HIDRA 2.0: Deep-learning-based Sea-level Forecasting in the Northern Adriatic

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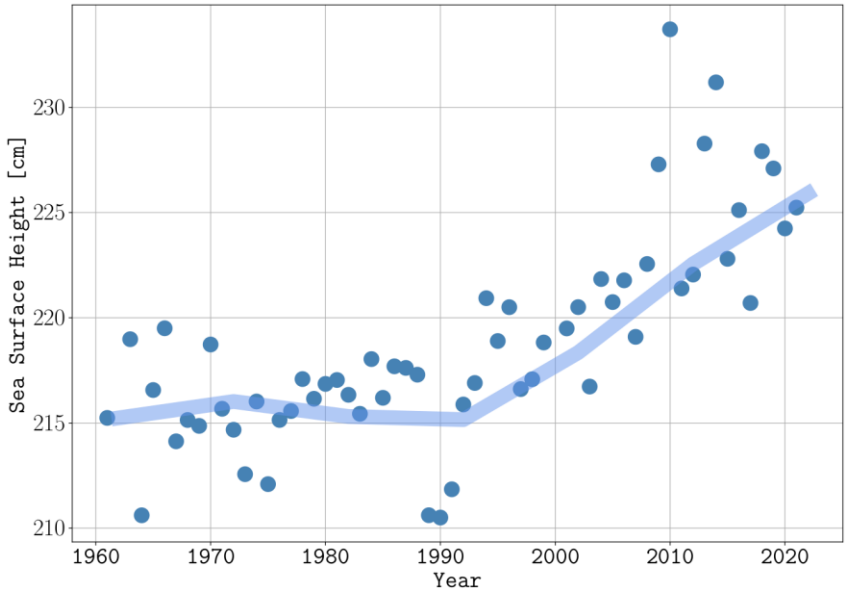
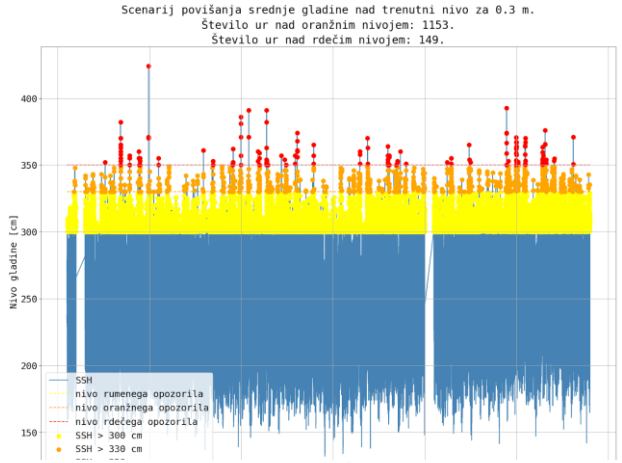
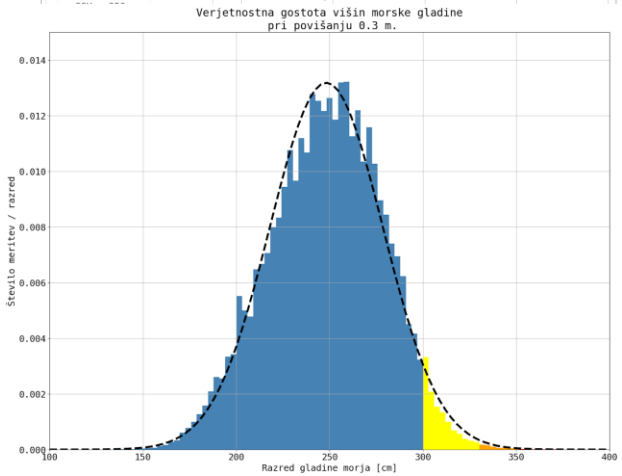
Motivation

- Coastal flood probability is rising due to climate change.
- Sea level rise in Koper (Slovenia) since 1990: **> 4 mm/year**
- At the end of this century best case predicted scenario: rise of 0.3 m.
  - 20x more frequent



