



**MedEWSa**

**Exploring AI-enhanced  
methods for the  
improvement of Sea Level  
warnings in Venice**

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GAME 2026, Bologna  
12/06/2026

# Venice as a case study for Early Warning Systems



Vulnerability of infrastructures  
and activities

Seasonality

Weather influence



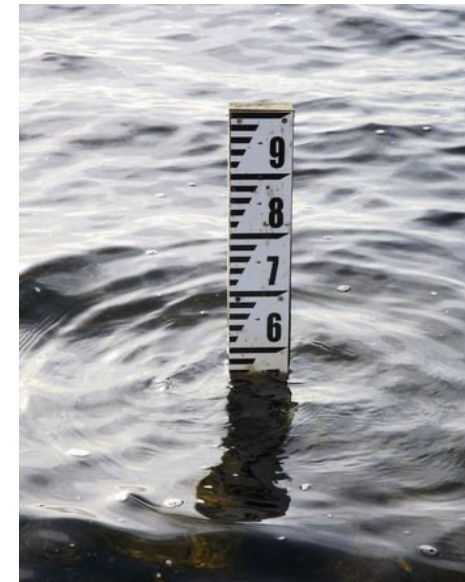
Investigate how hybrid methods  
can help build stronger

# Early Warning Systems

Integrate the current EWS  
with forecasts that reach the

## sub-seasonal horizon

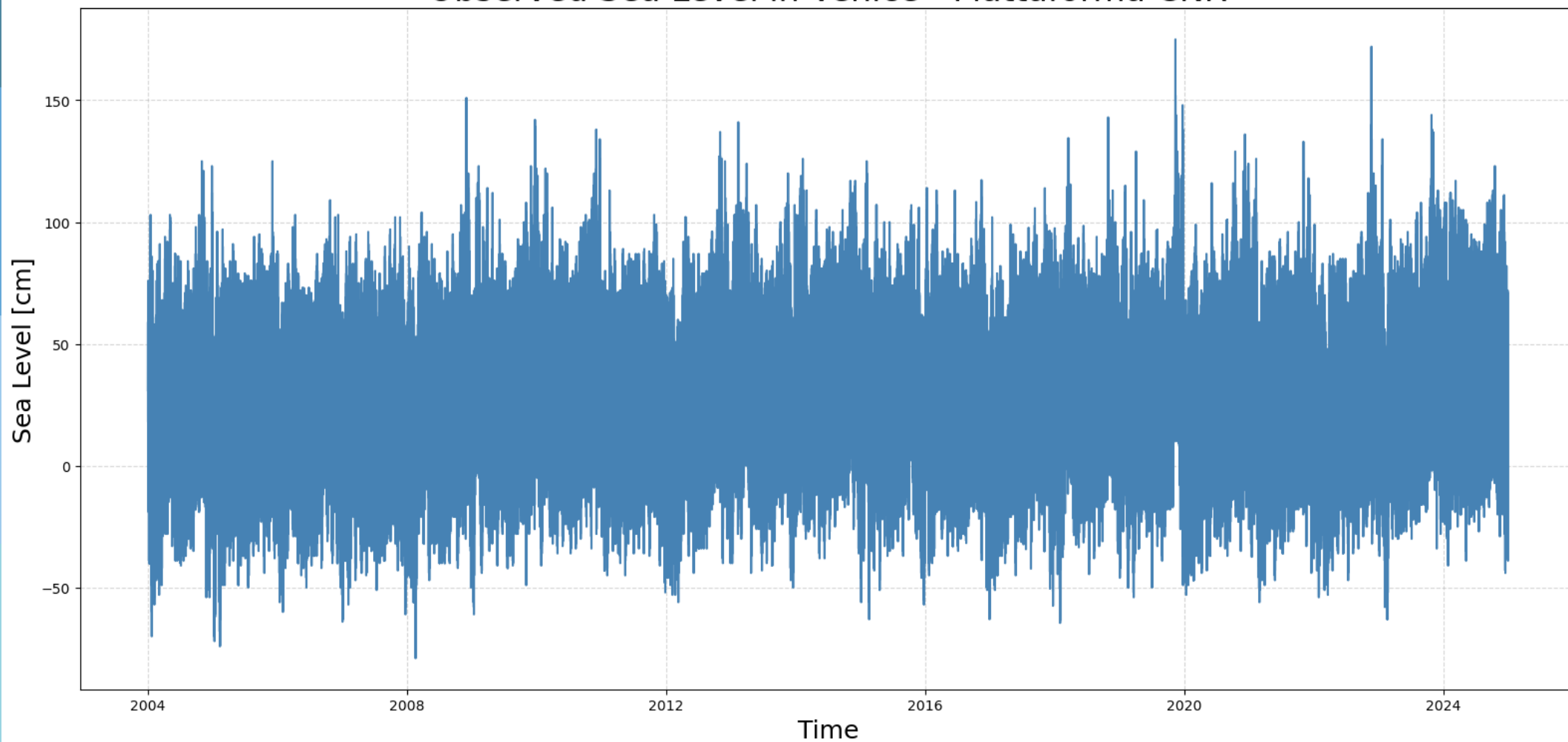
Historical  
observations of  
Sea Level from an  
off-shore gauge





# The target series

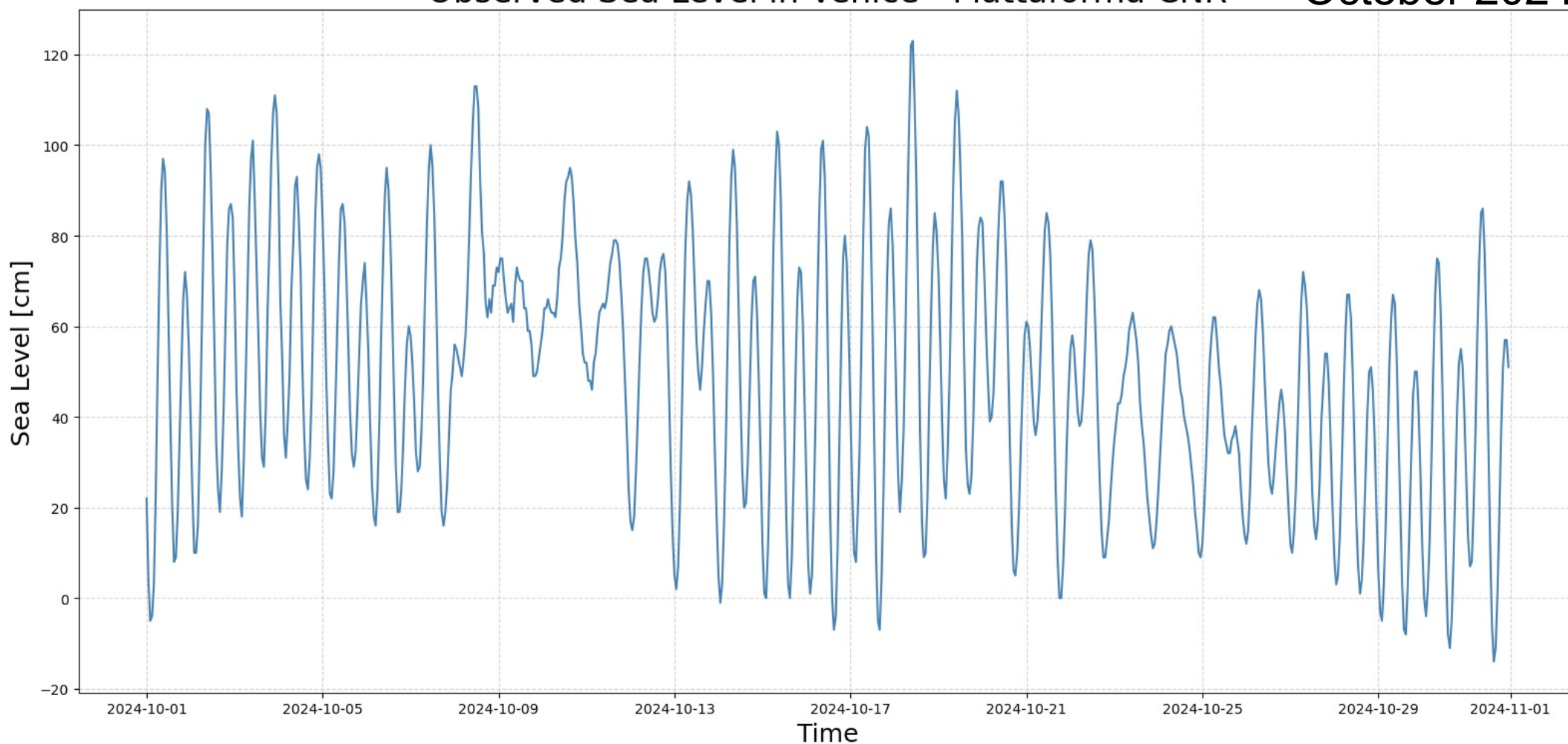
Observed Sea Level in Venice - Piattaforma CNR



