Ocean Predict

SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

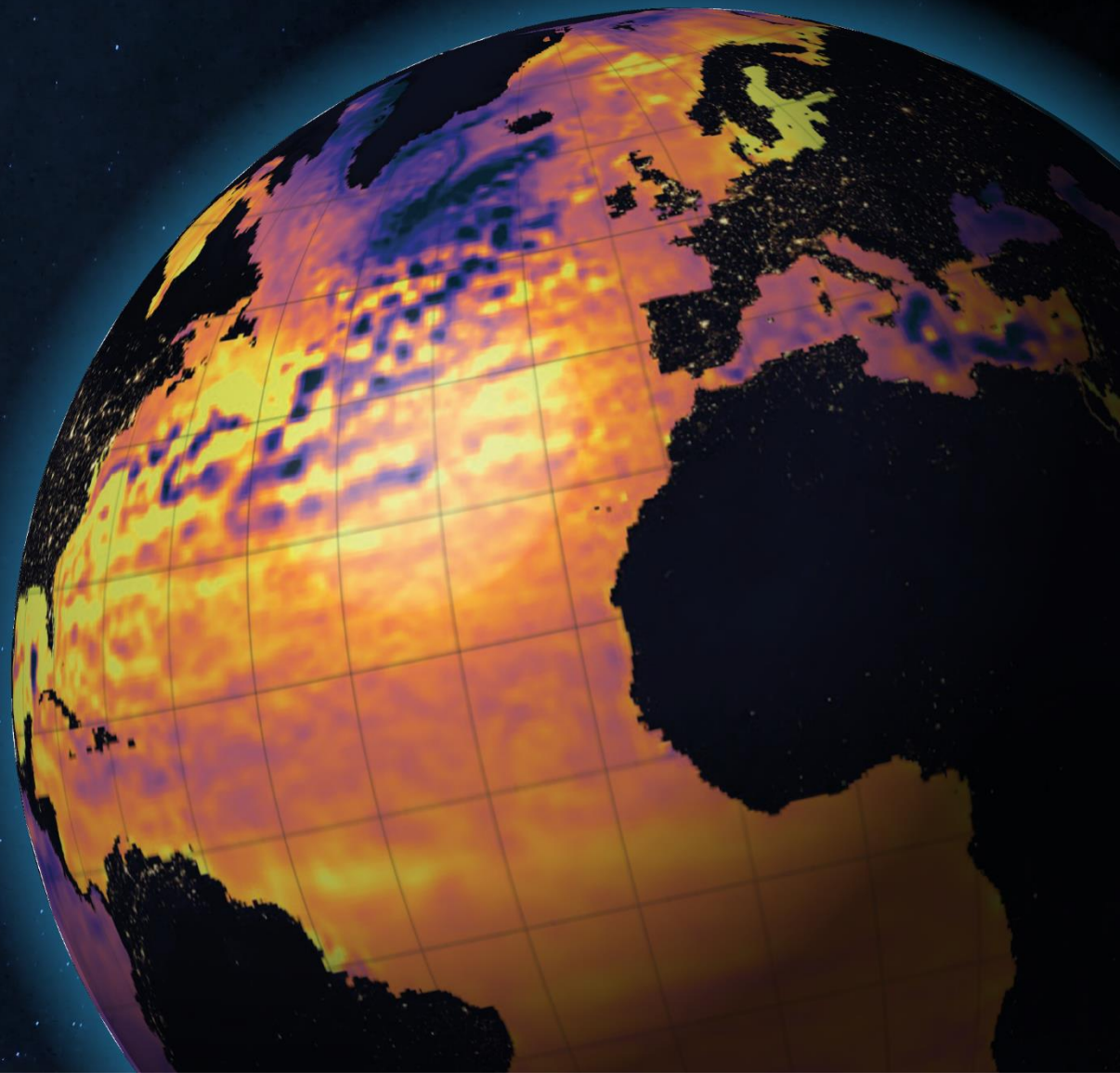
2021 2030 United Nations Decade of Ocean Science for Sustainable Development

How uncertain is the sea level?

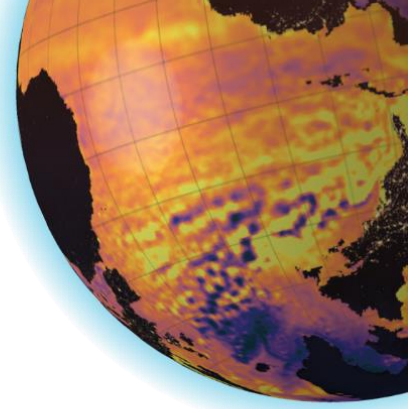
Sara Morucci, Gabriele Coccia, Andrea Bonometto, Elisa Coraci, Riccardo Alvise Mel

ISPRA

Italian Institute for Environmental Protection and Research

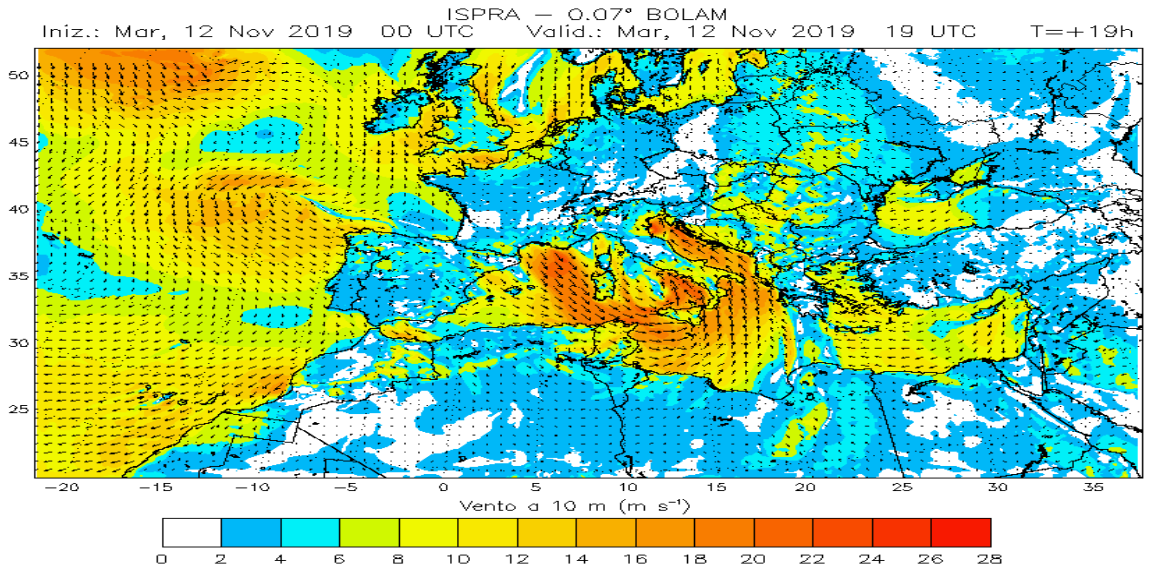


What are we talking about…



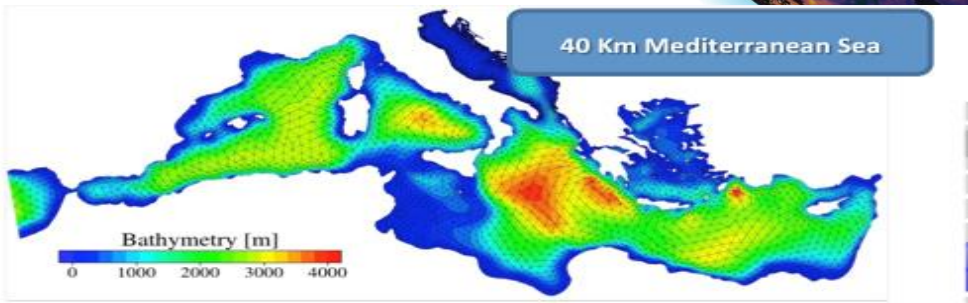
- Sea Level: how to forecast and why
  “ACQUA ALTA” in Venice
- …needing a probabilistic forecast
- Model Conditional Processor v1.0 and v2.0
- Results
  - Analysis of performance
  - Analysis of forecast for the events: 15.12.2022 and 10.08.2022
  - Analysis of storm surges events

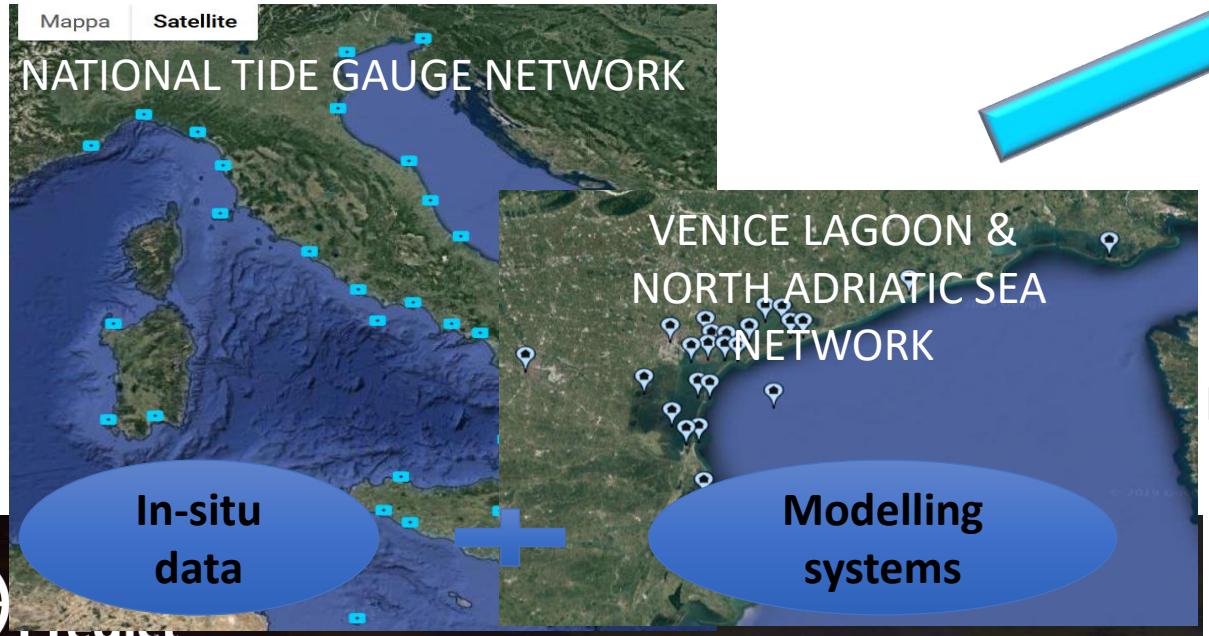
Acqua Alta in Venice



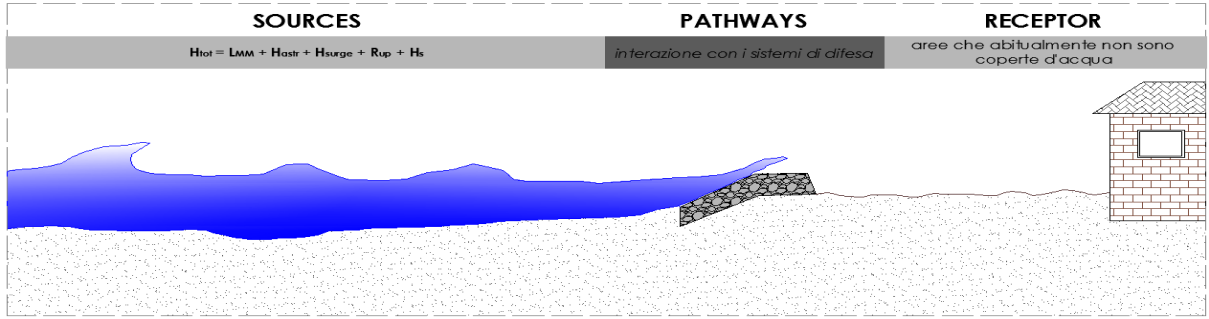
ISPRA INTEGRATED METEO & MARINE OPERATIONAL SYSTEM