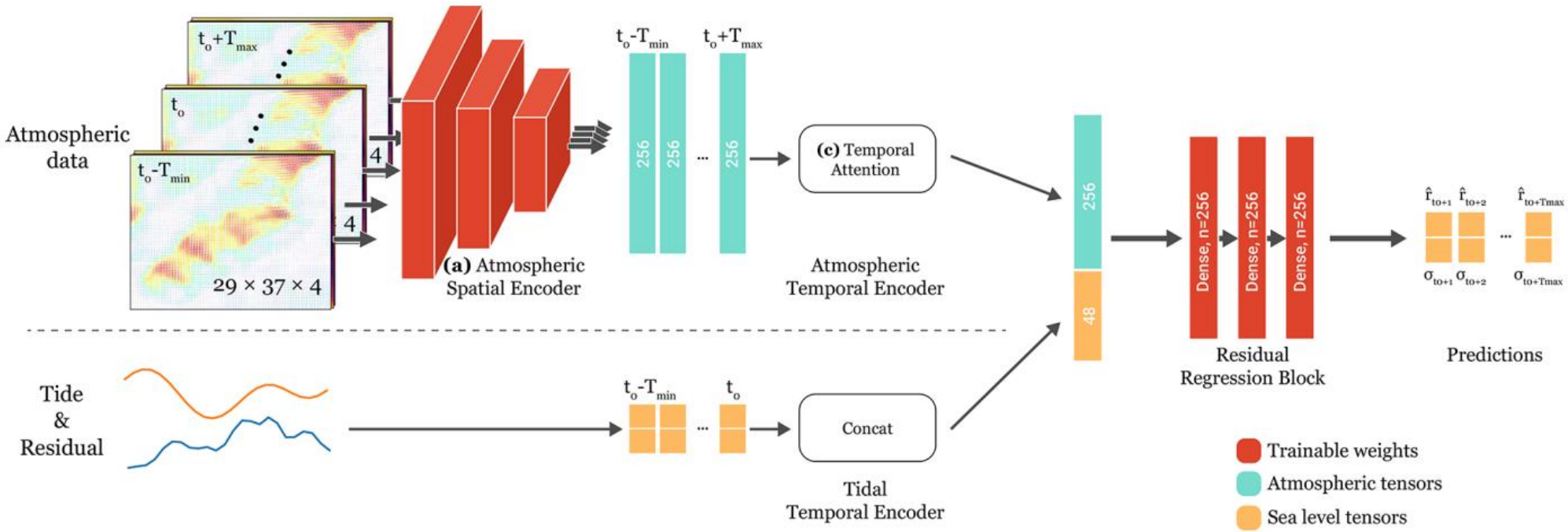
1960-2018 **+ 0.3 m**:



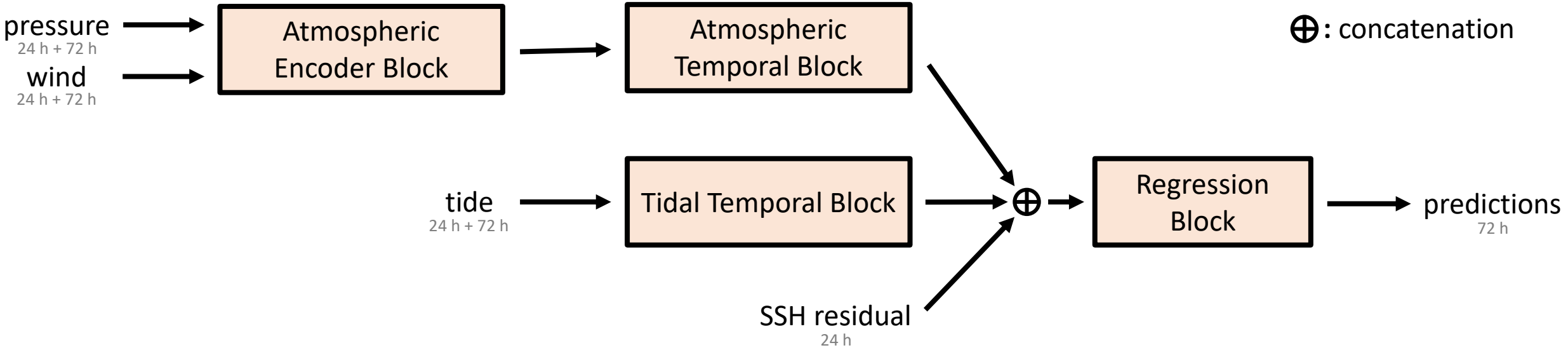


State-of-the-art

- Numerical model NEMO [Madec,NEMO ocean engine,2009]
- SOTA in Machine-learning based models: **HIDRA 1.0** [Žust et al.,GMD2021]
  - But potentially too complex Atmospheric Encoder,
  - Temporal Attention does not operate independently from the prediction point.

