially-dense physics-informed** predictions for the entire region (e.g. Adriatic Sea).
  - Challenges:
    - Training from a spatially highly sparse ground truth.
    - Inference from spatially highly sparse measurements.