STORM SURGE MODEL





SEA LEVEL, STORM SURGES



Acqua Alta in Venice

ISPRA Sea Level Forecasting System

INTEGRATED SYSTEM

1. Observed data

2. Operational chain

RMN, RMLV

ECMWF, BOLAM

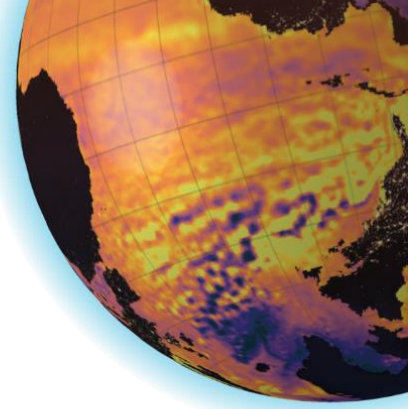
Det

SHYFEM

Meteo Input

Sea Level

Acqua Alta in Venice: Why forecast?



- Risk prediction and reduction
- **Decision making support**

Assuming models output as certain estimates of future events can lead to wrong decisions and result in economic losses and loss of human lives

…needing a probabilistic approach and a statistical treatment of predictions

Uncertainty Prediction Evaluation

Estimation of the probability of exceeding alert thresholds

… needing a probabilistic forecast

RISK MANAGEMENT

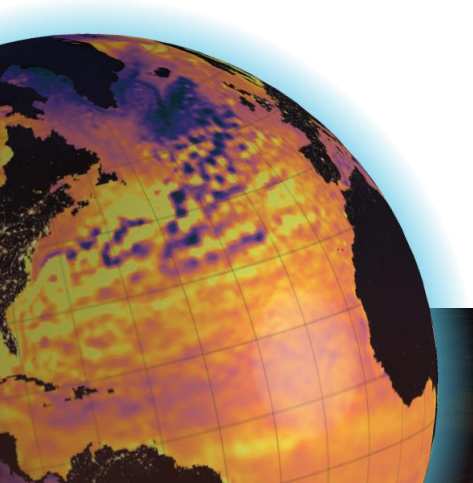
Storm surges and floods are natural phenomena, which cannot be avoided, but their effects can be reduced if they are predicted sufficiently in advance

SEA LEVEL FORECASTING SYSTEMS

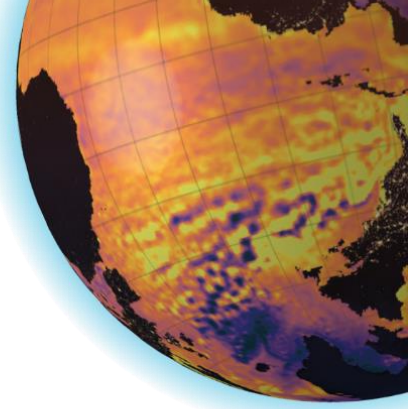
Important information about the evolution of future events, **BUT…**

…models are imperfect and uncertainty on what will happen still remains

- How can a decision maker deal with these predictions?
- How model predictions can be translated into an effective intervention strategy?



… needing a probabilistic forecast



Predictive Probability Distribution

sadly known as

Predictive Uncertainty

- **Predictive Uncertainty** can be defined as **the probability of occurrence of a future value** (such as sea level) **conditional on all the information available in the present and that can be obtained on the future value**, through a deductive process

  ➢ source of information ⟹ **models predictions**

  ⇓

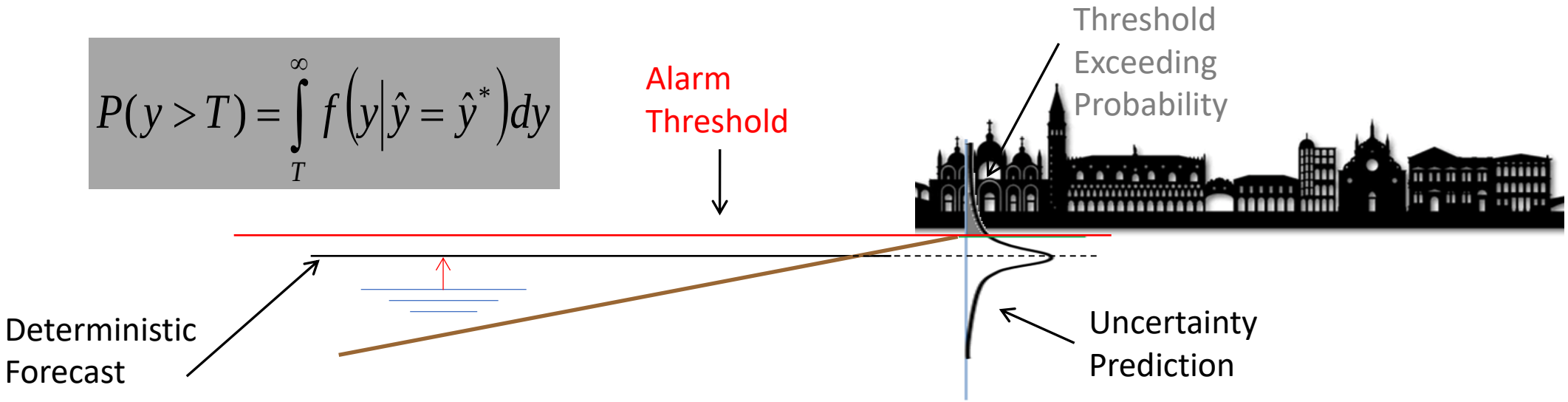
  Uncertainty Prediction is the **probability of a real future event (y)** conditional on models forecast **(y)** represented as $f(y|\hat{y})$

… needing a probabilistic forecast

Probability of Exceeding a Threshold

As the integral of the probability distribution function
(uncertainty prediction)

$$P(y > T) = \int_{T}^{\infty} f\left(y \middle| \hat{y} = \hat{y}^{*}\right) dy$$



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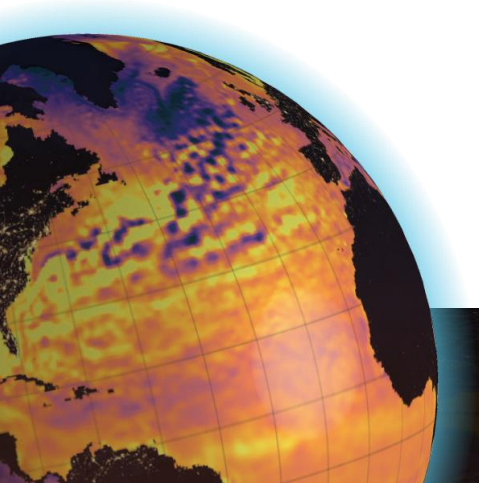
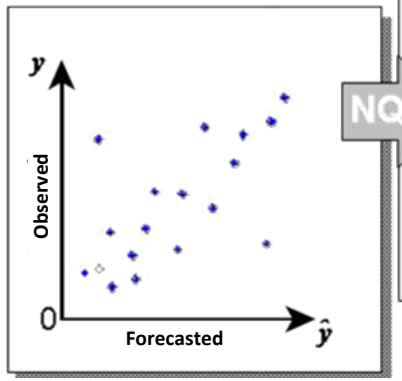


Model Conditional Processor MCP

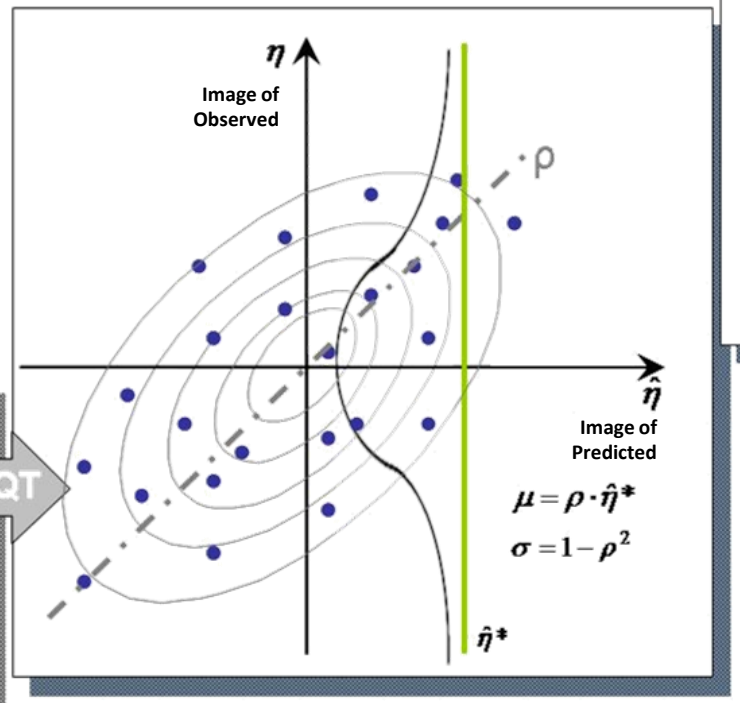
1) Conversion from the Real Space to the Normal Space using the NQT