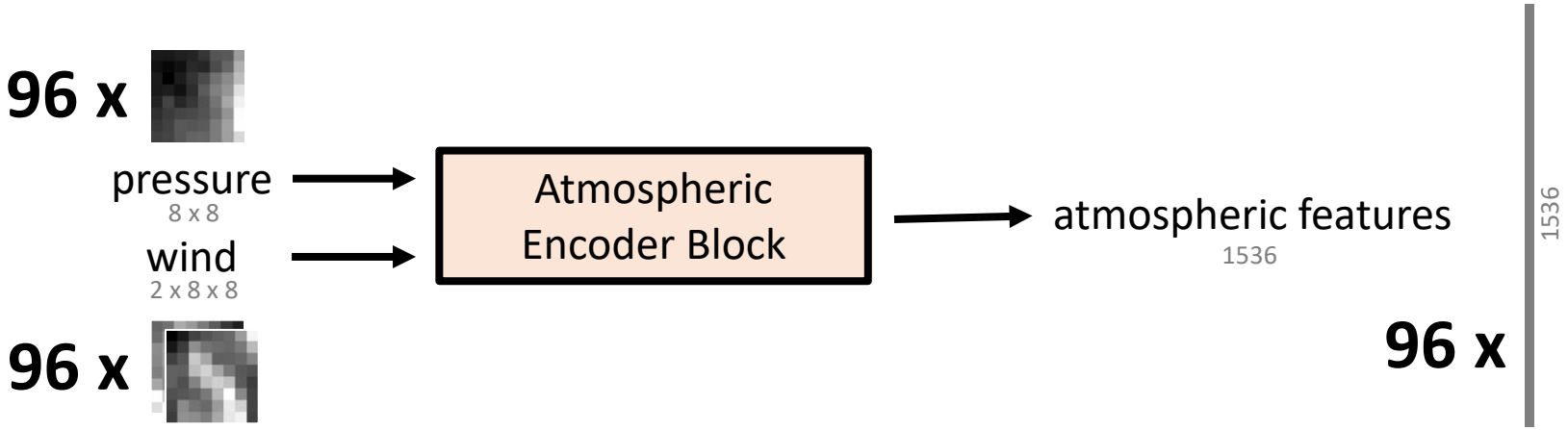


Architecture of **HIDRA 2.0**



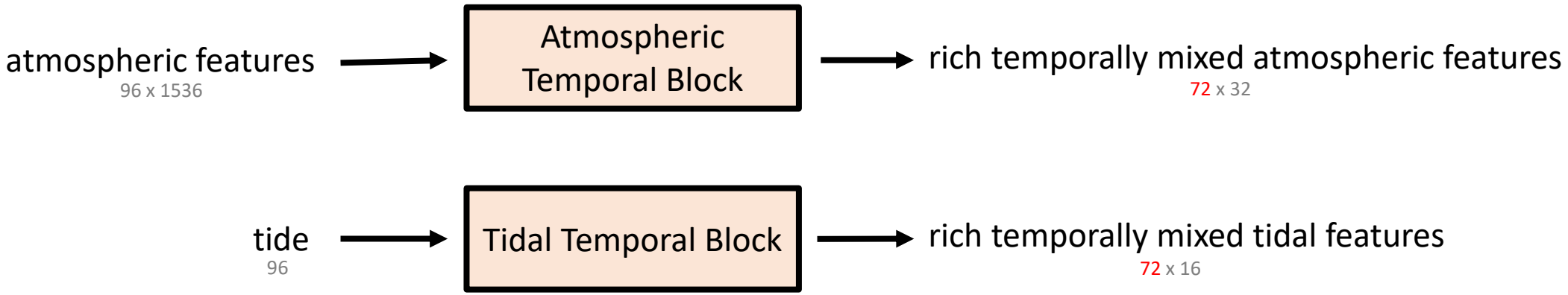
- Simple Atmospheric Encoder Block.
- Atmospheric and Tidal Temporal Blocks share weights between 72 prediction points.