# The target series: understanding the signal

Observed Sea Level in Venice - Piattaforma CNR

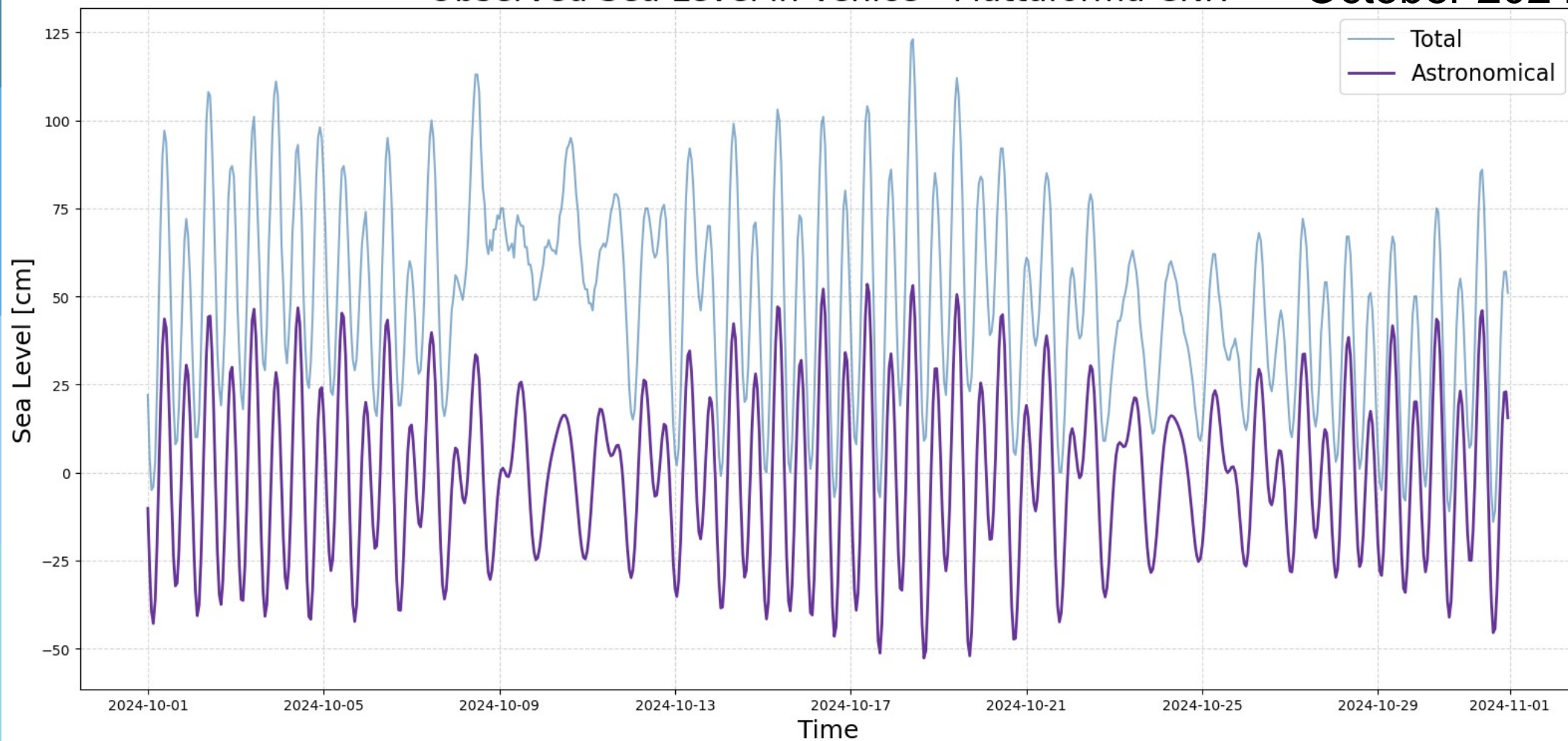
October 2024



# Astronomical Tide

Observed Sea Level in Venice - Piattaforma CNR

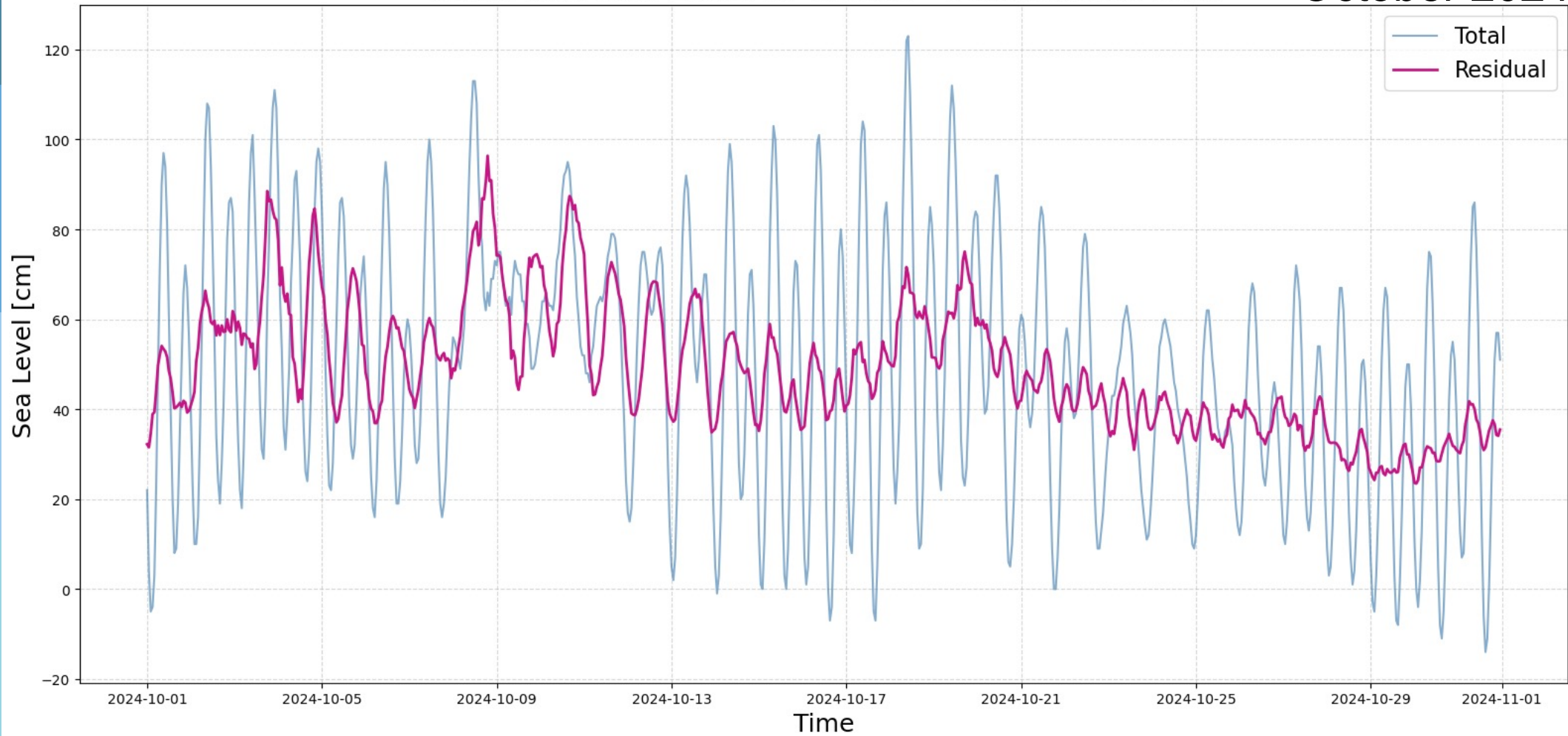
October 2024



# Residual Sea Level

Observed Sea Level in Venice - Piattaforma CNR

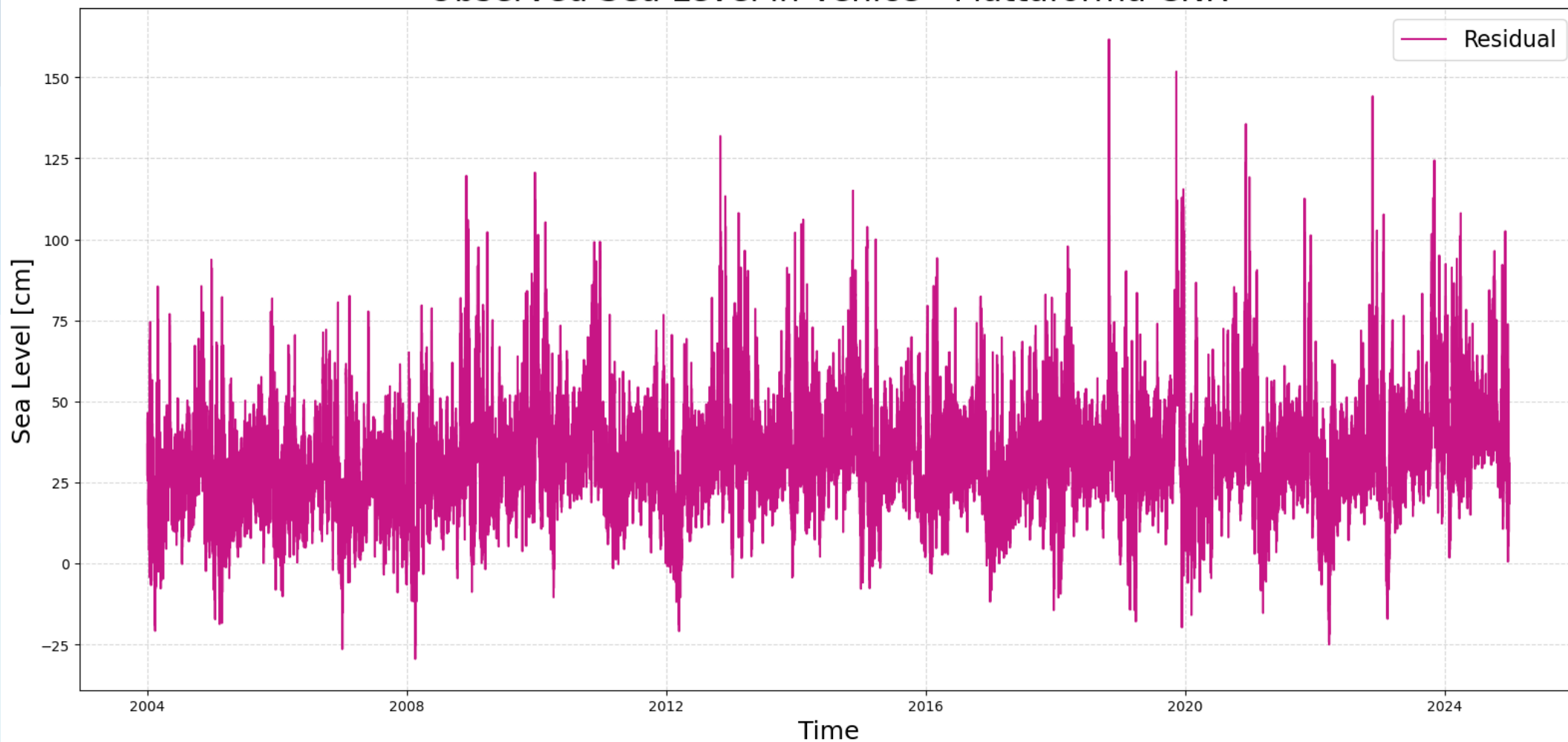
October 2024



# Residual Sea Level

Observed Sea Level in Venice - Piattaforma CNR

2004-2024

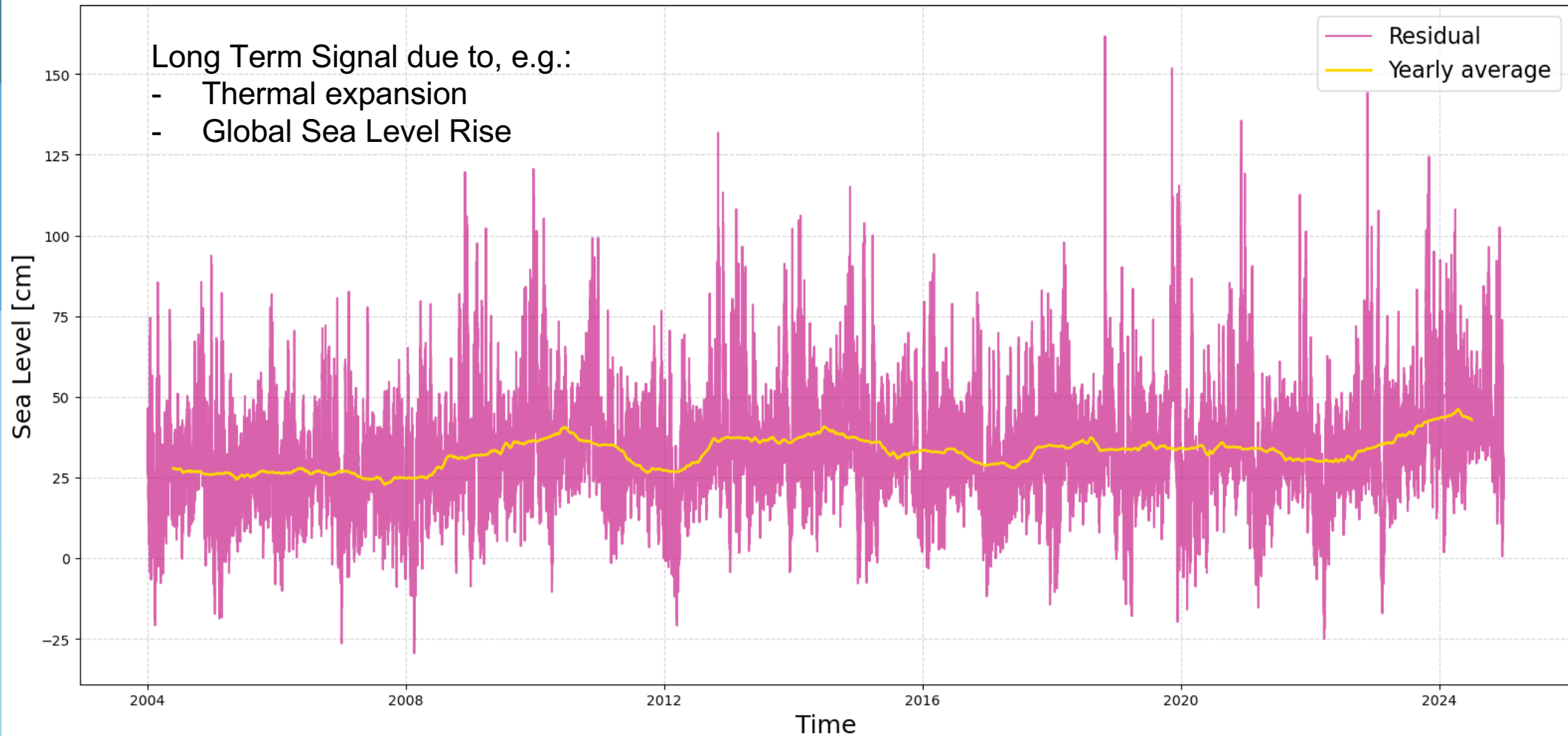




## Residual Sea Level influence by Long Term variability

Observed Sea Level in Venice - Piattaforma CNR

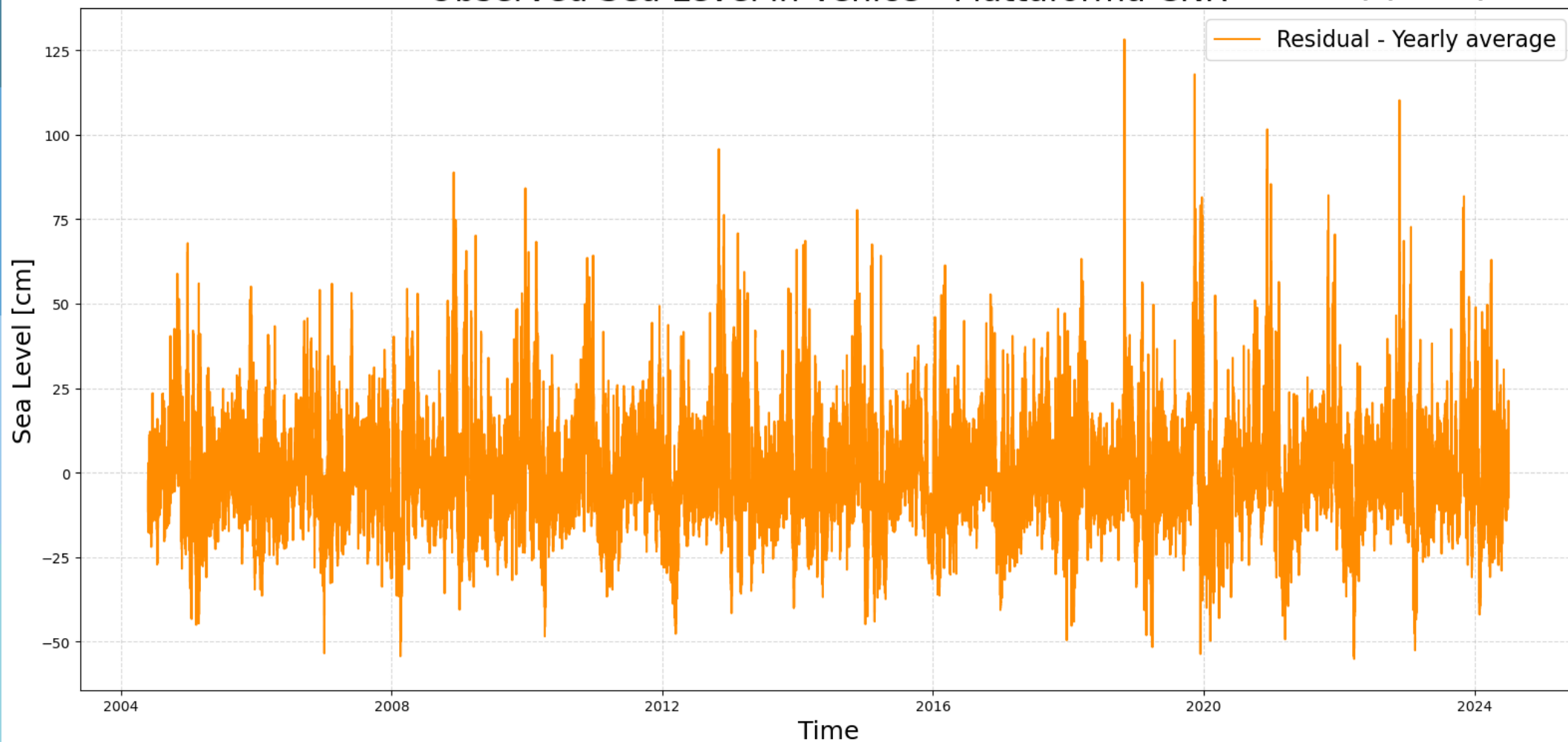
2004-2024



# Meteorological component

Observed Sea Level in Venice - Piattaforma CNR