Historical data

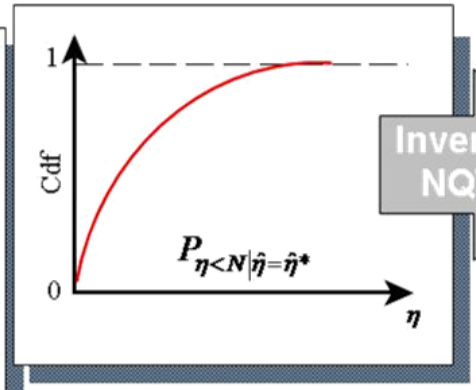


NQT

Joint PDF



Conditional PDF



Inverse NQT

$$f(y|\hat{y})$$

2) Joint distribution is assumed to be a Normal Bivariate Distribution

3) Predictive Uncertainty is obtained by the Bayes Theorem and its mean and variance are:

$$\mu_{\eta|\hat{\eta}} = \rho_{\eta\hat{\eta}}\hat{\eta}$$

$$\sigma^2_{\eta|\hat{\eta}} = 1 - \rho^2_{\eta\hat{\eta}}$$

4) The Predictive Uncertainty is computed sampling the probability density function in the Normal Space and reconverting to the Real Space the obtained quantiles by the Inverse NQT:

$$\eta^* = E\left[f\left(\eta|\hat{\eta} = \hat{\eta}^*\right)\right]$$

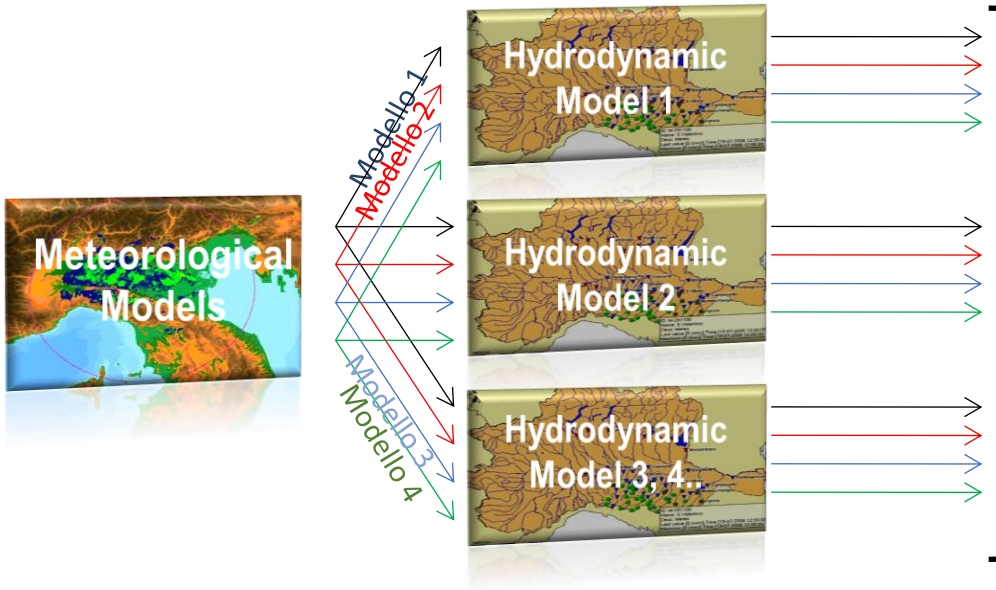
Todini, E.: A model conditional processor to assess predictive uncertainty in flood forecasting, Intl. J. River Basin Management, 6 (2), 123-137, 2008

Model Conditional Processor MCP

More than one forecasting model (N), generalizing to N dimensional space > Normal Distribution N+1 variate

More than one time step (T), generalizing to (N*T) dimensional space > Normal Distribution N*T +1 variate

MULTI – MODEL APPROACH



Bayesian Combination

Uncertainty Prediction

$$f\left(\eta \mid \hat{\eta}_{i,i=1..N}\right) = \frac{f\left(\eta, \hat{\eta}_{i,i=1..N}\right)}{f\left(\hat{\eta}_{i,i=1..N}\right)}$$

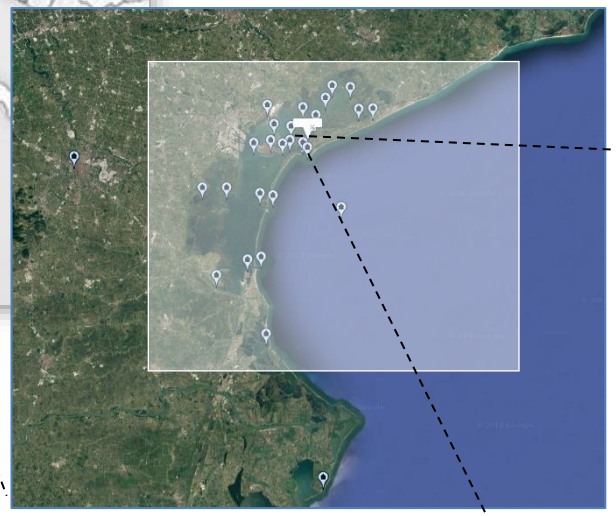
MULTI MODEL – MULTI TEMPORAL APPROACH

$$f\left(\eta_{j(j=1..T)} \middle| \hat{\eta}_{ij(i=1..N,j=1..T)}\right) = \frac{f\left(\eta_{j(j=1..T)}, \hat{\eta}_{ij(i=1..N,j=1..T)}\right)}{f\left(\hat{\eta}_{ij(i=1..N,j=1..T)}\right)}$$

Measurement Stations

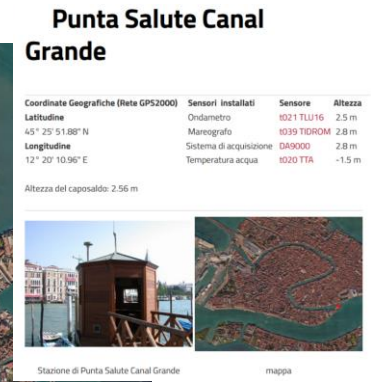
- **PUNTA DELLA SALUTE** and **LIDO DIGA SUD (MCP v1.0)**
- Hourly prediction
- Hourly observed data

Forecasting time 96 hours

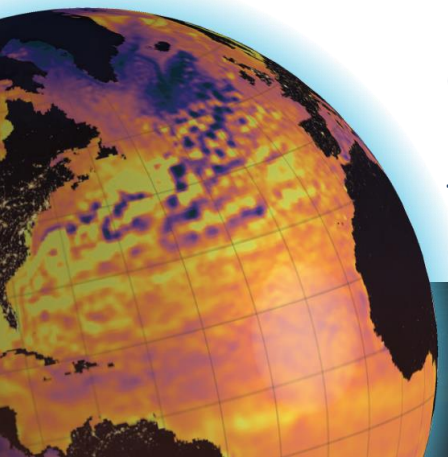


01-01-2018 — 31-12-2019 — 01-01-2020 — 31-12-2021

MT CALIBRATION VALIDATION



Hopefully and fortunately during storm surges, peaks in PS are cut, thanks to MOSE elevation **(MCP v2.0, only L.D.S.)**



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MCP v1.0

- Thresholds: 110 cm, 130 cm, 140 cm
- Lido Diga Sud and Punta della Salute
- Calibration Period: 2018-2020
- Validation Period 2021

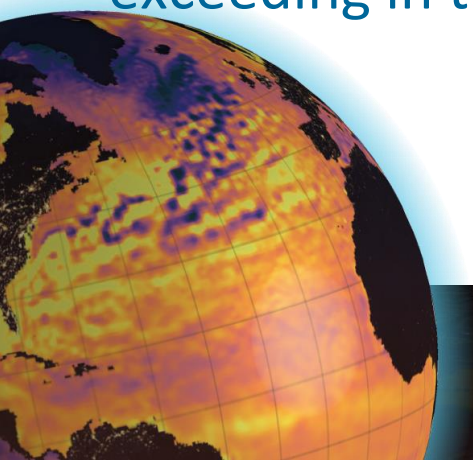
Cumulated Probability of threshold exceeding in the next 96 hours

MCP v2.0

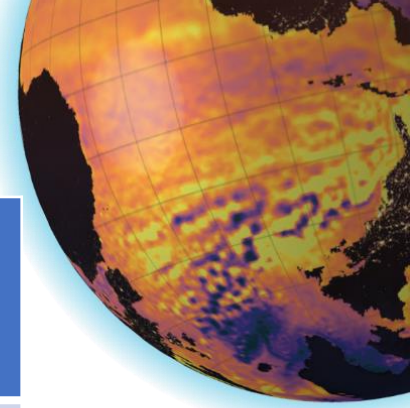
- Thresholds: 110 cm, 130 cm, 140 cm
- **Lido Diga Sud** station
- Extended Calibration Period 2019-2021
- Validation Period: 2022
- Separated Components: Astronomical and Meteorological

Cumulated Probability of threshold exceeding in the next 96 hours

Probability of exceeding for intervals of 1h, 6hrs, 12hrs, 24hrs, 48hrs

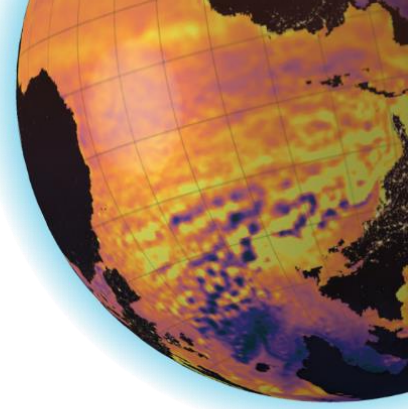


Operative Models



	Models	Cod.	Grid Resolution	Version	Input meteo	Initial Meteo Instant	Release time
	Statistico	1	-	-	ECMWF 50km (passo 6 ore)	00.00 UTC	
From 2018	Deterministic	4s	Low	Standard	ECMWF 50km (passo 6 h)	00.00 UTC +96h	10.00
From 2018	Deterministic	4as	Low	Assimilation	ECMWF 50km (passo 6 h)	00.00 UTC +96h	10.00
From 2018	Deterministic	5s	High	Standard	ECMWF 50km (passo 6 h)	00.00 UTC +96h	11.00
From 2018	Deterministic	5as	High	Assimilation	ECMWF 50km (passo 6 h)	00.00 UTC +96h	11.00
From 2019	Deterministic	8s	High	Standard	BOLAM 7.8km (passo 1 h)	12.00 UTC (ieri) +144h	9.00
From 2019	Deterministic	8as	High	Assimilation	BOLAM 7.8km (passo 1 h)	12.00 UTC (ieri) +144h	9.00
From 2019	Deterministic	80s	High	Standard	BOLAM 2.6km (passo 1 h)	00.00 UTC+144h	13.00
From 2019	Deterministic	80as	High	Assimilation	BOLAM 2.6km (passo 1 h)	00.00 UTC+144 h	13.00