Atmospheric Encoder Block



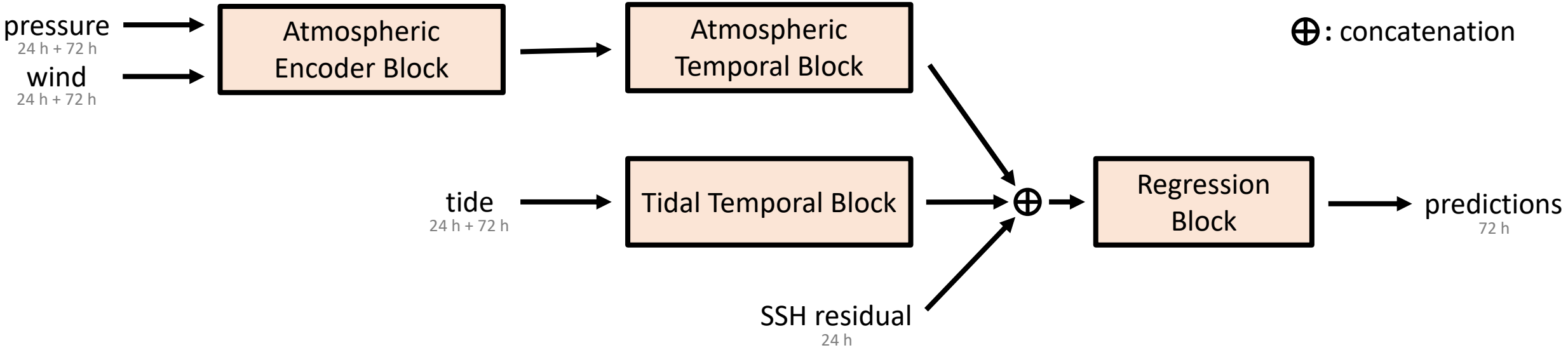
- Each time step encoded separately.
- Extracts atmospheric forcings at specific positions.
- Spatial attention is achieved by a large kernel size.

Atmospheric and Tidal Temporal Blocks



- Weights are shared between 72 prediction points:
  - At every prediction point, receptive field size spans 24 h in the past.
  - Implemented with 1D convolutional layers.

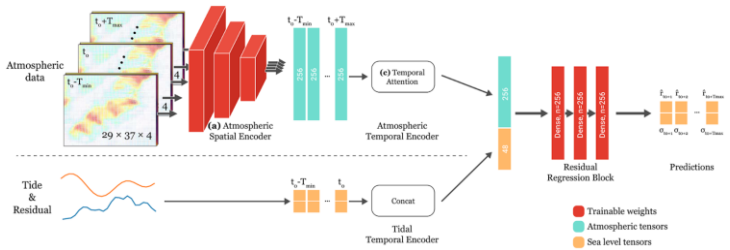
Architecture of HIDRA 2.0

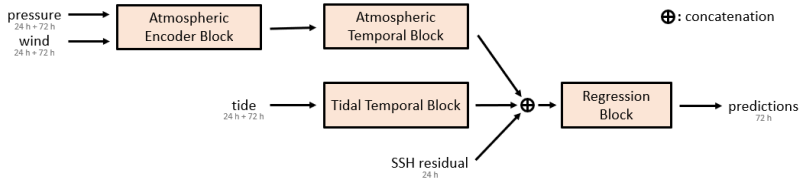


- Regression Block: dense neural network.