2004-2024

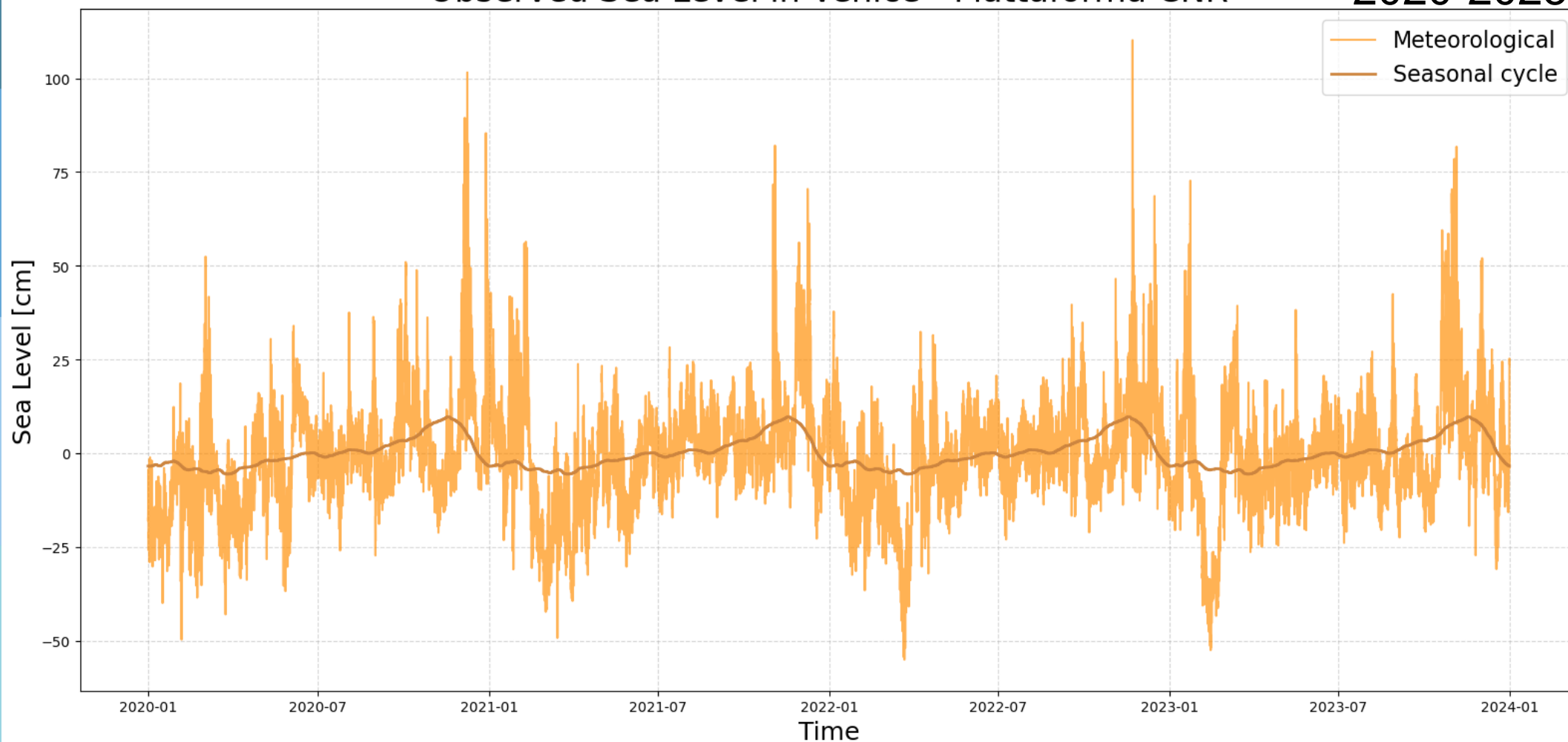




# Meteorological component: climatology

Observed Sea Level in Venice - Piattaforma CNR

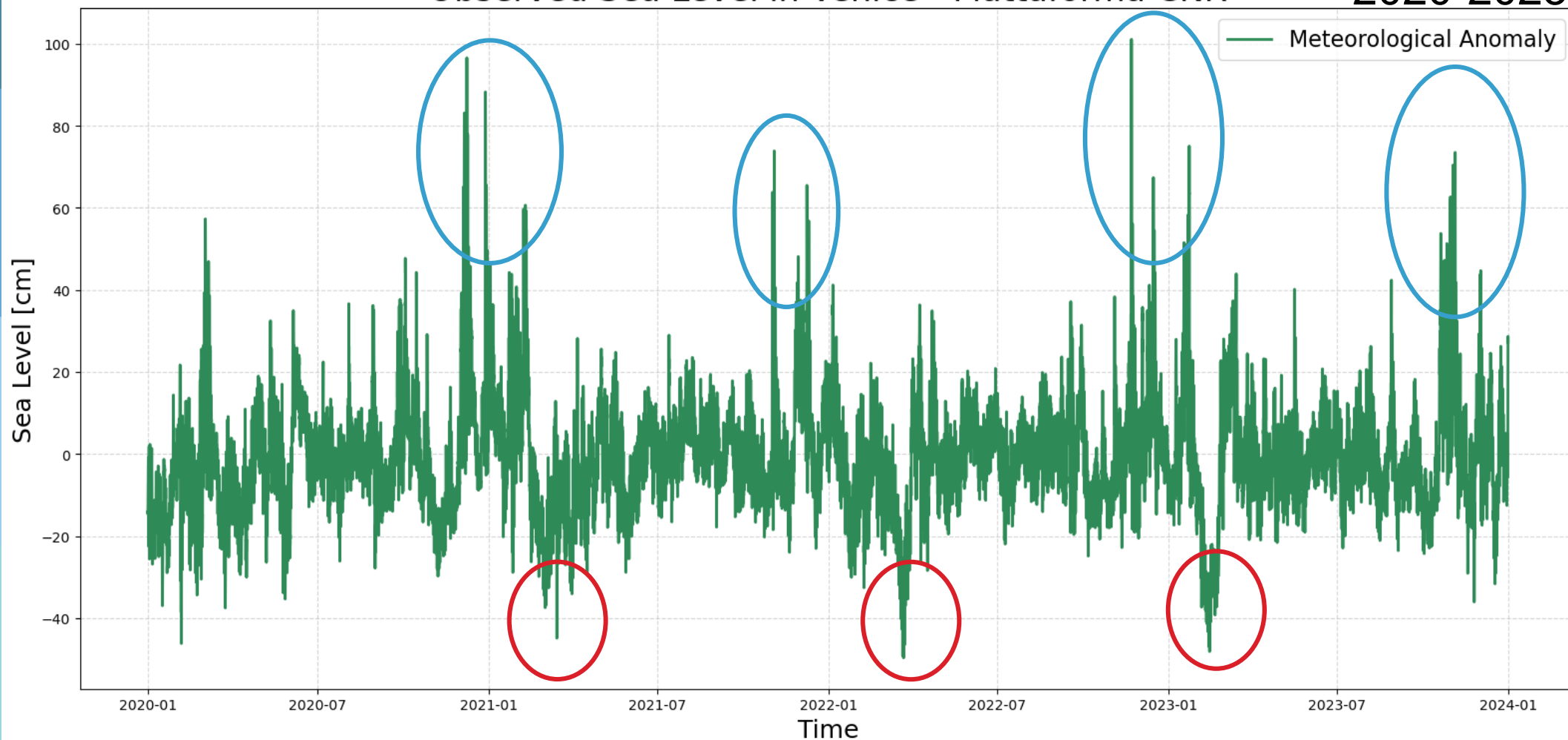
2020-2023



# Meteorological component: anomaly

Observed Sea Level in Venice - Piattaforma CNR

2020-2023



# Finding the good predictors among daily series of:

Wind



Pressure

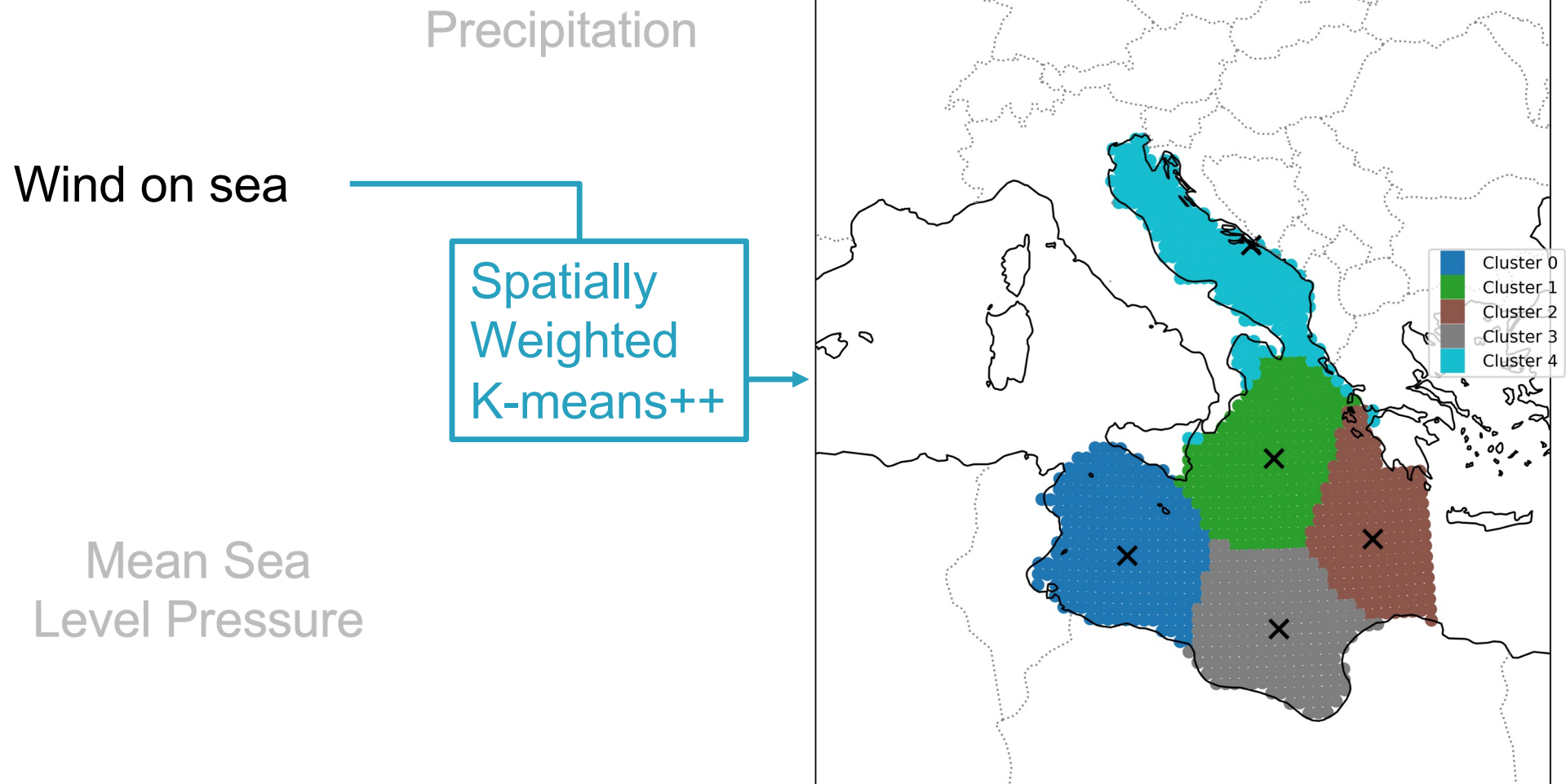


Temperature

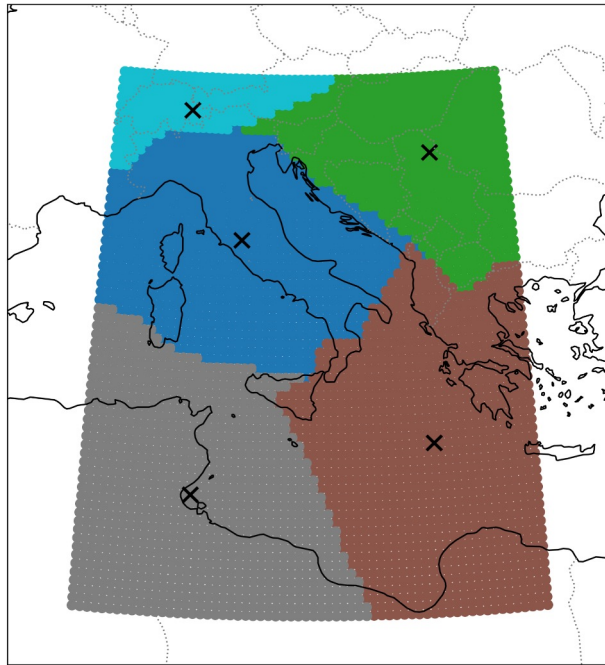
Precipitation



# Candidate predictors: geographical clusters of anomalies

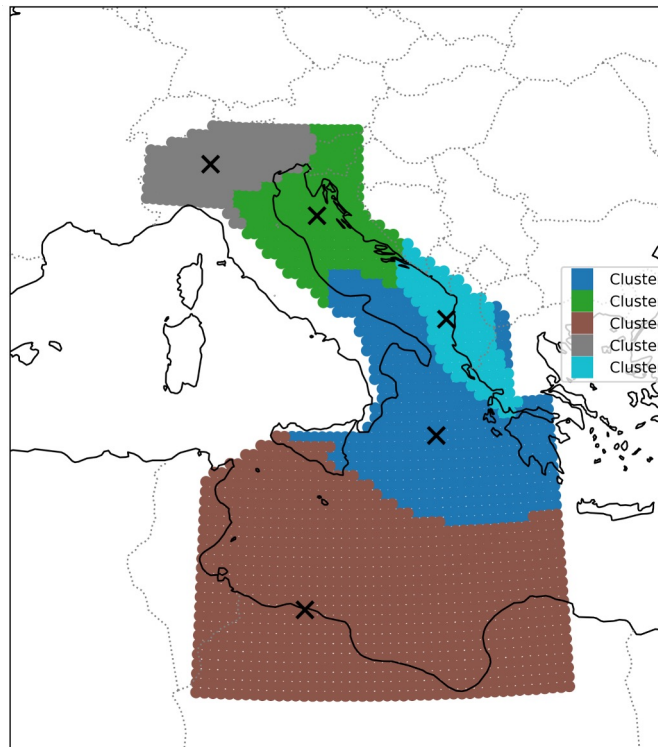


# Candidate predictors: geographical clusters of anomalies

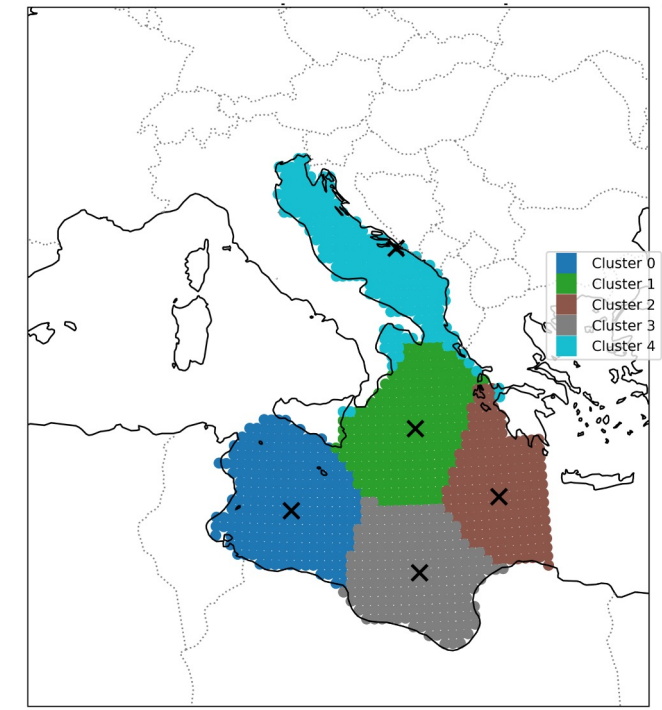


Mean Sea  
Level Pressure  
(MSLP)