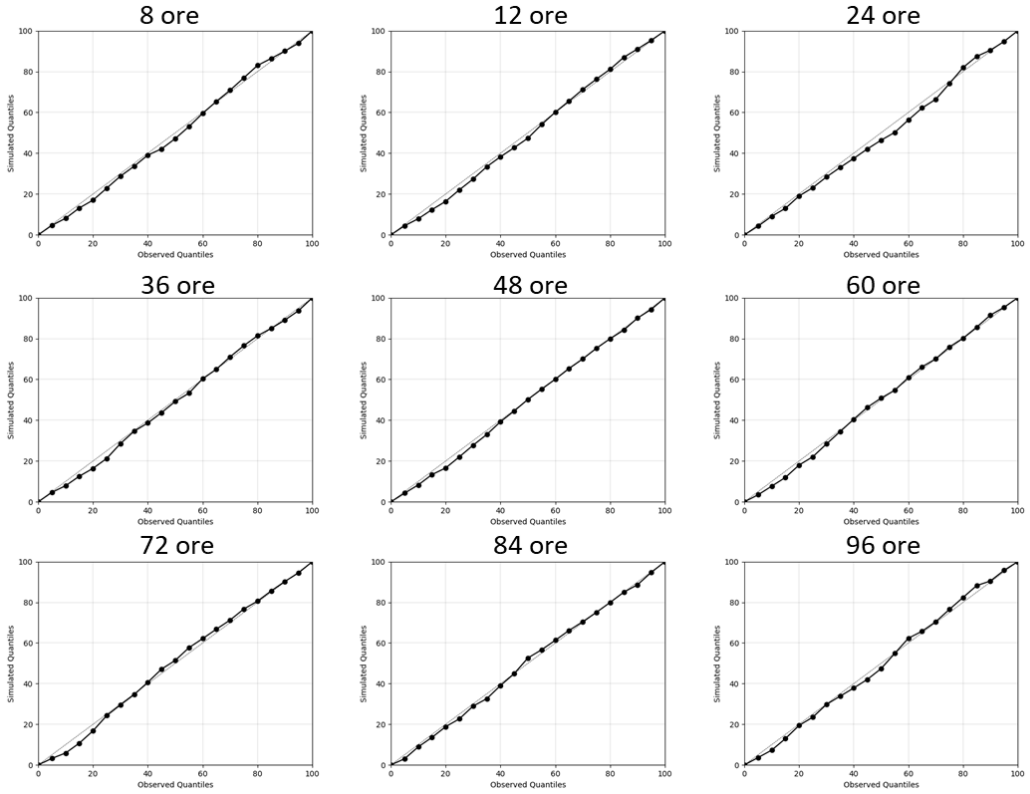
MCP configurations



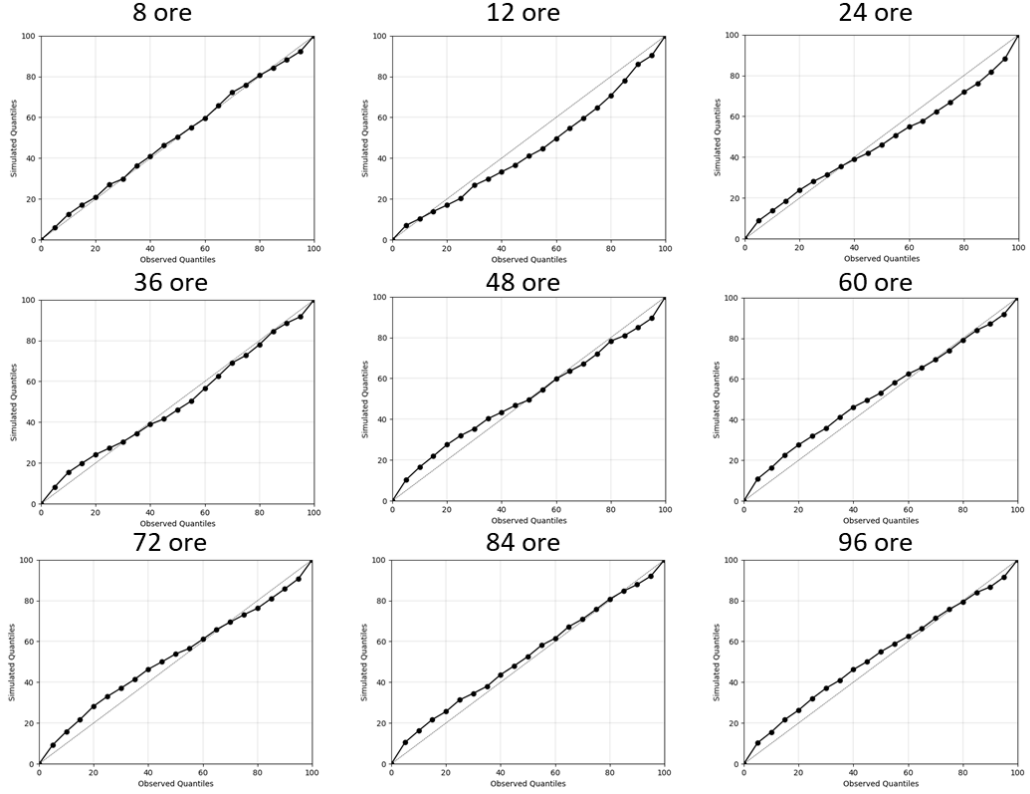
Config.	Available Models	Observed Data	Calibration Period	Validation Period
EBao	4s – 4as – 5s – 5as – 8s – 8as	0.00 – 7.00 UTC	01/01/2018 - 31/12/2021	01/01/2022 - 31/12/2022
EBa	4s – 4as – 5s – 5as – 8s – 8as	No		
EB	4s – 5s – 8s	No		
Eao	4s – 4as – 5s – 5as	0.00 – 7.00 UTC		
Ea	4s – 4as – 5s – 5as	No		
E	4s – 5s	No		
Bao	8s – 8as	0.00 – 7.00 UTC		
Ba	8s – 8as	No		
B	8s	No		
EBCao	4s – 4as – 5s – 5as – 8s – 8as – 80s – 80as	0.00 – 7.00 UTC	01/01/2019 - 31/12/2021	01/01/2022 - 31/12/2022
EBCa	4s – 4as – 5s – 5as – 8s – 8as – 80s – 80as	No		
EBC	4s – 5s – 8s – 80s	No		
ECao	4s – 4as – 5s – 5as – 80s – 80as	0.00 – 7.00 UTC		
ECa	4s – 4as – 5s – 5as – 80s – 80as	No		
EC	4s – 5s – 80s	No		
BCao	8s – 8as – 80s – 80as	0.00 – 7.00 UTC		
BCa	8s – 8as – 80s – 80as	No		
BC	8s – 80s	No		
Cao	80s – 80as	0.00 – 7.00 UTC		
Ca	80s – 80as	No		
C	80s	No		

MCP v2.0 Reliability

Calibration

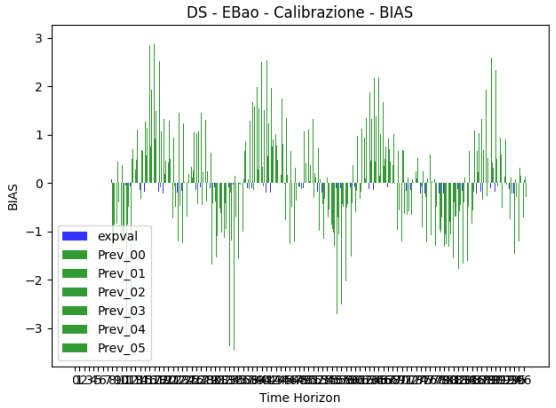


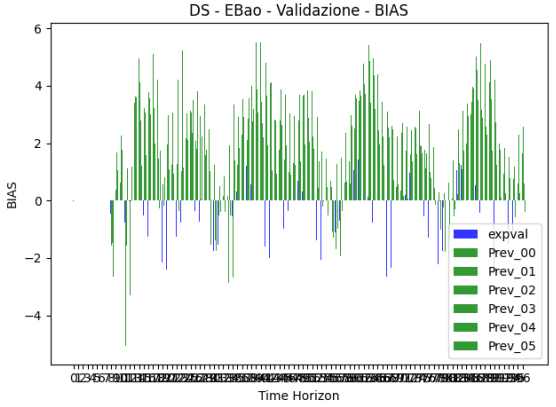
Validation



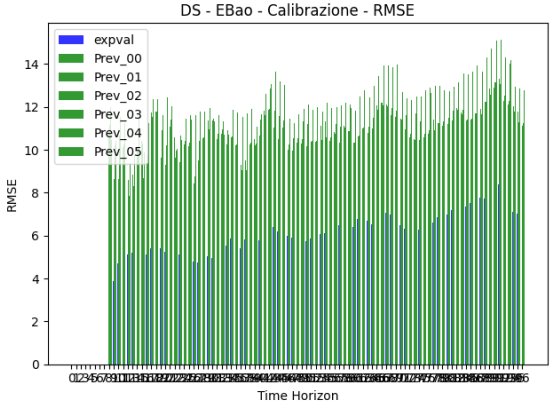
MCP v2.0 statistical indicators for the first calibration
(6 models)