Comparison of HIDRA 1.0 and HIDRA 2.0

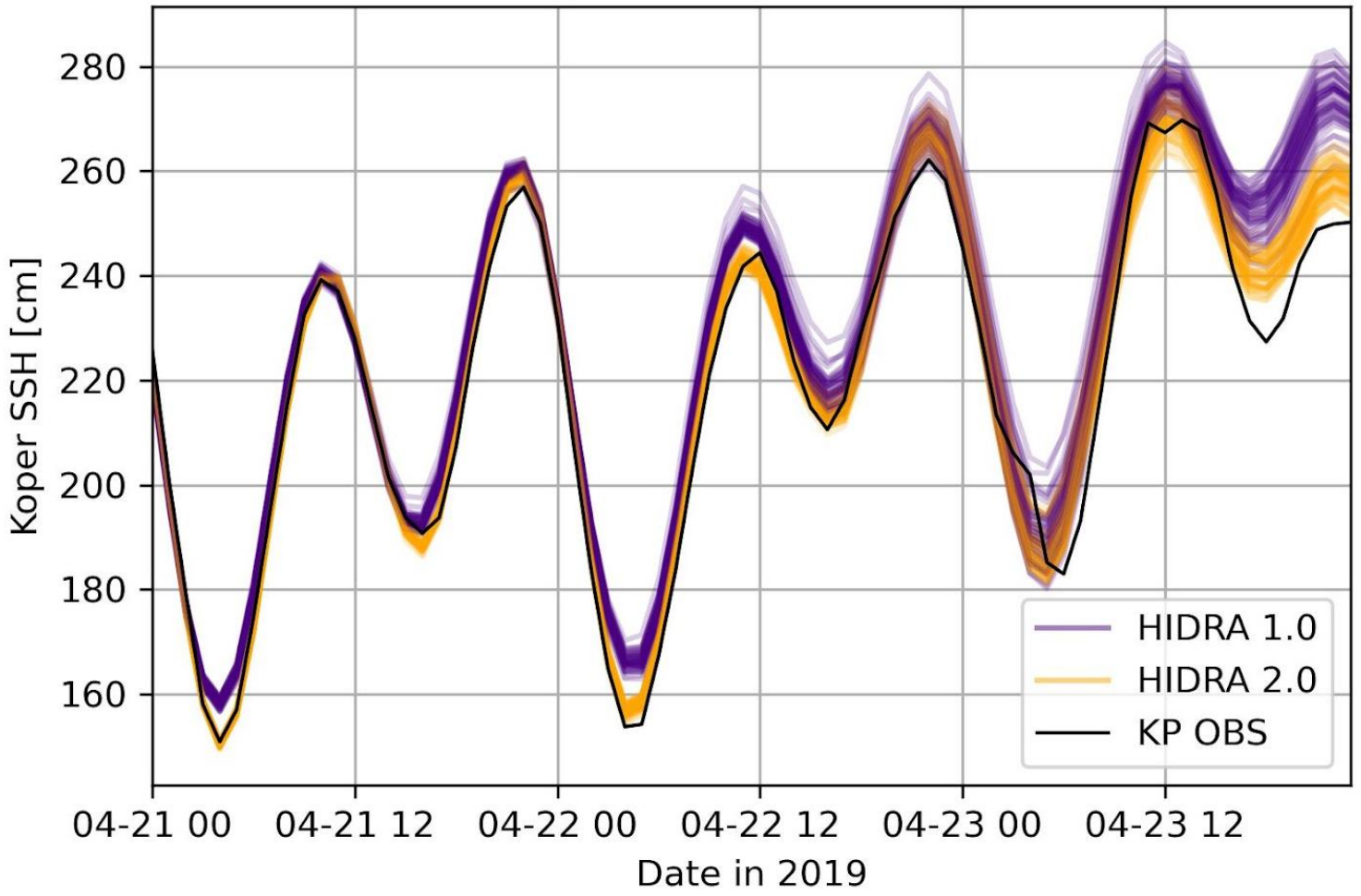
	HIDRA 1.0	**HIDRA 2.0**
atmospheric input	29x37 air pressure, wind, temperature	8x8, no temperature
atmospheric encoder	ResNet20 v2	shallow convolutional network, separate for air pressure and wind
spatial encoding	2 channels with x and y positions	not needed
temporal reduction	weighted linear combination	1D convolution
regression	fully-connected neural network	fully-connected neural network with skip connections
dropout	before the final layer	through the entire network
MAE	5.20 cm	**4.20 cm**