## Precipitation



Wind on Sea



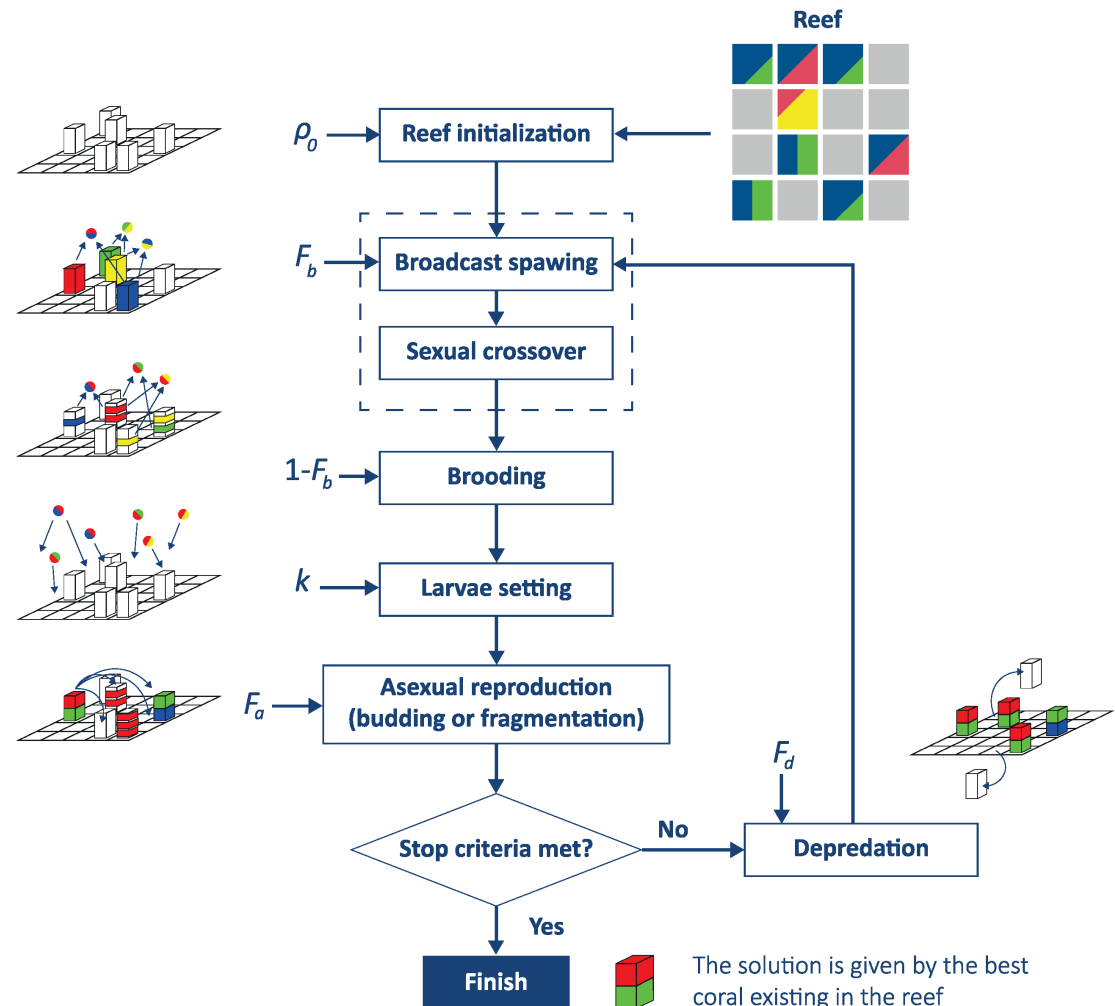
Day-by-day series of cluster-wise averages of the anomalies



# Probabilistic Coral Reef Optimization with Substrate Layers

Evolution-based  
ensemble algorithm

Research of populations of  
drivers characterized by  
optimal variables and lags



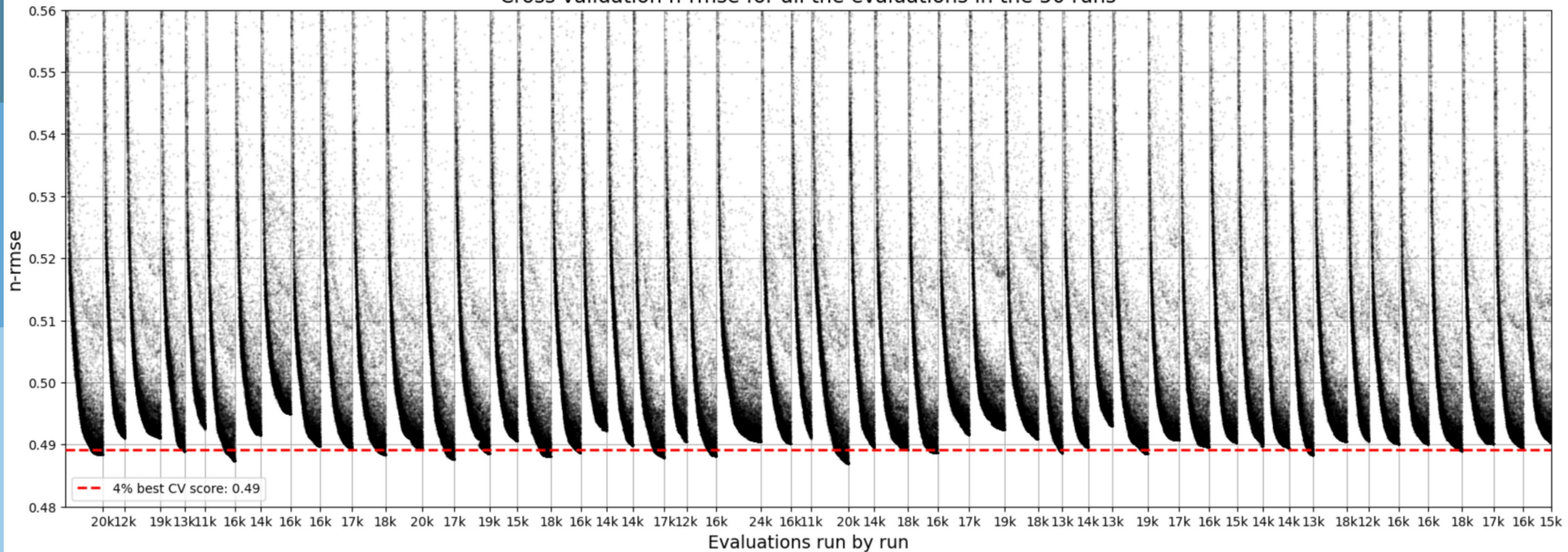
Salcedo-Sanz et al. (2016) - A novel Coral Reefs Optimization algorithm with substrate layers for optimal battery scheduling optimization in micro-grids

Pérez-Aracil et al. (2023) - New Probabilistic-Dynamic Multi-Method Ensembles for Optimization based on the CRO-SL



# PCRO-SL: optimization and functionality

Cross validation n-rmse for all the evaluations in the 50 runs



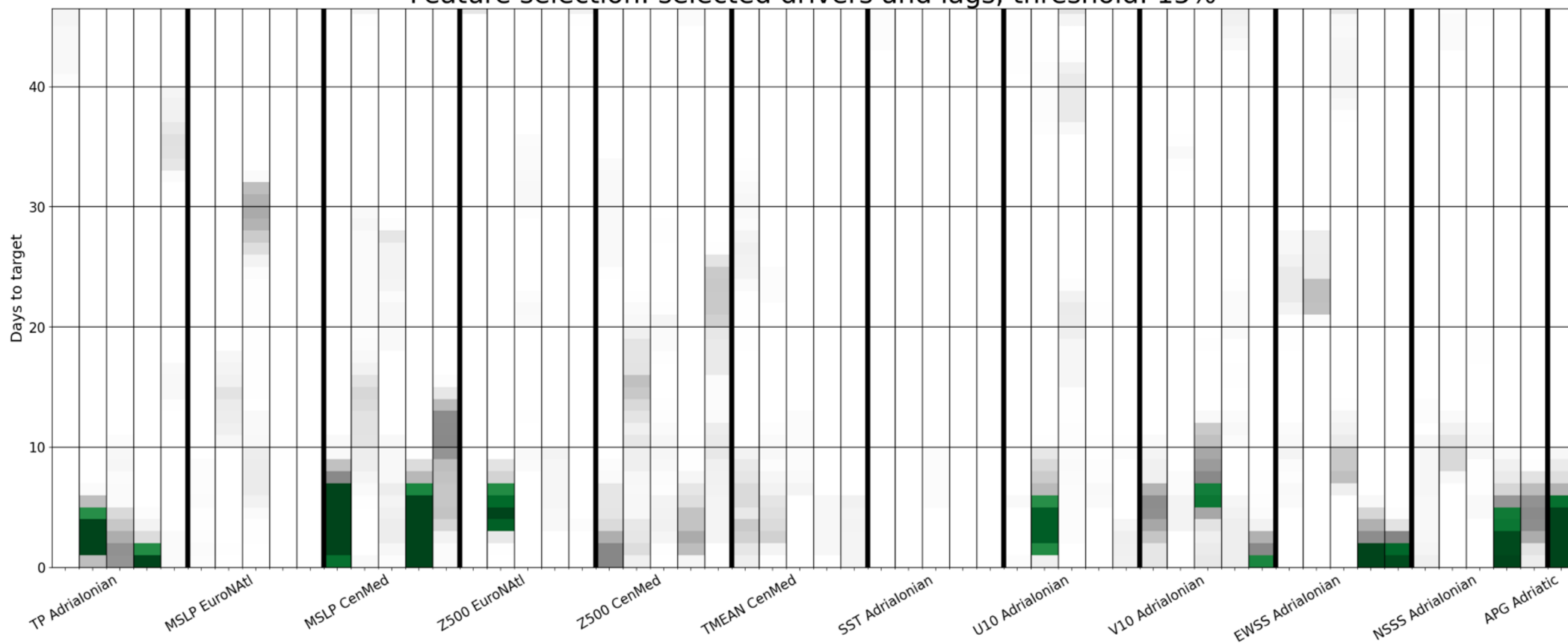
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Pérez-Aracil et al. (2023) - New Probabilistic-Dynamic Multi-Method Ensembles for Optimization based on the CRO-SL

Parameters defined with  
physics-based constraints

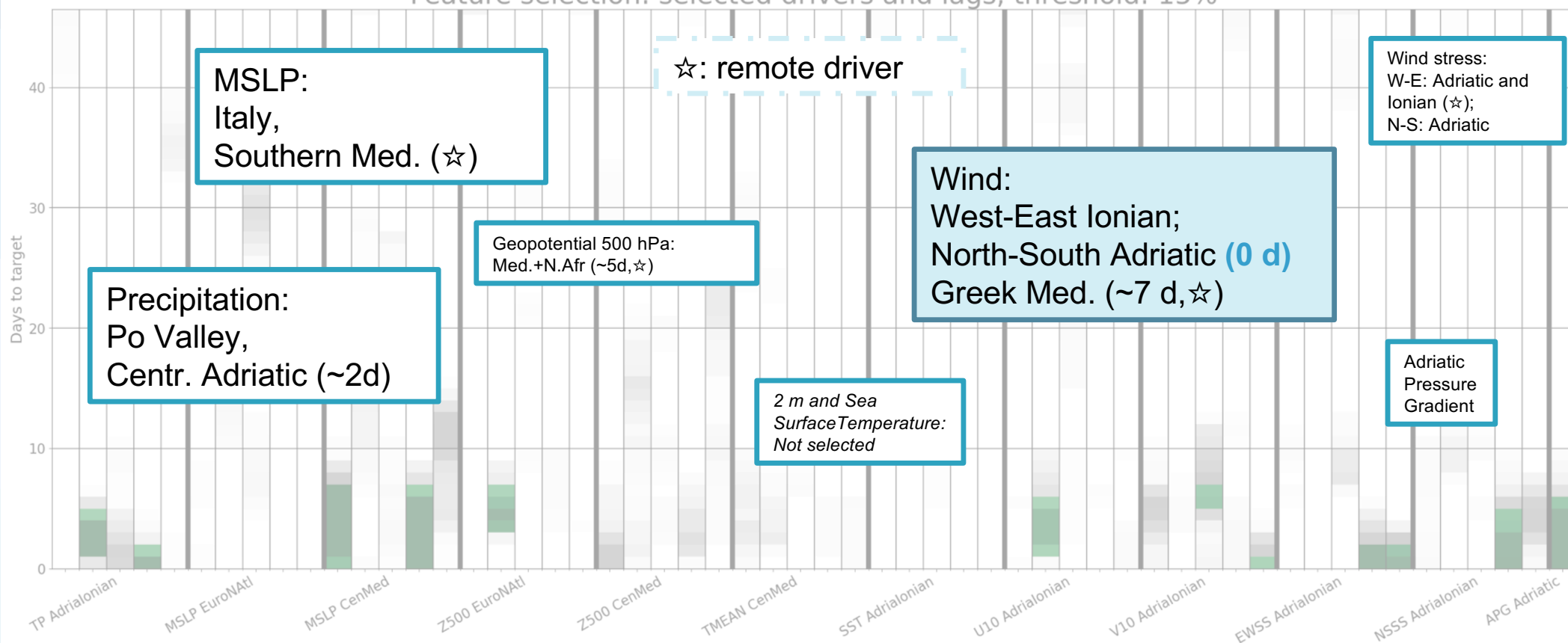
# Selection of drivers through PCRO-SL

Feature selection: selected drivers and lags, threshold: 15%



# Selection of drivers through PCRO-SL

Feature selection: selected drivers and lags, threshold: 15%



# Same lagged drivers for LR and standard ML algorithms

sci-kit learn  
**Linear Regression**

Keras/TensorFlow  
**Sequential**

**PyTorch**-based  
MultiLayer Perceptron

sci-kit learn  
**MultiLayer Perceptron**

sci-kit learn  
**Gradient Boost Regressor**

sci-kit learn  
**AdaBoost**

sci-kit learn  
**Random Forest**

**XGBoost**  
eXtreme Gradient Boosting

# Training set-up: target and predictor series

Training dataset (2004-2019)

5-fold cross validation (groups of 3y)