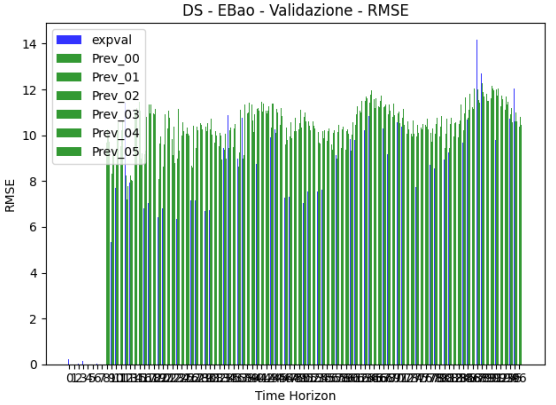
Bias



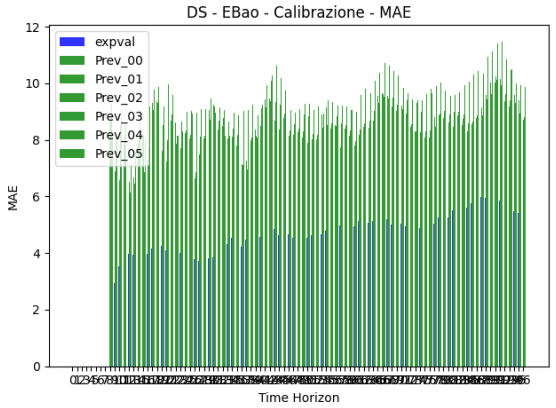


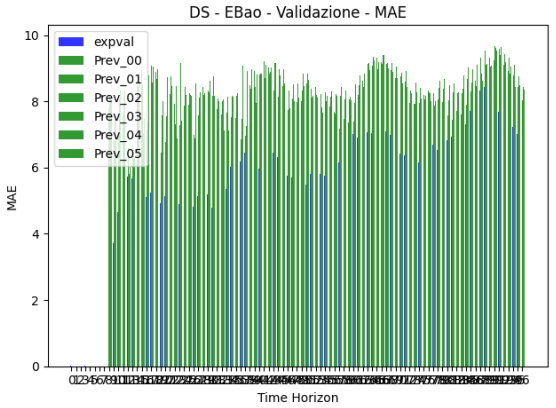
Root Mean Square Error



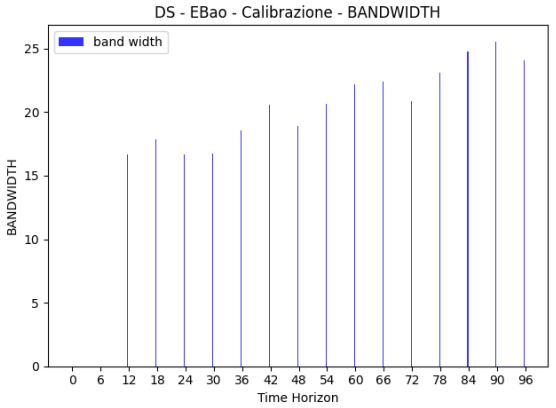


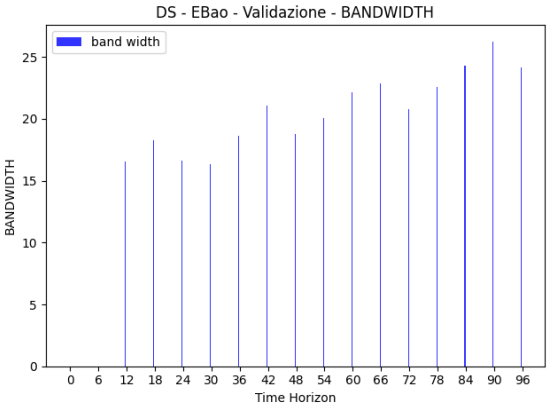
Mean Absolute Error





Band Width



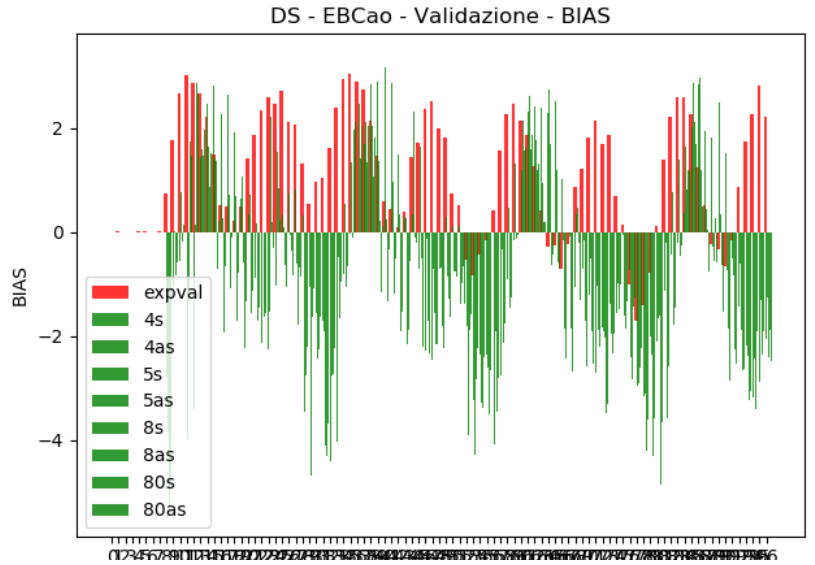


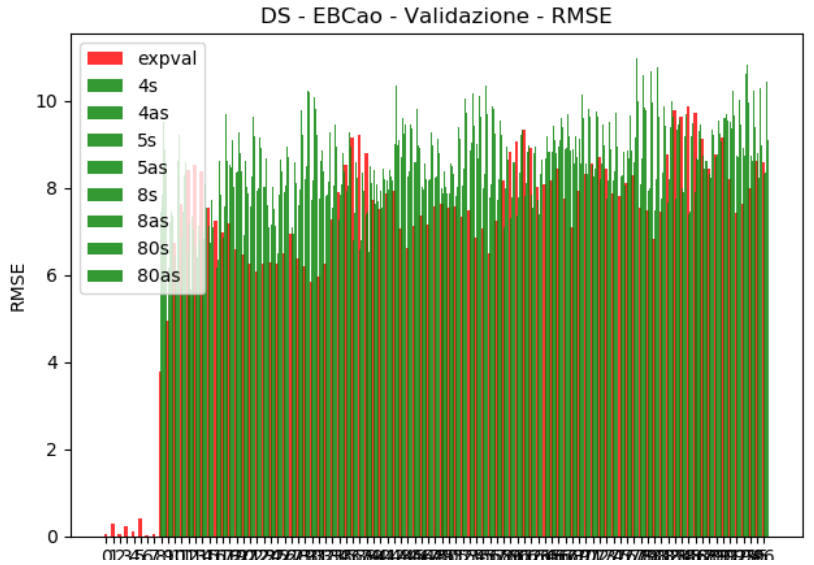
MCP v2.0 performance analysis for the second calibration
(8 models)

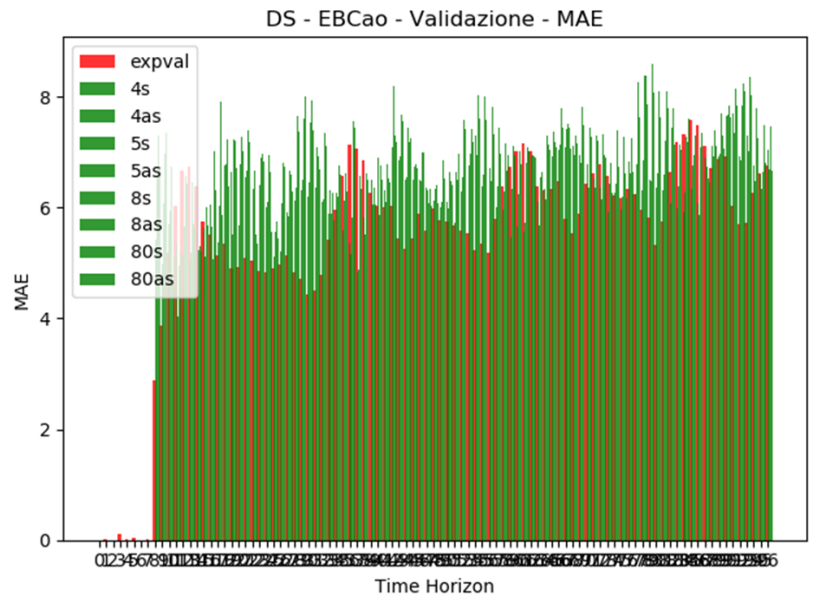
Validation period
01.2022 – 12.2022

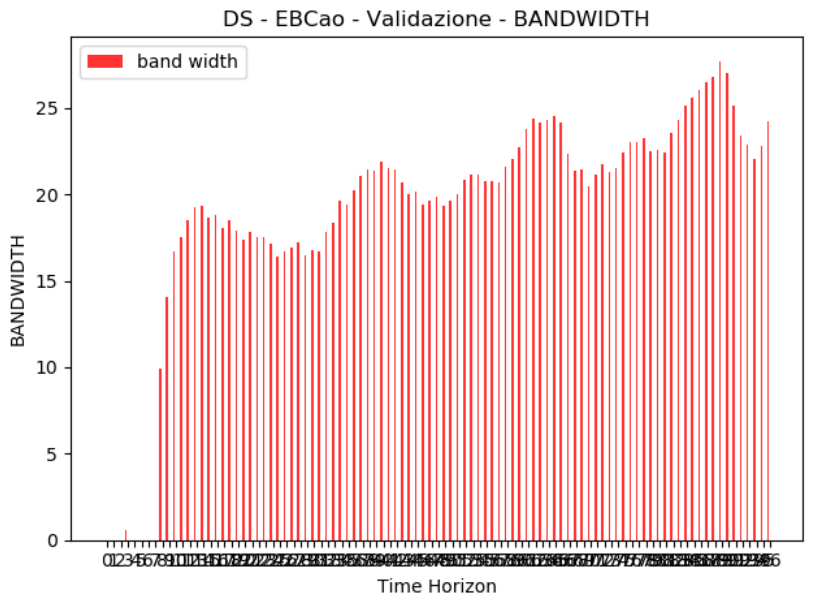
The RMSE and MAE of MCP are less than using all the other models for almost all time steps

Accuracy of forecasts decreases as the time steps increase, as expected (due to the loss of quality in meteorological predictions)