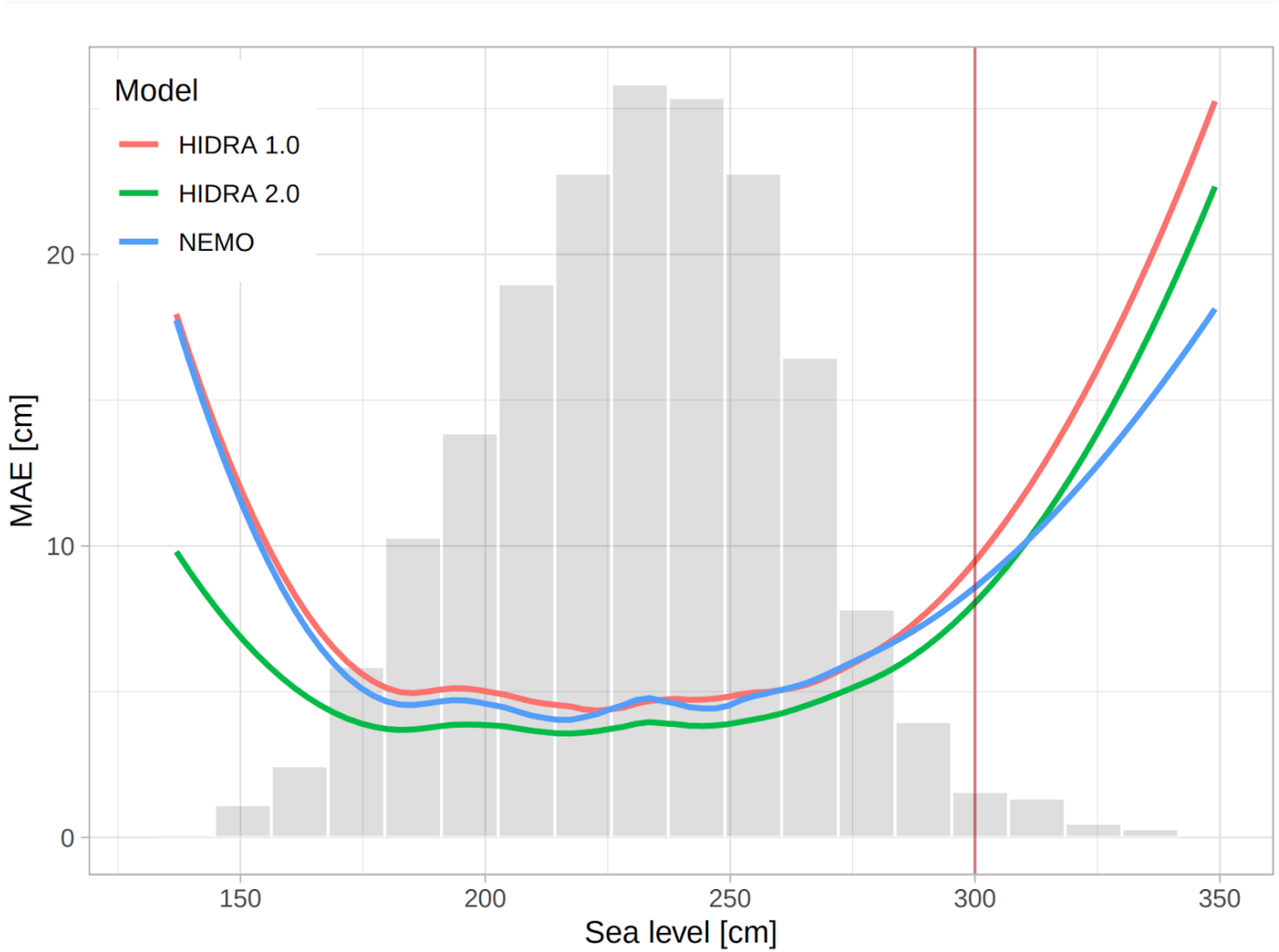


Qualitative Example

- 50 forecasts based on 50 ECMWF atmospheric ensembles.



MAE over Sea-level Distribution



NEMO: Copernicus CMEMS Mediterranean Sea Physics Analysis and Forecast product

Summary of Results

Sea Surface Height

Rank	Low	Normal	Floods
1.	**HIDRA 2.0**	**HIDRA 2.0**	NEMO
	∨	∨	∨
2.	NEMO	NEMO	**HIDRA 2.0**
	≈	≈	∨
3.	HIDRA 1.0	HIDRA 1.0	HIDRA 1.0

- Overall, **HIDRA 2.0** outperforms all other models.
- On high sea levels, **NEMO** slightly outperforms **HIDRA 2.0**. But on low sea levels, HIDRA 2.0 significantly outperforms NEMO.
  - Accurate prediction of low sea levels is crucial for opening/closing of large vessel waterways to the Ports of Koper and Trieste.

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Acknowledgements

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