## TARGET SERIES

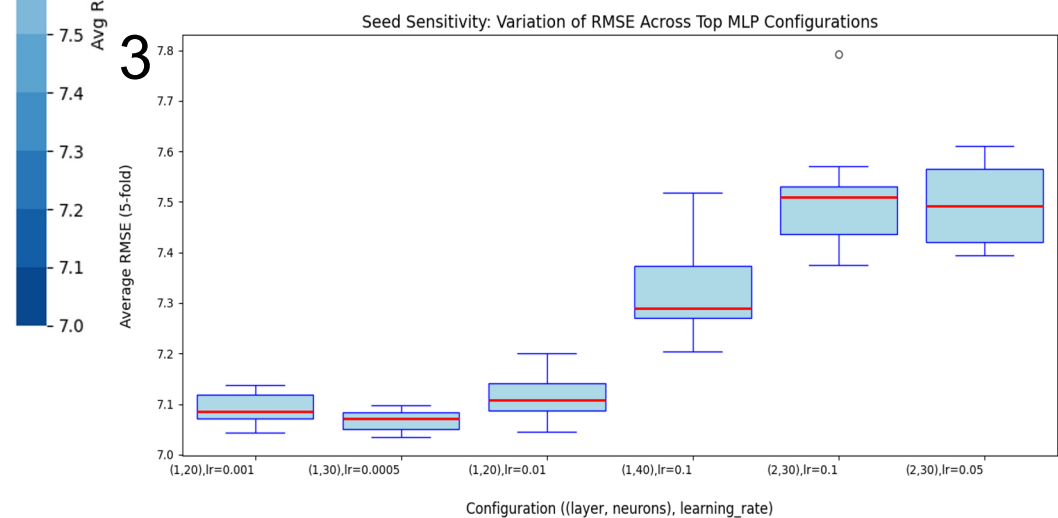
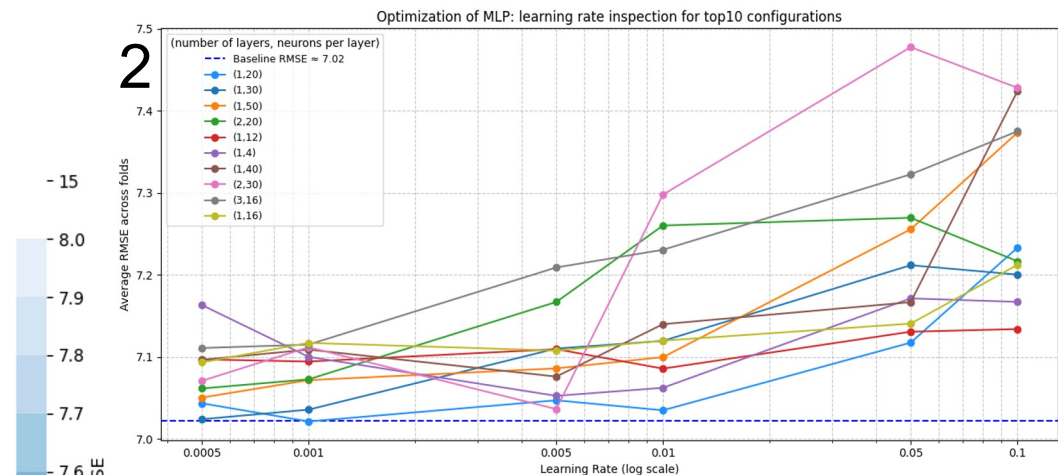
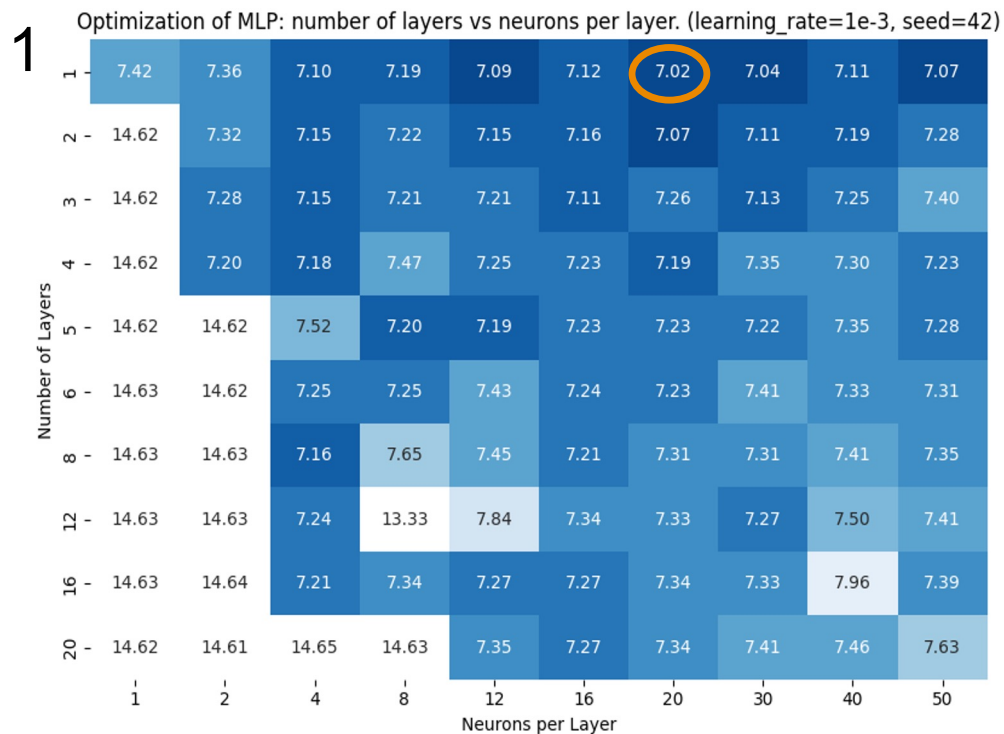
Daily maximum of  
meteorological component  
of Sea Level Anomaly  
(metSLA-max) in Venice

## PREDICTOR SERIES

Daily cluster-averaged  
variables from ERA5  
(selected with PCRO-SL)

# MLP optimization

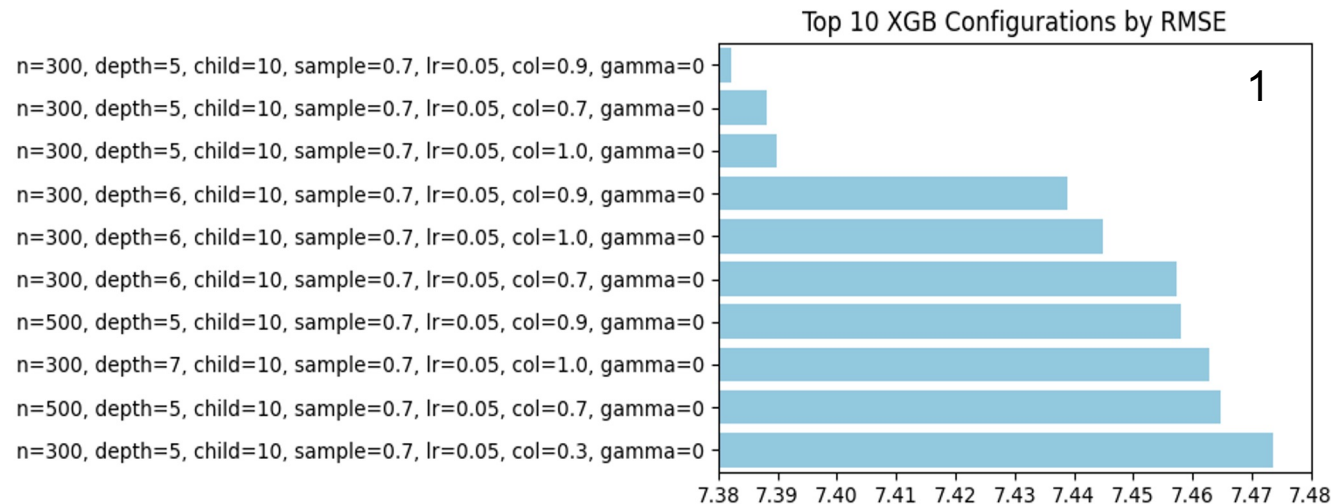
## Multi-step optimization





# XGB optimization

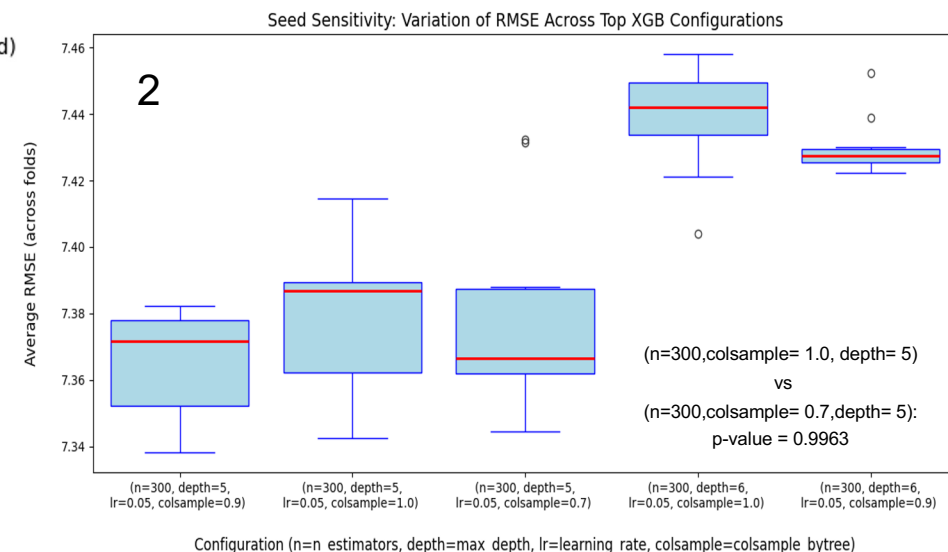
Hyperparameter Combo



First step with  
default seed

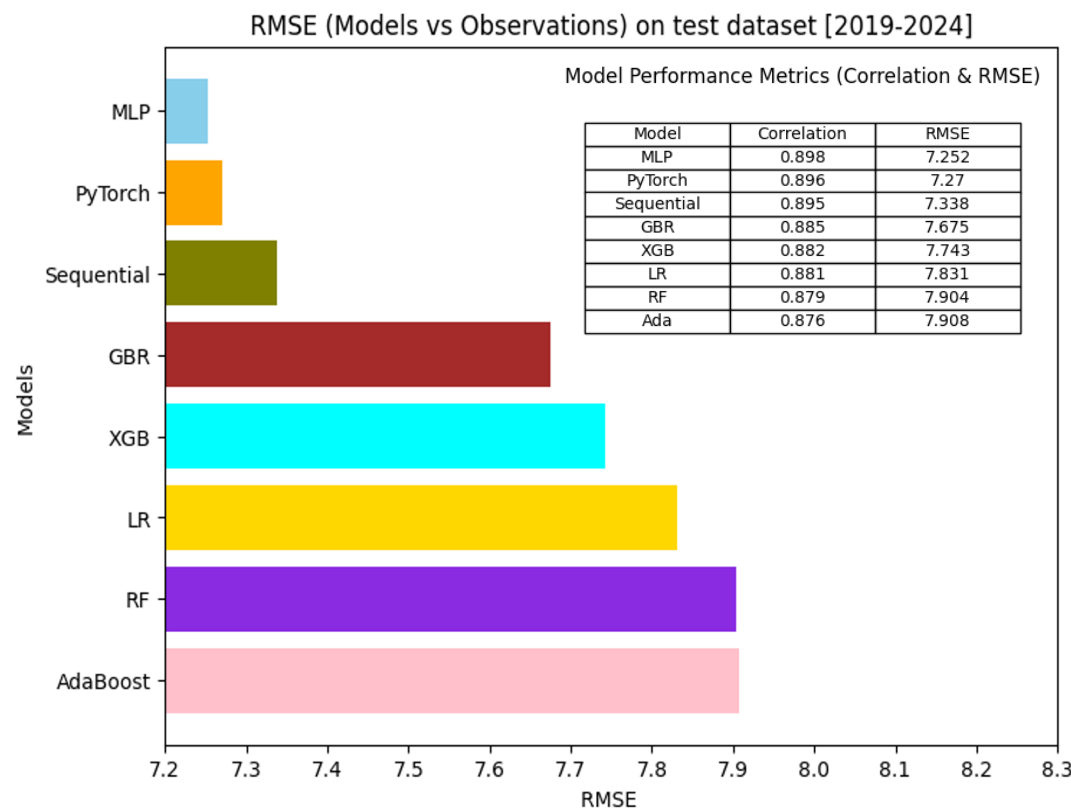
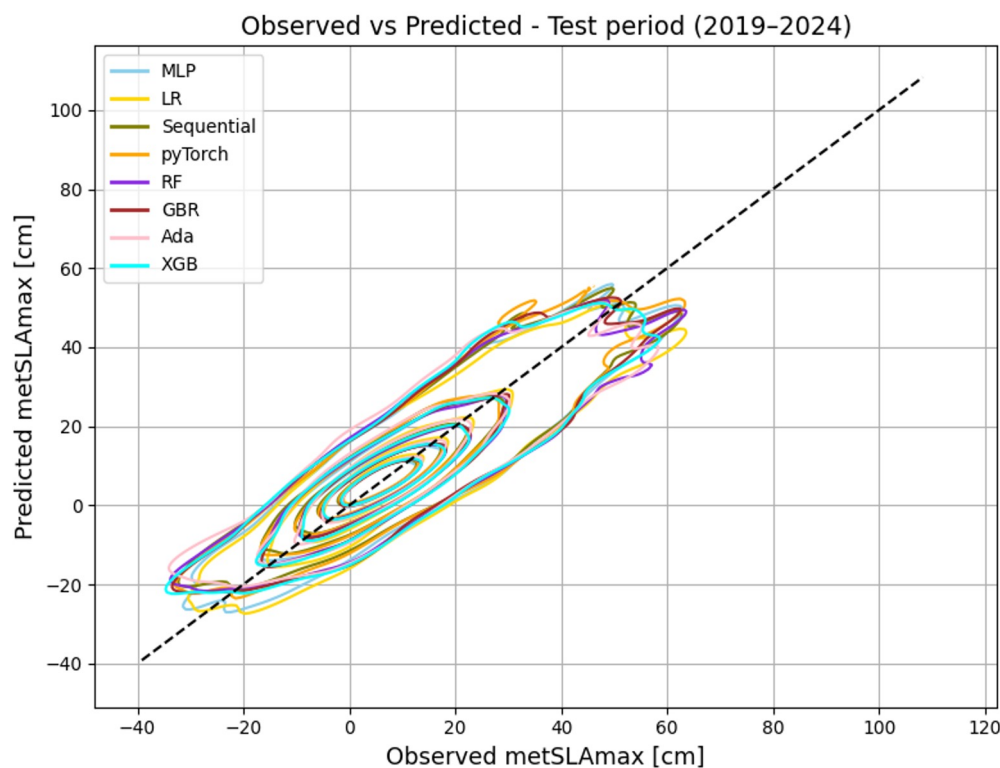
The seed influences the optimization