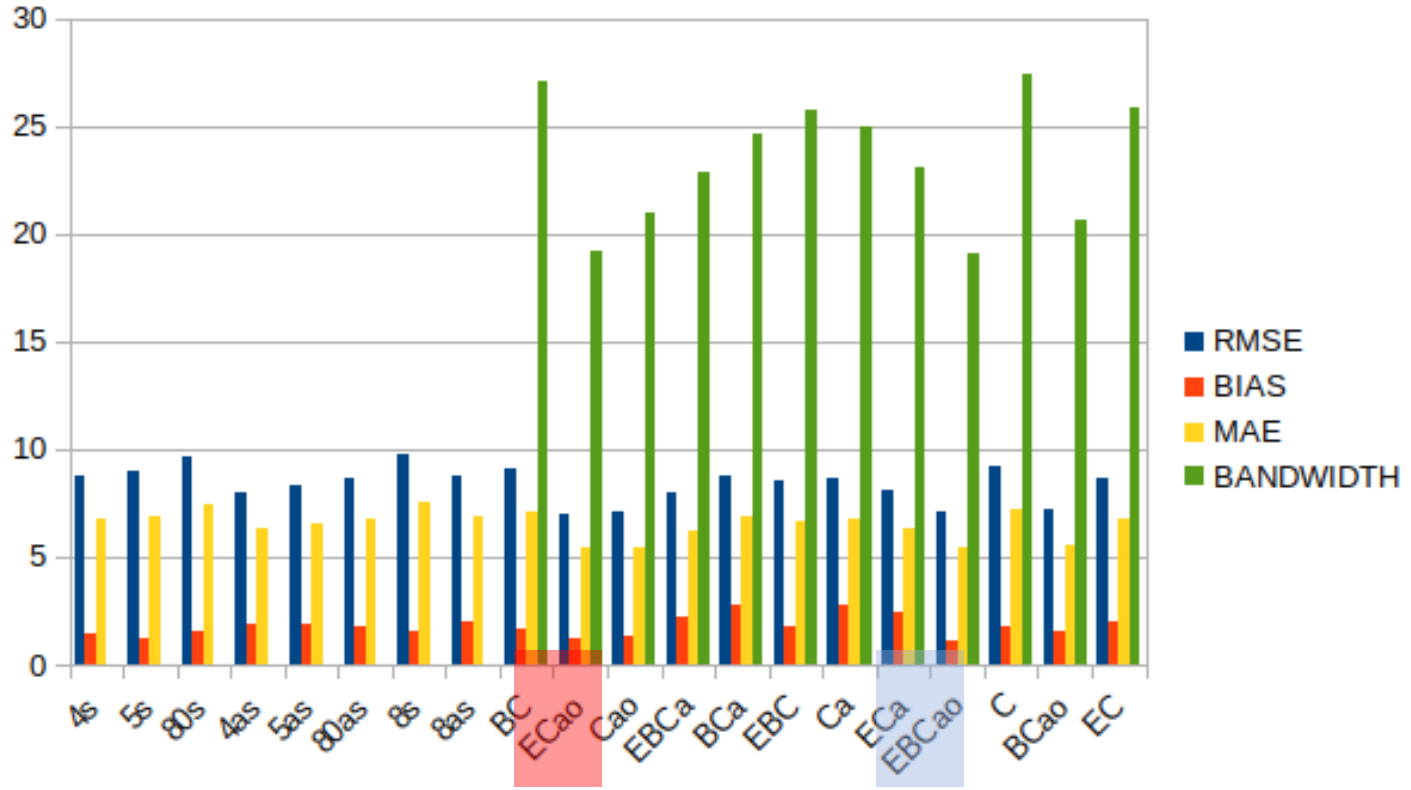
MCP v2.0 performance analysis

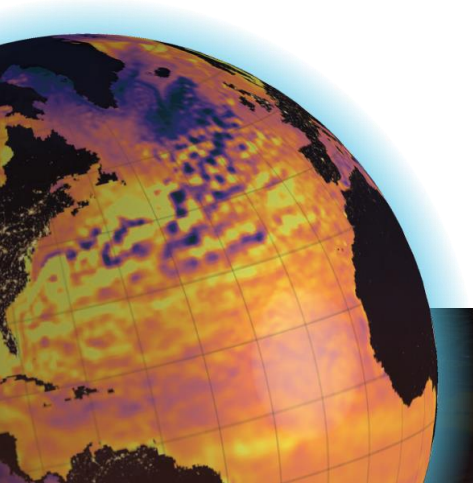
Mean values on 96 hours time steps

EBCao best results for BIAS and BANDWIDTH

ECao best results for RMSE and MAE

Forecast of BOLAM 8s e 8as (indicated as B) do not improve significantly the results





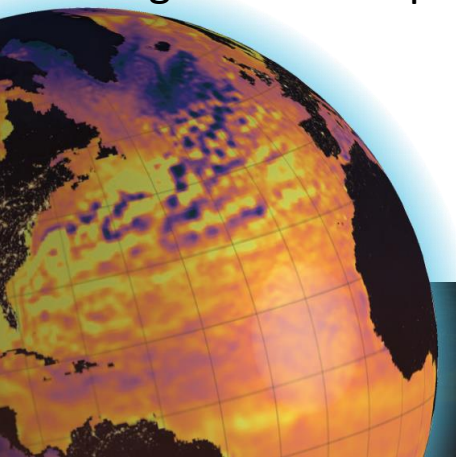
MCP v2.0 performance analysis: episode 1

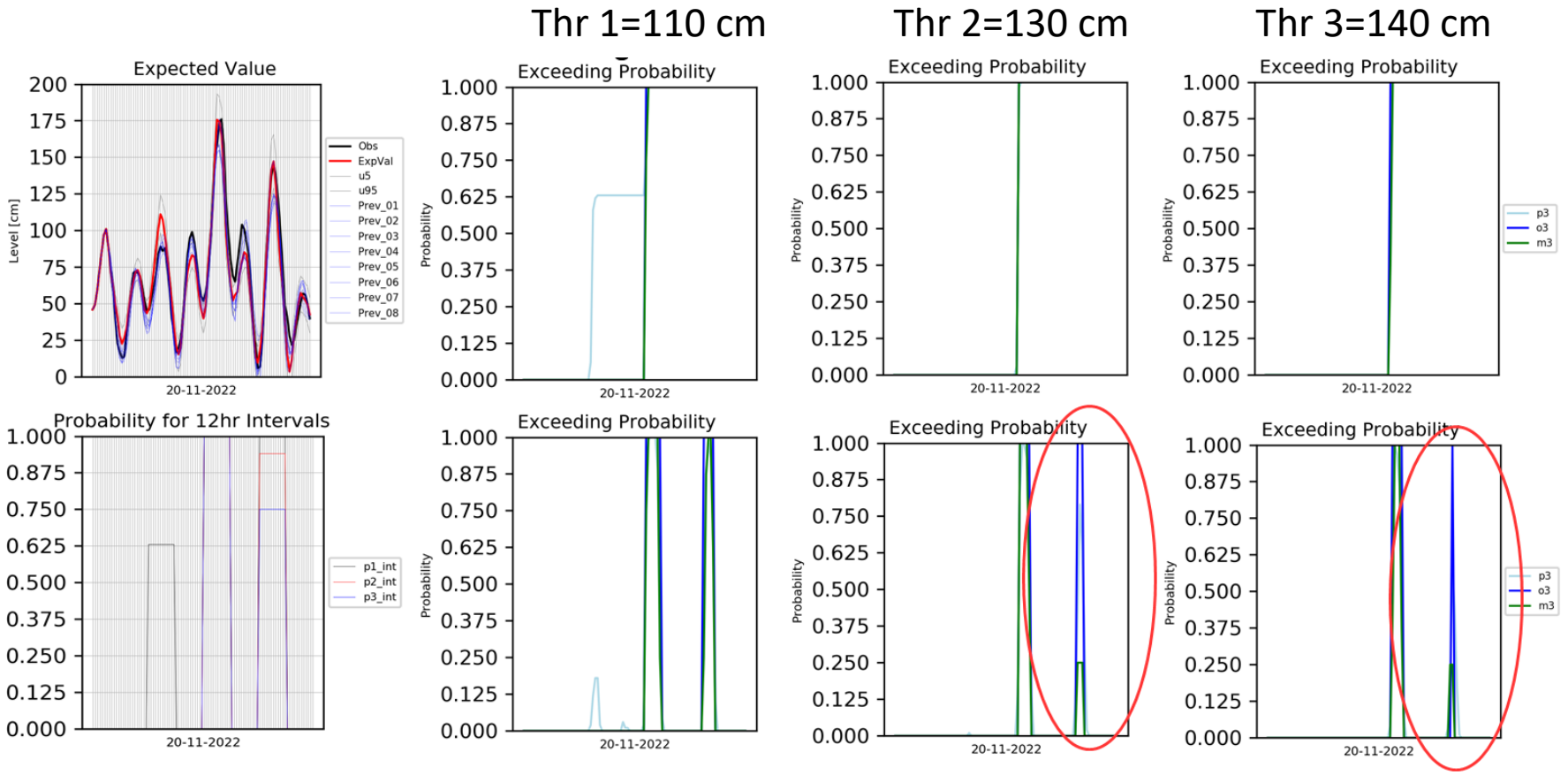
20.11.2022

Higher influence of astronomical component

MCP provides best forecasts for the highest and lowest peaks, with variable performance for medium-intensity peaks.

The exceedance probability is well predicted by all models for the first peak, while for the second peak (80 hours time step), **only two models** predict the exceedance. MCP returns a probability of around 100% for the first peak and 75% and 60% for the two highest thresholds during the second peak.