Priority to simpler configurations

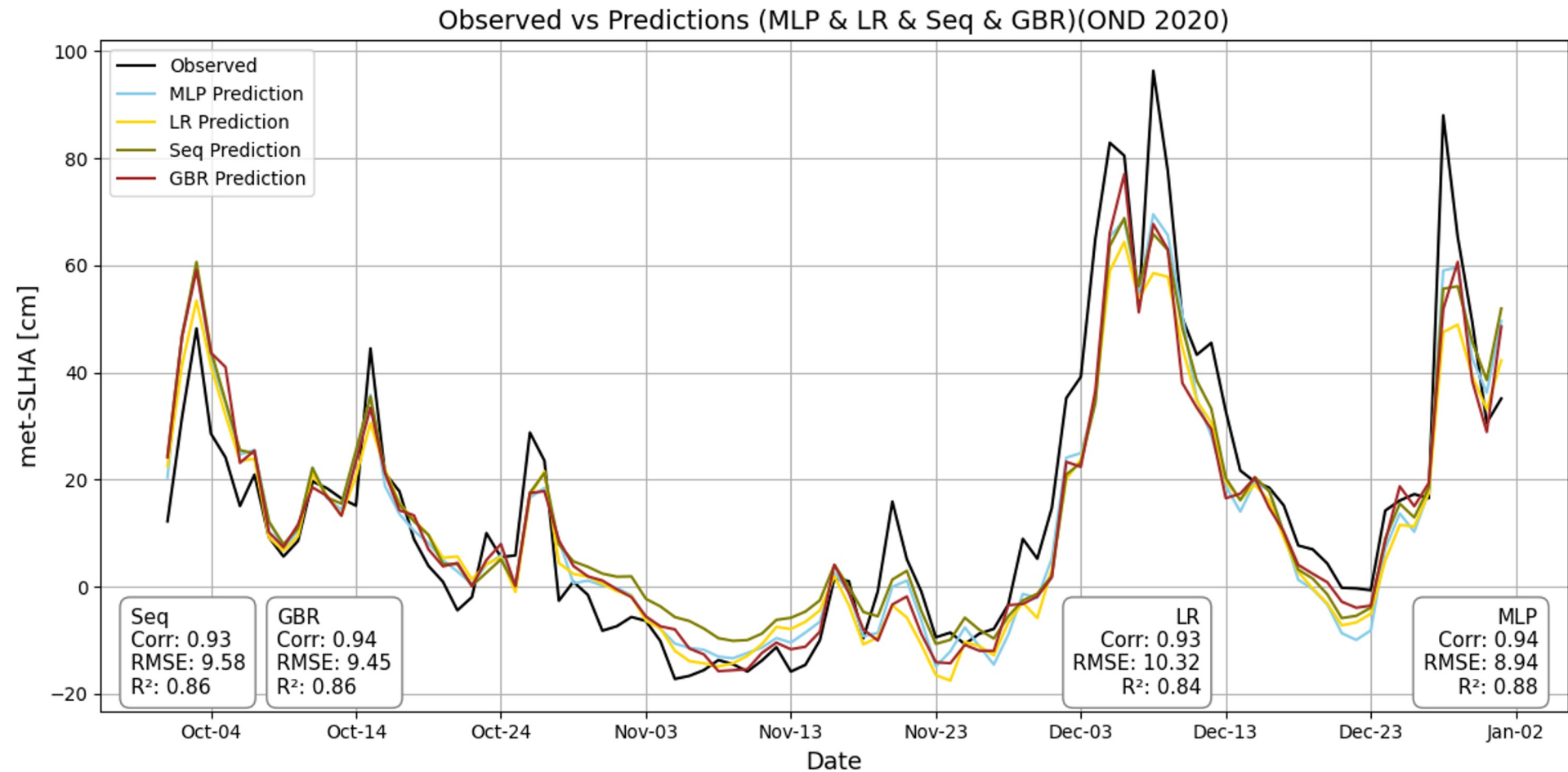


# Testing and selecting the best model

## Testing dataset (2019-2024)



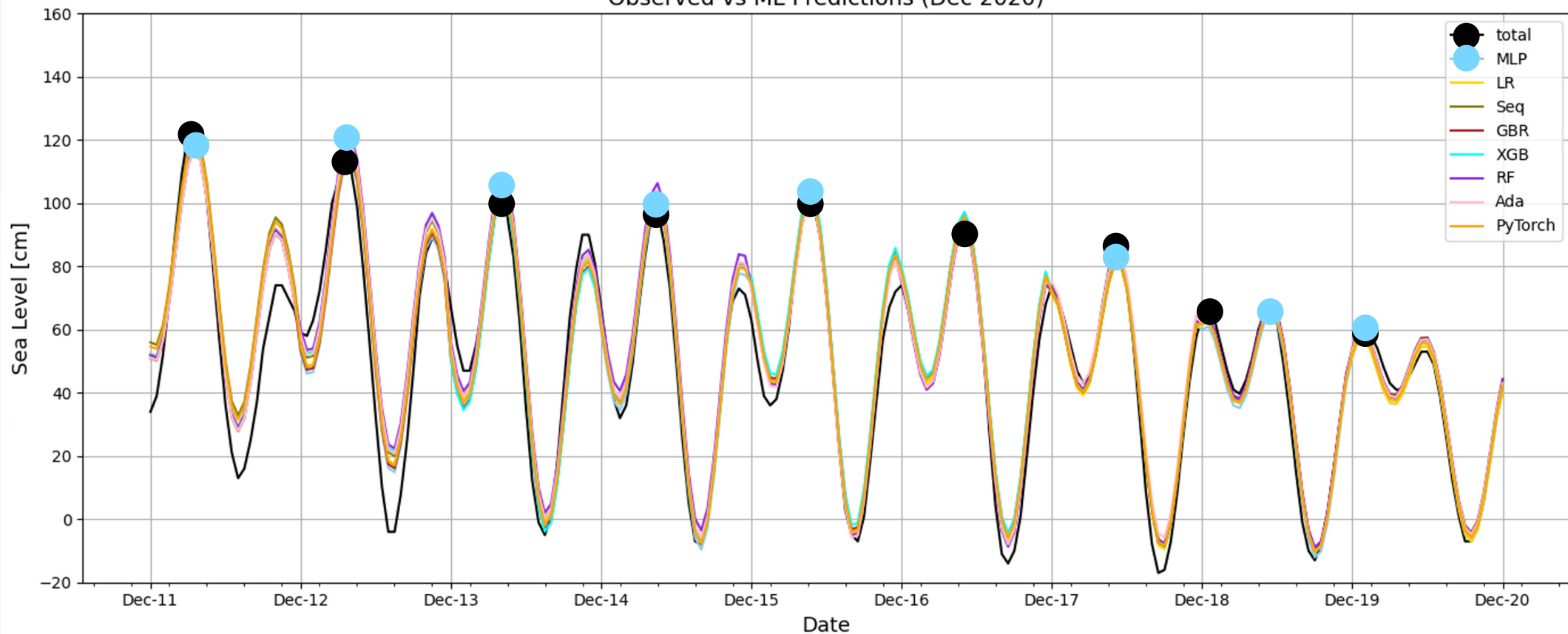
# Reconstructed metSLA-max



# Reconstructed Total Sea Level signal

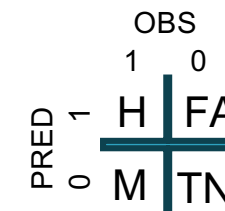
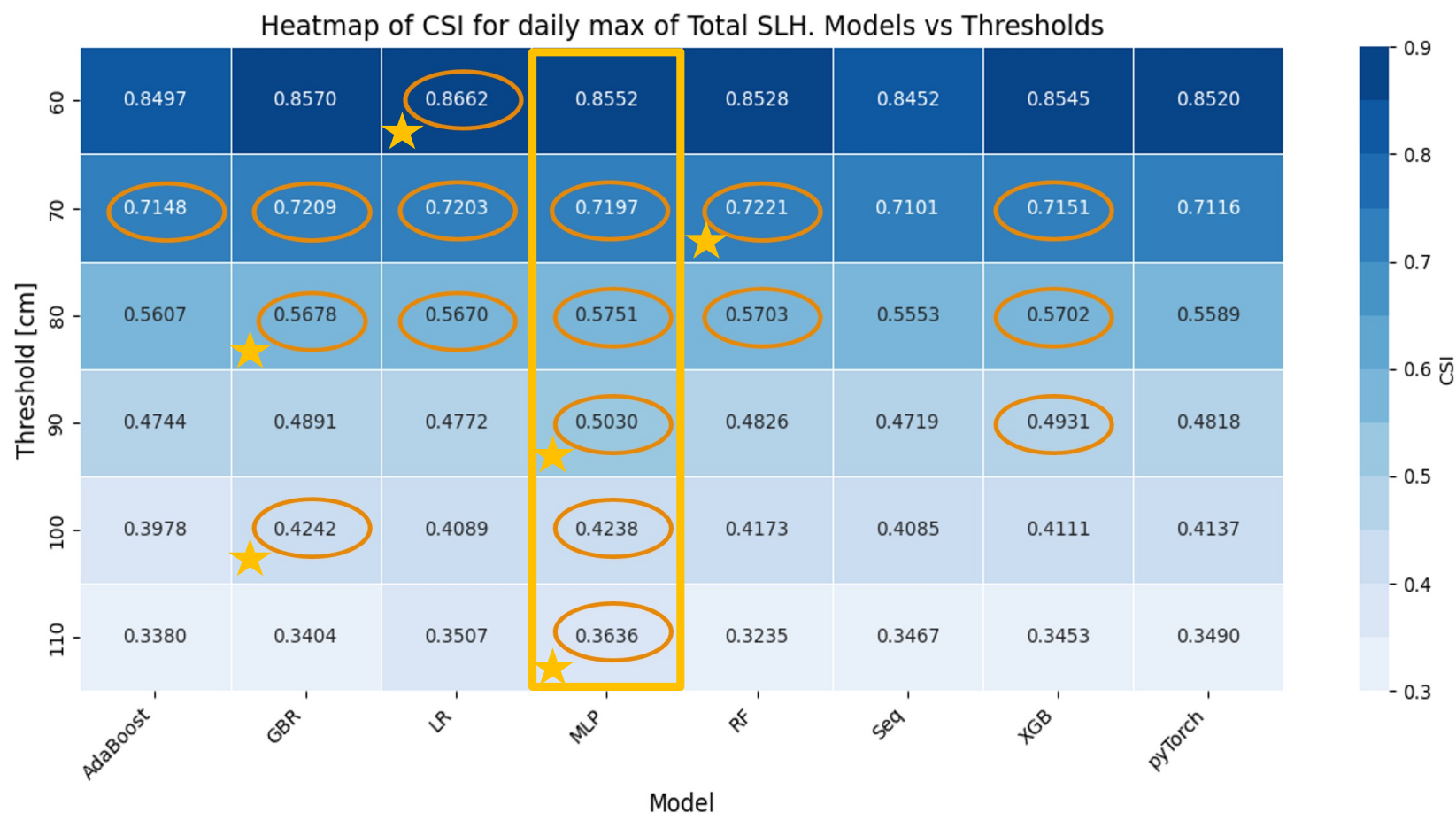
**TOTAL SEA LEVEL HEIGHT =**  
Long Term + Seasonal Cycle + Astronomical Tide + **metSLA**

Observed vs ML Predictions (Dec 2020)



# Threshold-based categorical verification

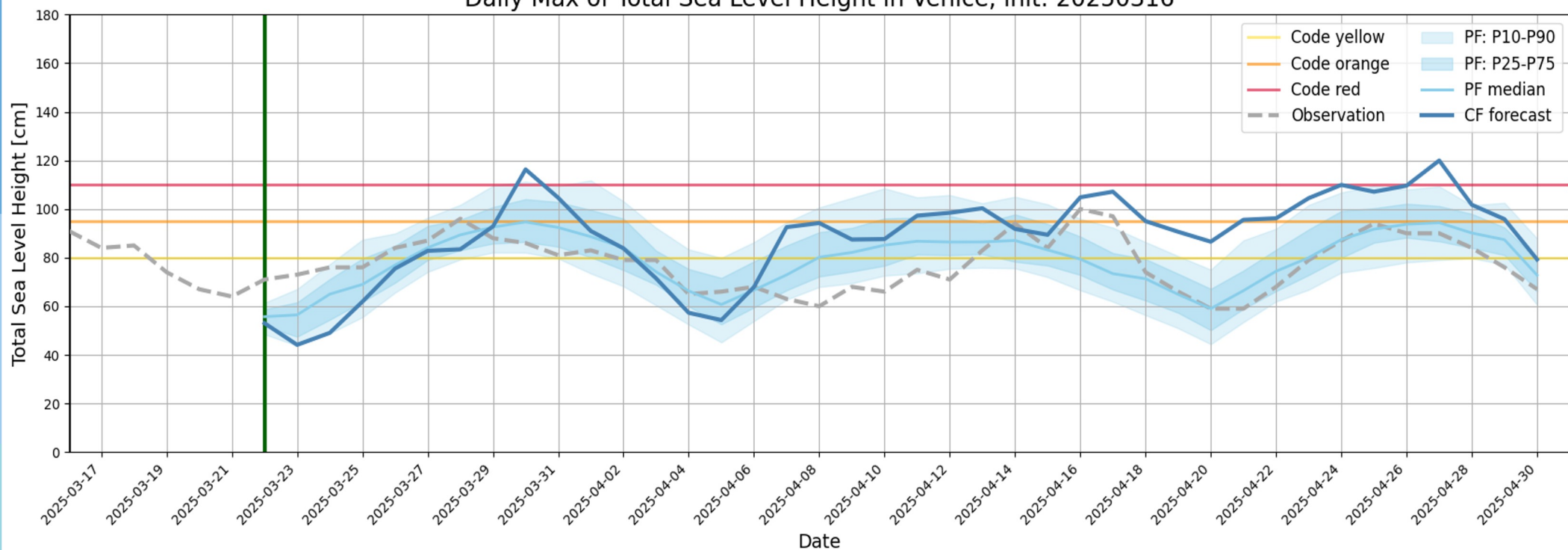
$$\text{CSI} = (\text{Hits}) / (\text{Hits} + \text{Misses} + \text{False Alarms})$$



# Application to historical ensemble forecasts

Applied individually on each ensemble member

Daily Max of Total Sea Level Height in Venice, init: 20250316

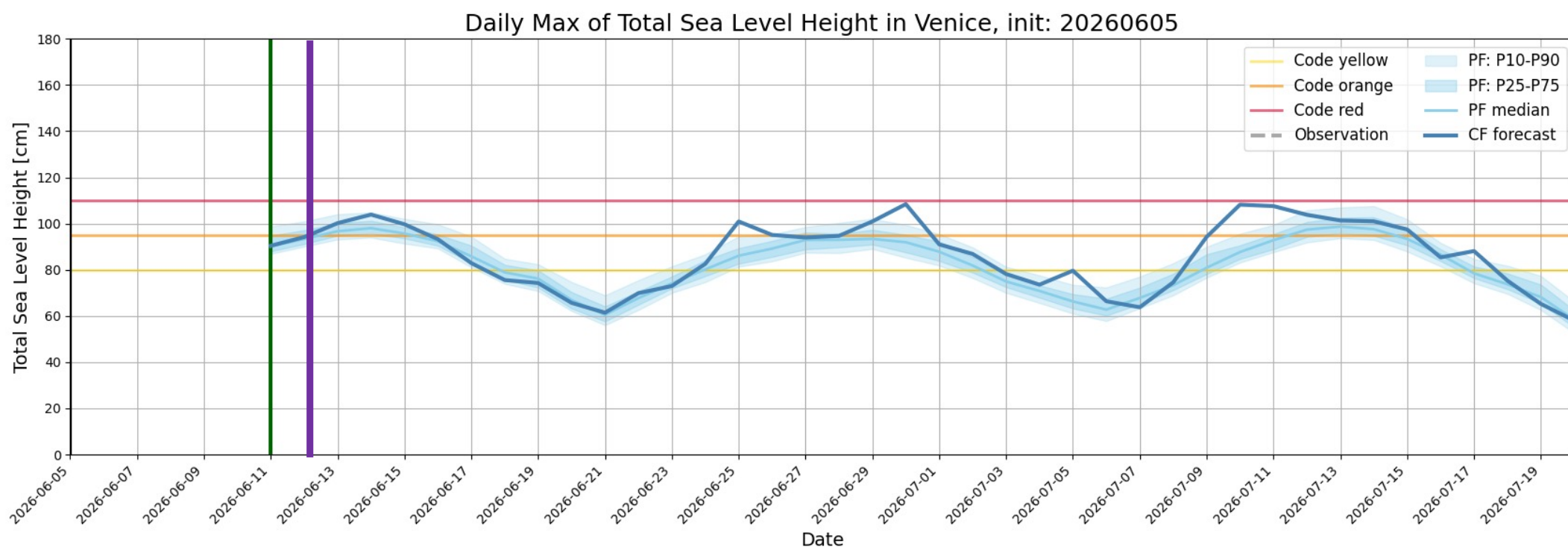


Deterministic and probabilistic forecast

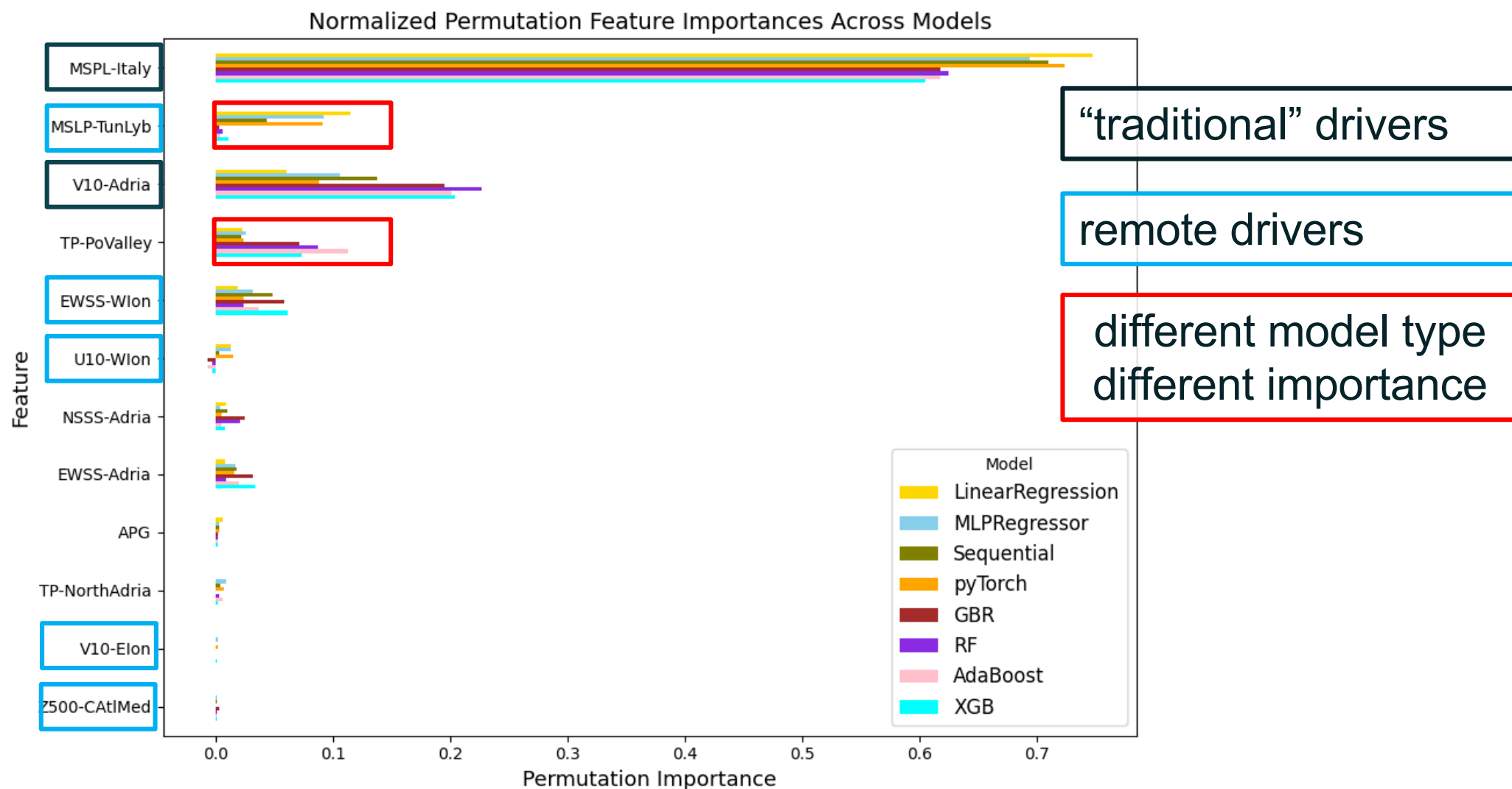


# Application to operational forecasts

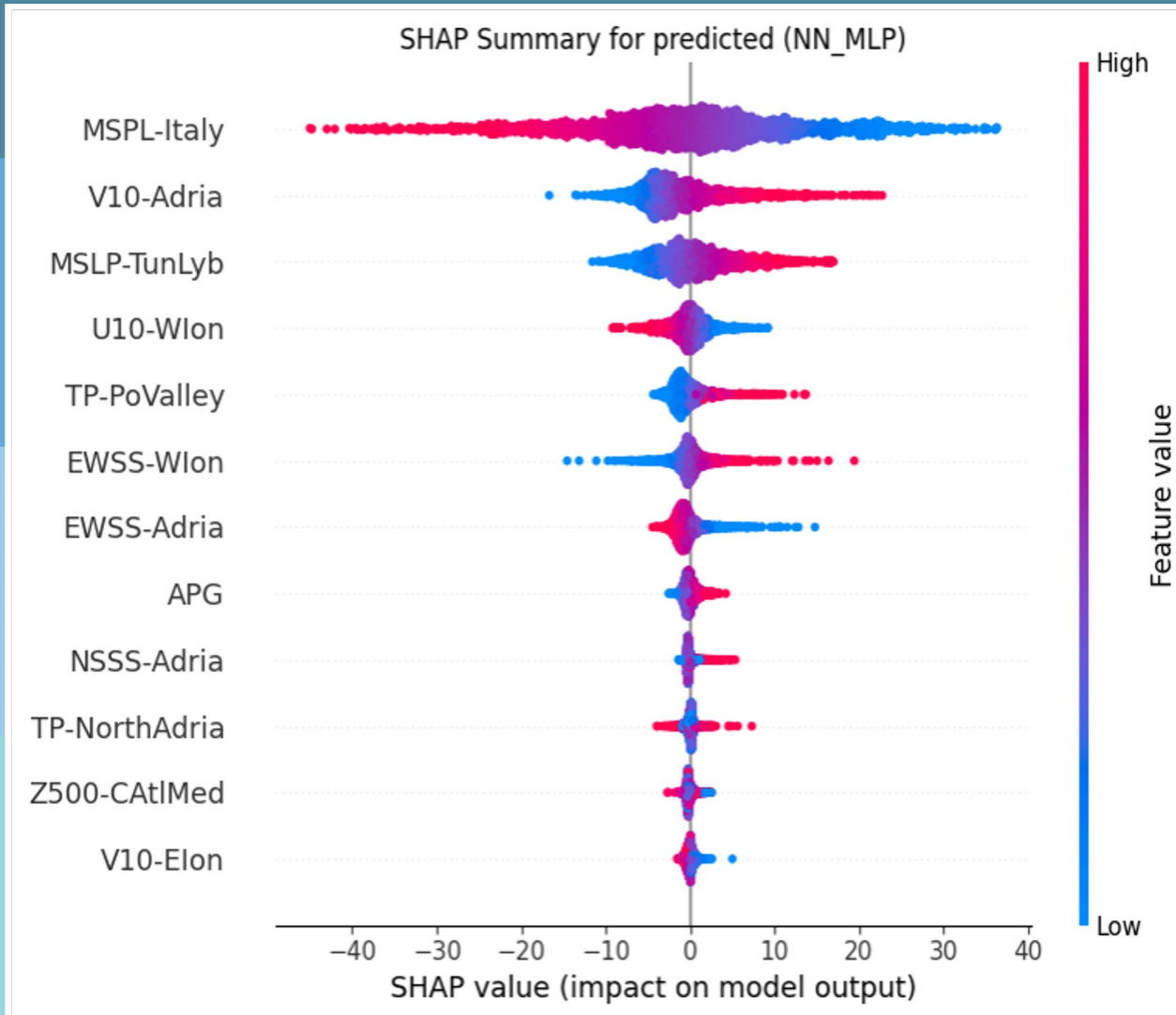
Applied to real-time forecasts provided daily by ECMWF



# Explainability: connection to physical interpretation



# Explainability of MLP Regressor



Local MSLP



Northward wind  
over the Adriatic



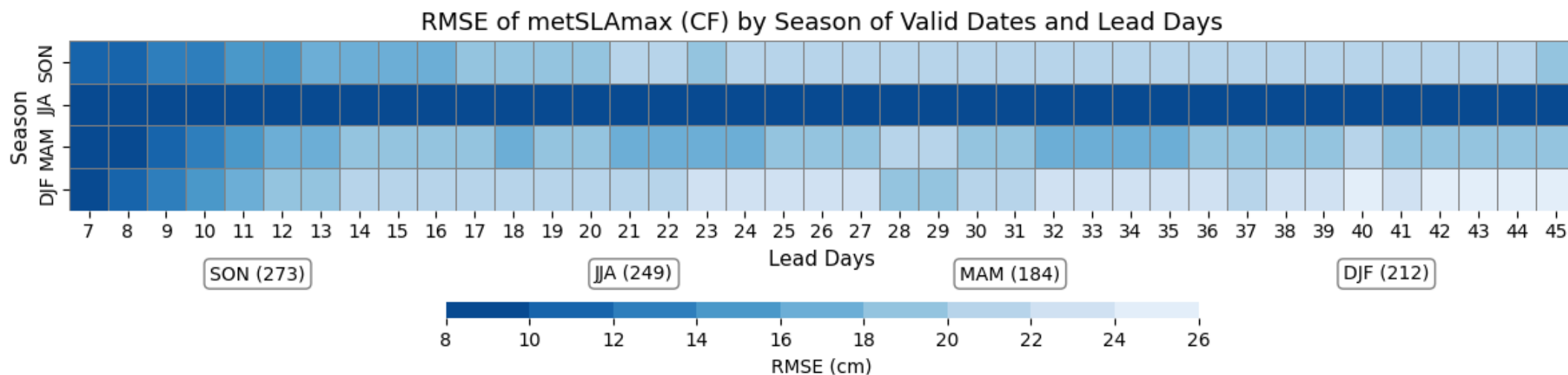
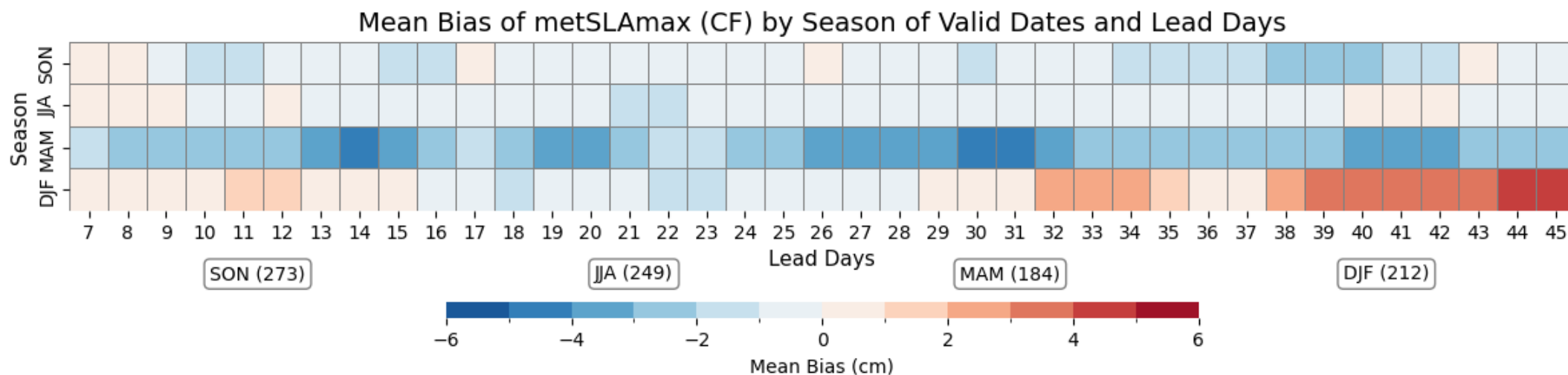
Remote MSLP  
(south)