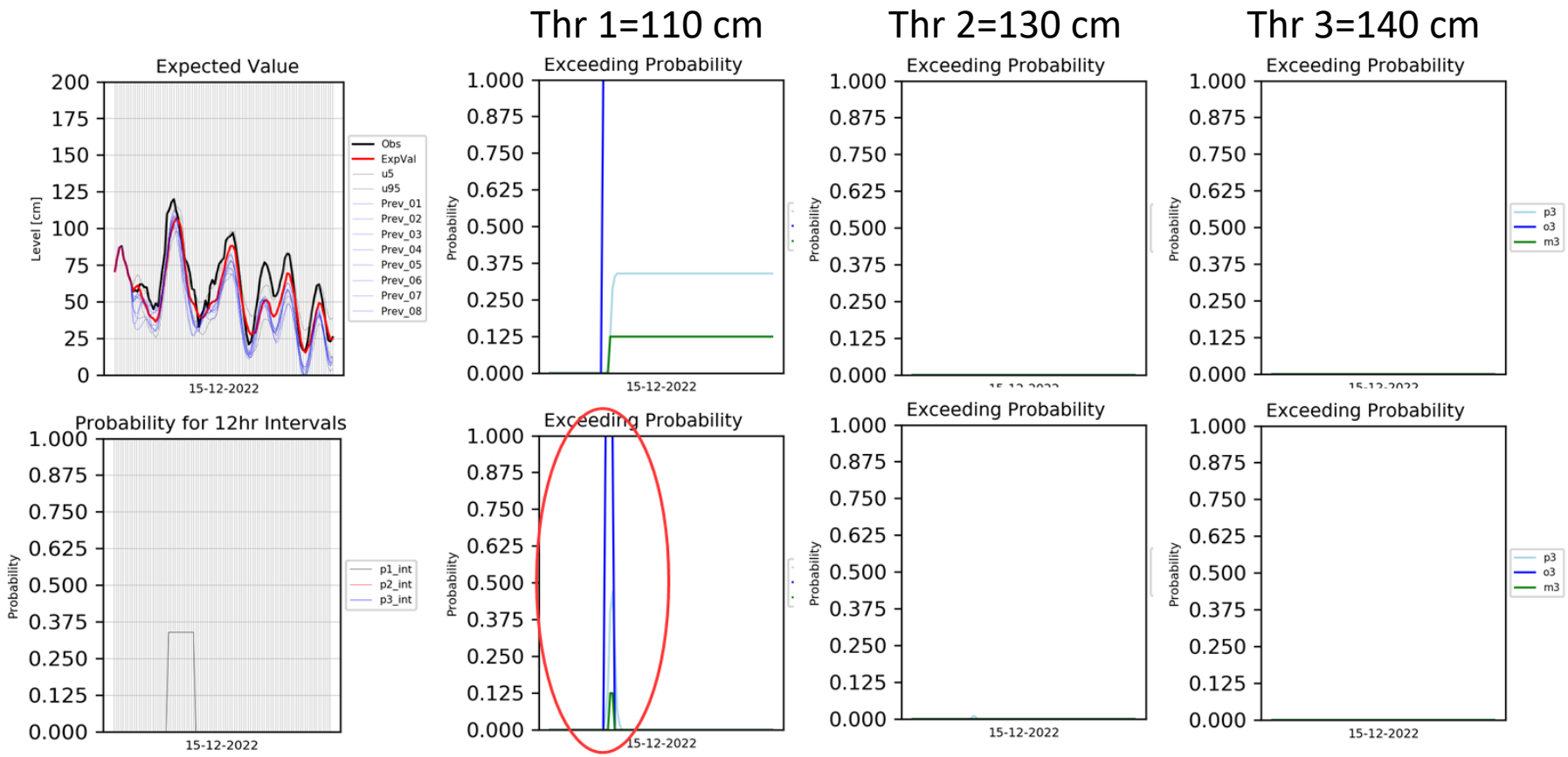




MCP v2.0 performance analysis: episode 2

15.12.2022

Higher influence of meteorological component with respect to the astronomical one, even though with lower peaks. Hence a smaller improvement in MCP forecast (but still better than deterministic forecasts)



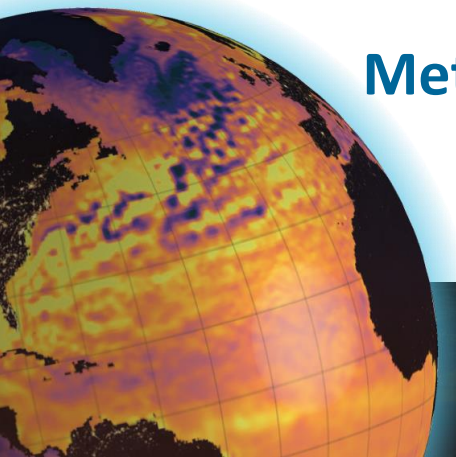
MCP v2.0 performance analysis and hence...

MCP is able to effectively **estimate the uncertainty** of the forecast **and improve the tide prediction**, but it is necessary to differentiate between cases where the meteorological component dominates and those where the astronomical component prevails

CALIBRATION WITH SEPARATED COMPONENTS

Astronomical, lower uncertainty and more frequent prevalence

Meteorological, higher uncertainty and less frequent cases of prevalence



MCP v2.0

New Improvements

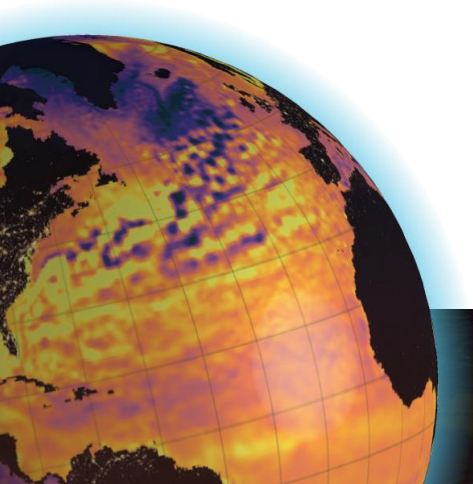
- Thresholds: 110 cm, 130 cm, 140 cm
- **Separated Components (SC)**:

  astronomical with very low associated uncertainty as it can be described by the astronomical laws governing it

  meteorological that has a rather wide uncertainty since it is a stochastic component

Application 1. Calibration Period 2019-2021 Validation Period 2022

Application 2. Calibration Period 2019-2022



Cumulated Probability of threshold exceeding in the next 96 hours

Probability of exceeding for intervals of 1h, 6hrs, 12hrs, 24hrs, 48hrs

MCP v2.0: standard vs SC

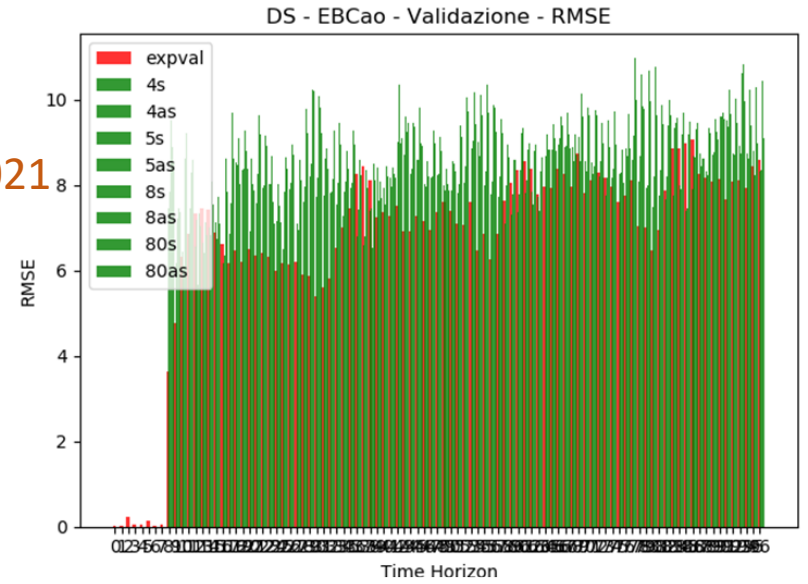
Application 1

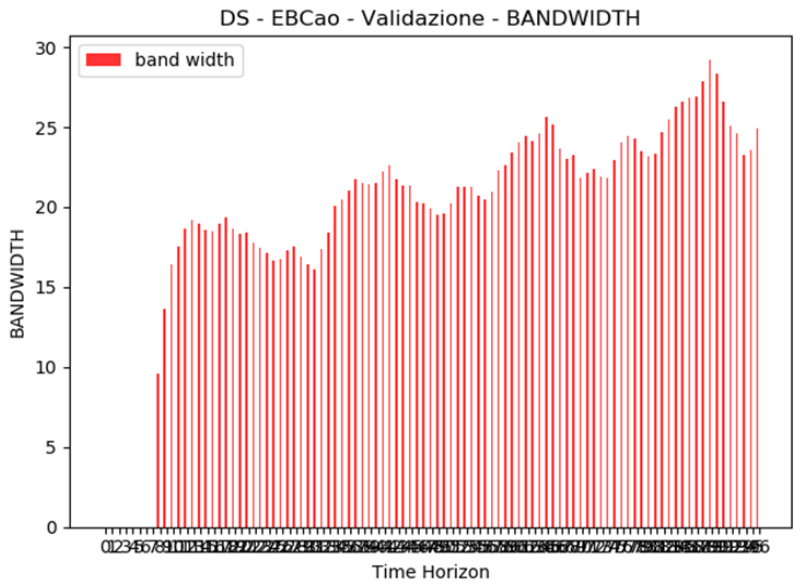
Calibration Period 2019-2021

Validation Period 2022

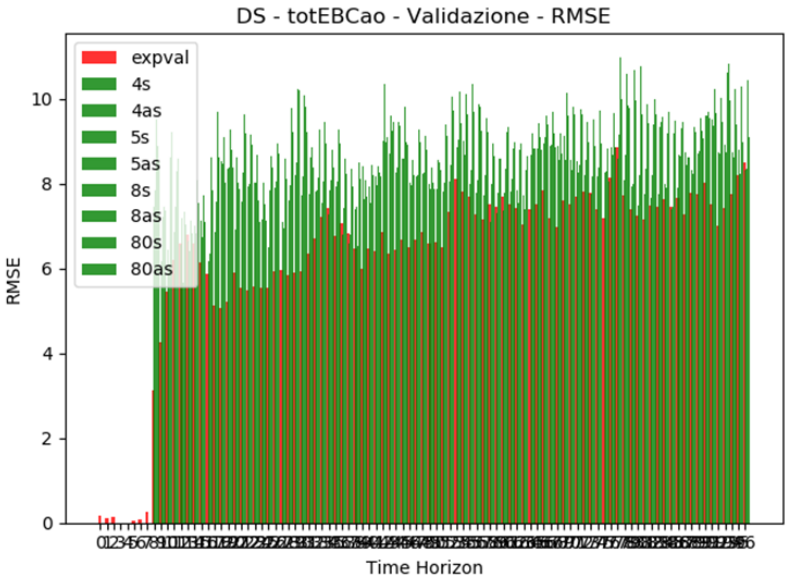
Comparison between standard configuration and with Separated Components(SC) RMSE, BANDWITH

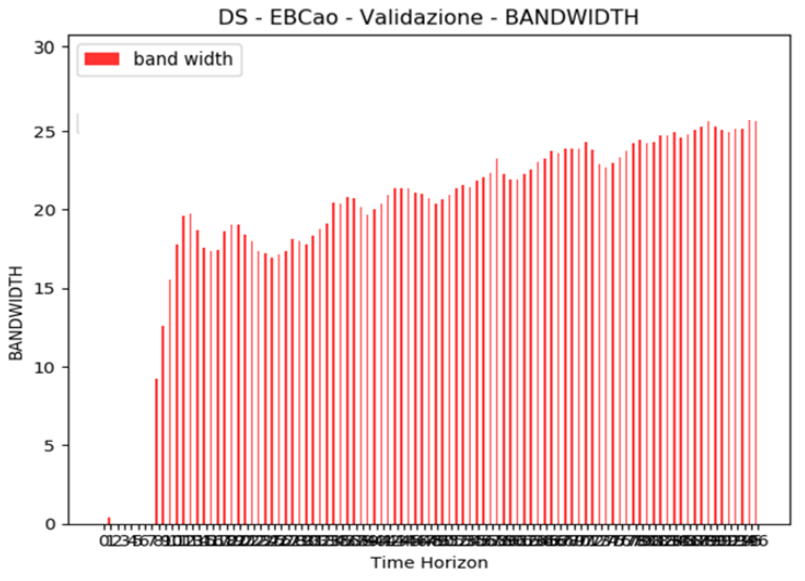
Standard

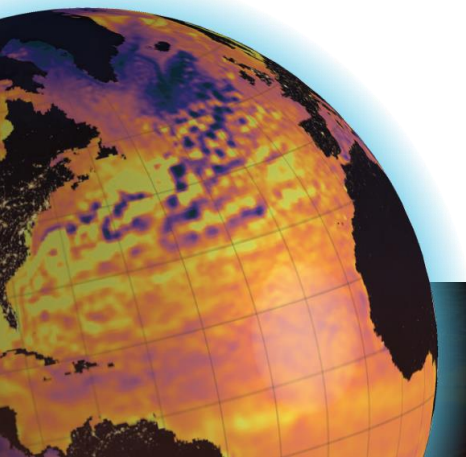




Separated Components (SC)