Westward wind  
over the Ionian



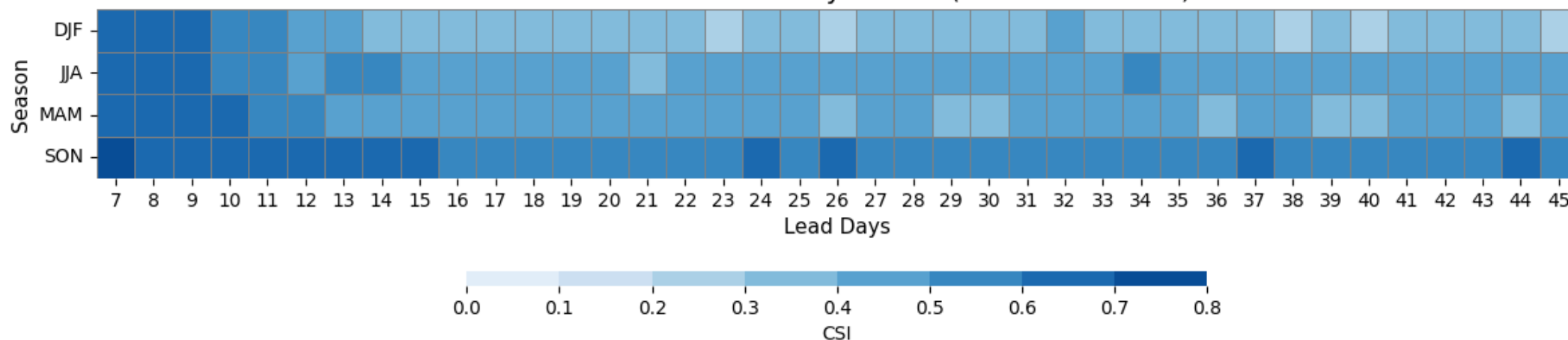
# Evaluation of deterministic forecasts on historical data



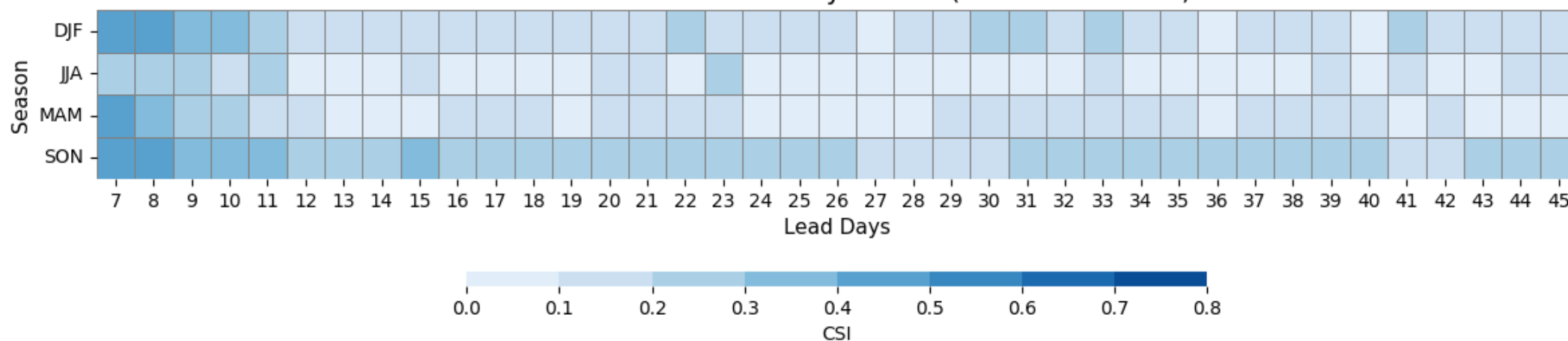
# Evaluation of deterministic forecasts on historical data

CSI = (Hits) / (Hits + Misses + False Alarms)

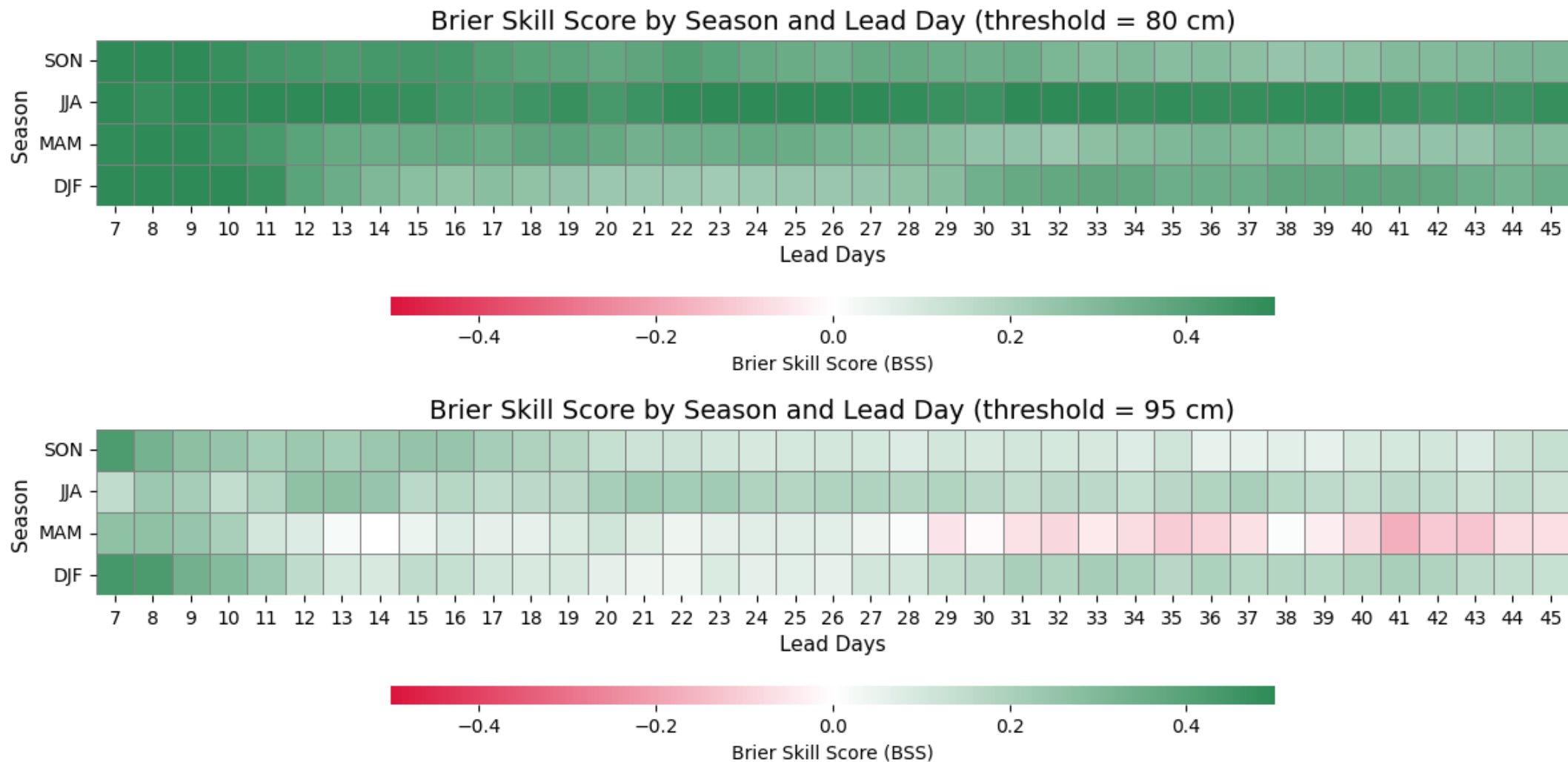
CSI of total SLH forecast by season (threshold: 80 cm)



CSI of total SLH forecast by season (threshold: 95 cm)



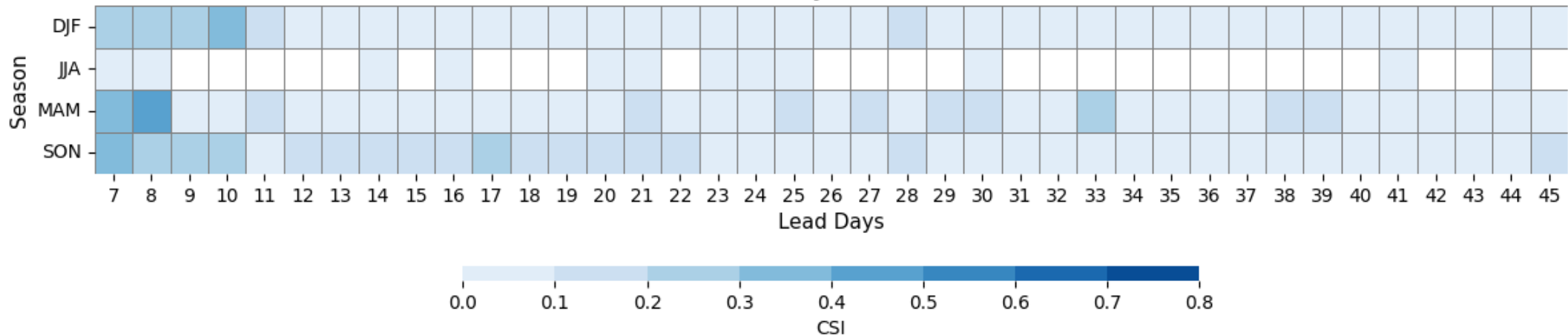
# Evaluation of probabilistic forecasts on historical data



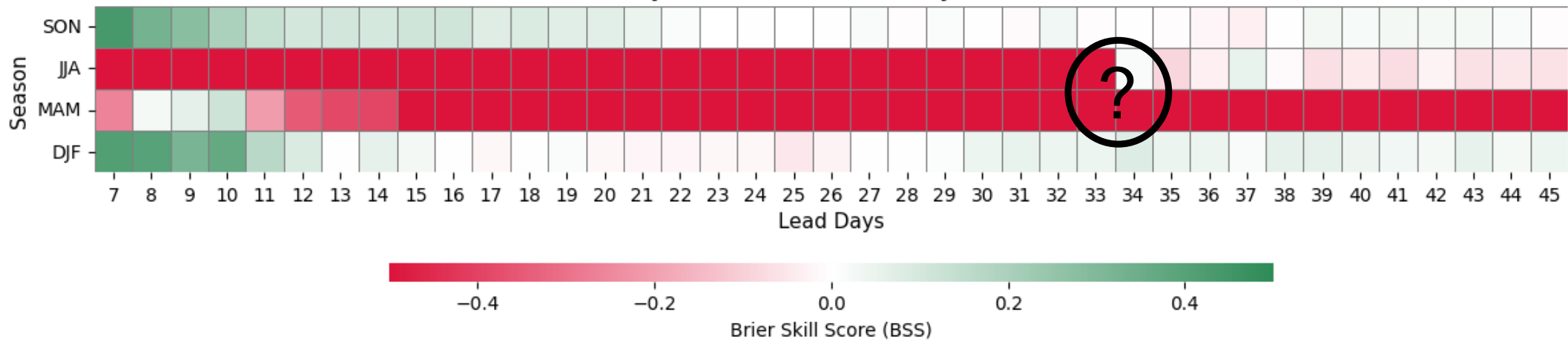


# Criticalities of the largest threshold

CSI of total SLH forecast by season (threshold: 110 cm)



Brier Skill Score by Season and Lead Day (threshold = 110 cm)

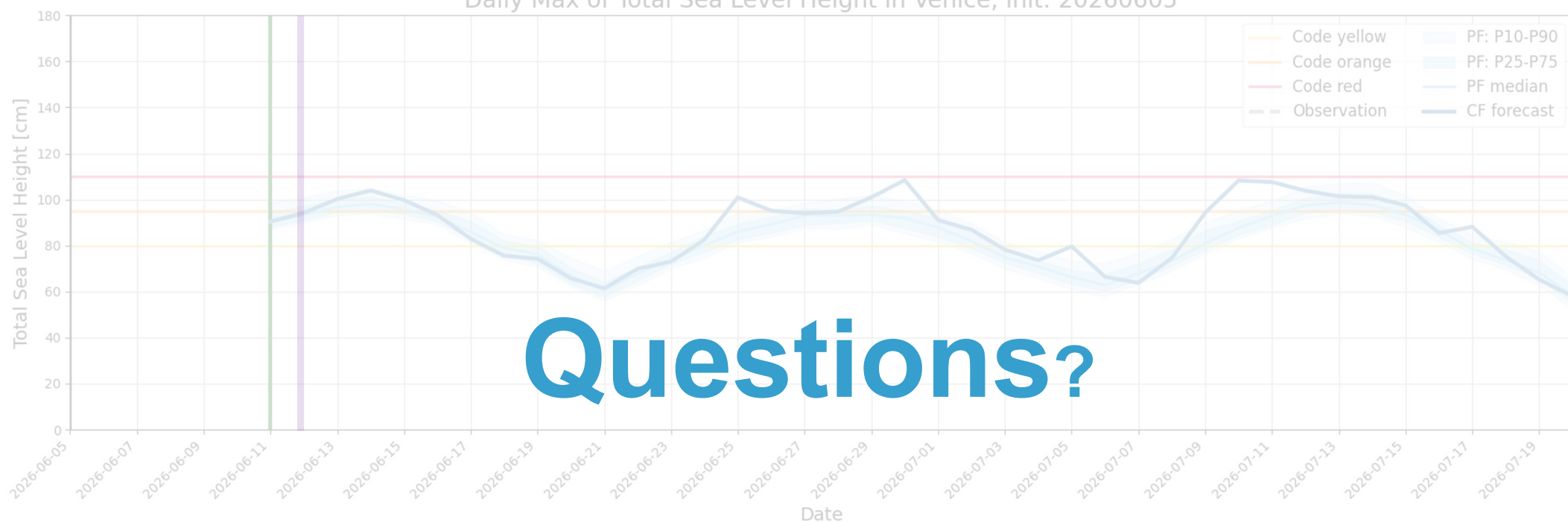


# full operationalization

Use of this method to generate a  
**member sub-sampling method**

e.g., RF that learns characteristics of a member that lead to high skill

Daily Max of Total Sea Level Height in Venice, init: 20260605



# Questions?

# THANKS



MedEWSa



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the European Union