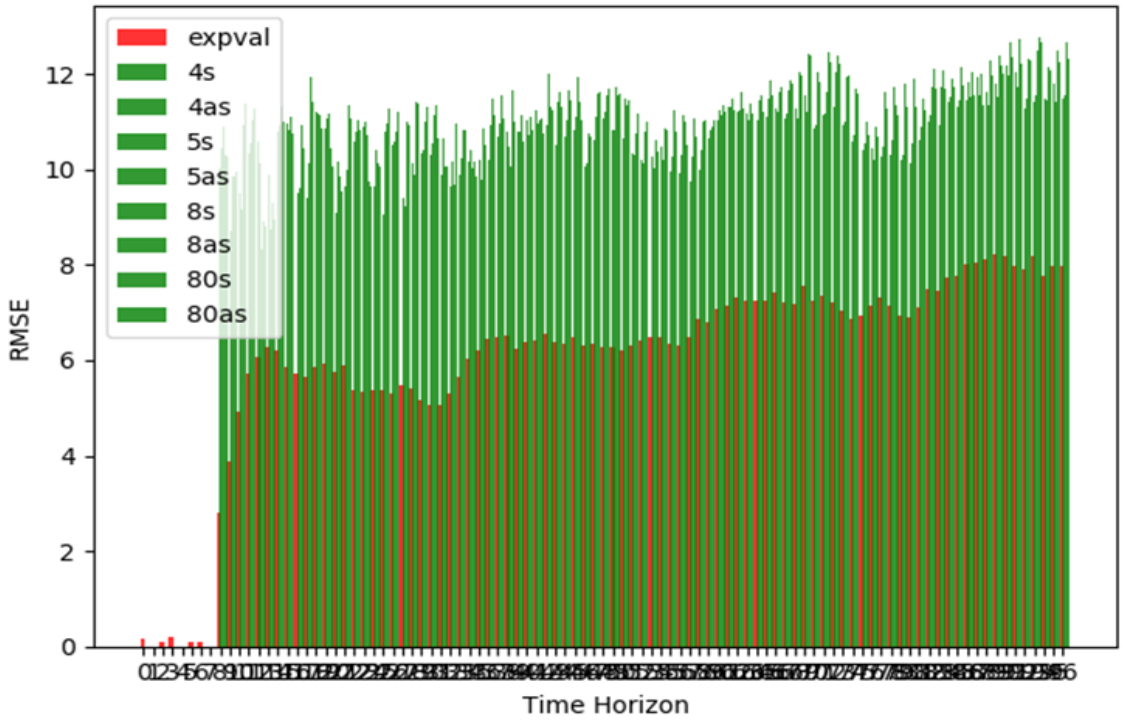


MCP v2.0: standard vs SC and calibration on 2019-2022

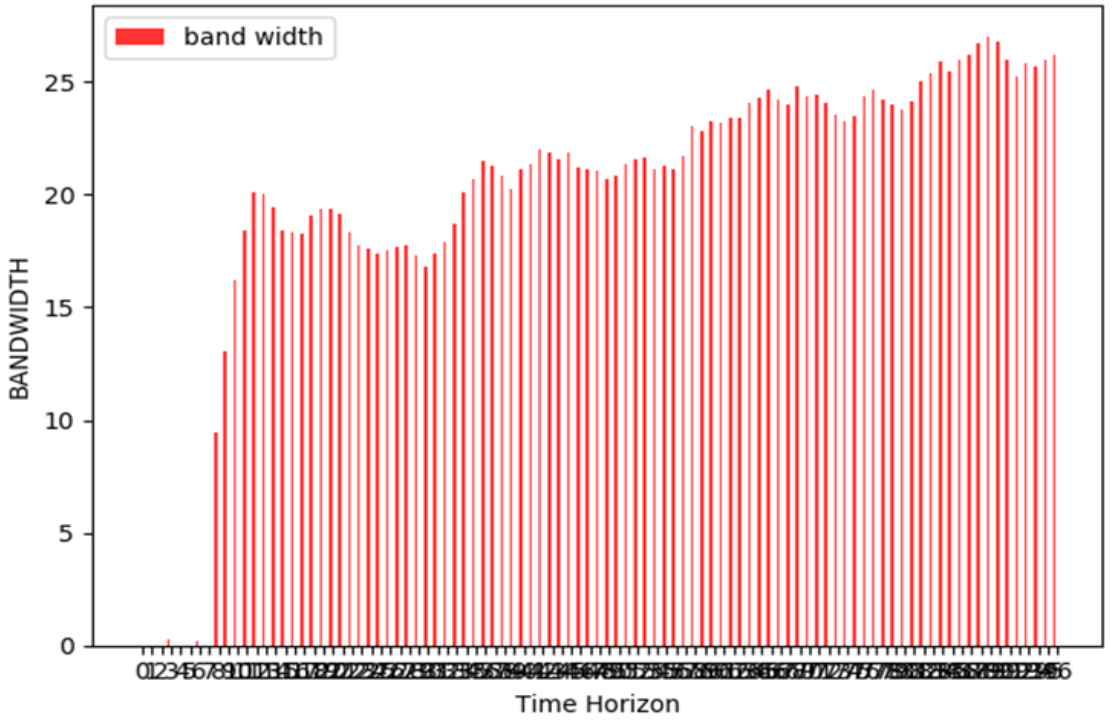
Application 2

Calibration Period 2019-2022

DS EBCao – Calibration Period - RMSE



DS EBCao – Calibration Period - BANDWIDTH



MCP v2.0: standard vs SC

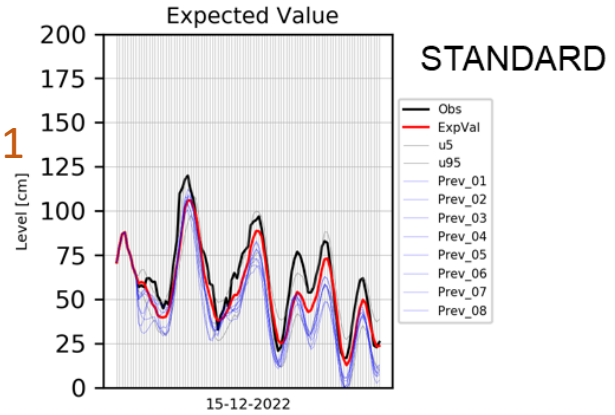
15.12.2022 and 10.08.2022

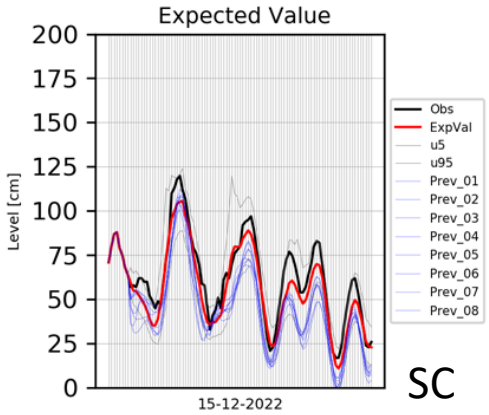
Application 1

Calibration Period 2019-2021

Validation Period 2022

Comparison between standard configuration and with Separated Components(SC) 15.12.2022 and 10.08.2022

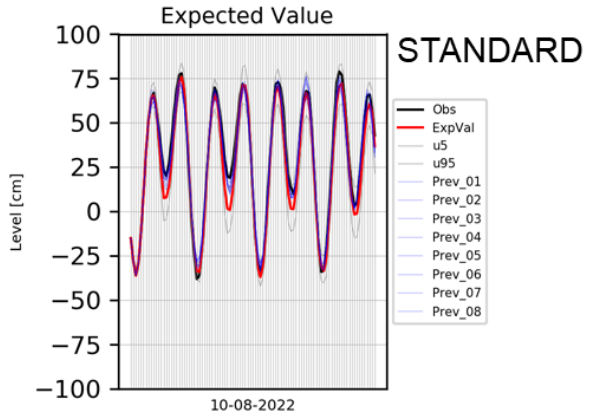


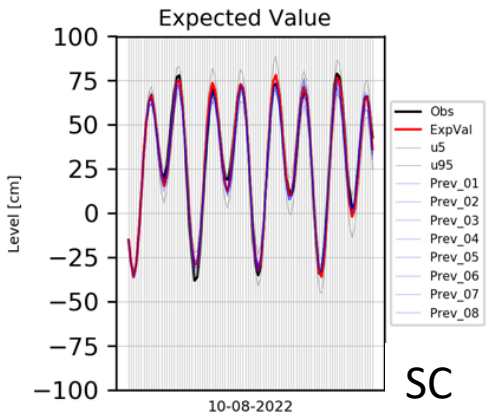


The higher the meteorological effect, the higher the uncertainty

METEOROLOGICAL EFFECT

ASTRONOMICAL EFFECT





The smaller the meteorological effect, the lower the uncertainty

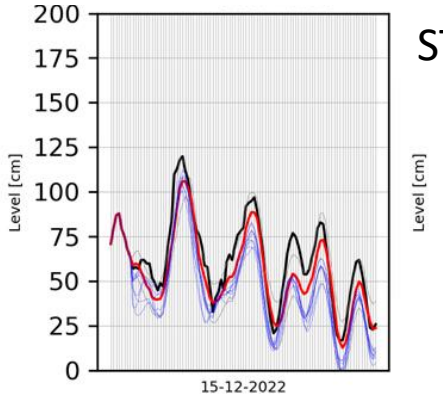
MCP v2.0: standard vs SC and calibration on 2019-2022

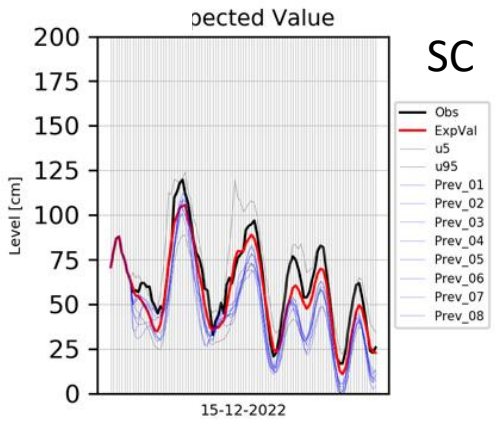
15.12.2022 and 10.08.2022

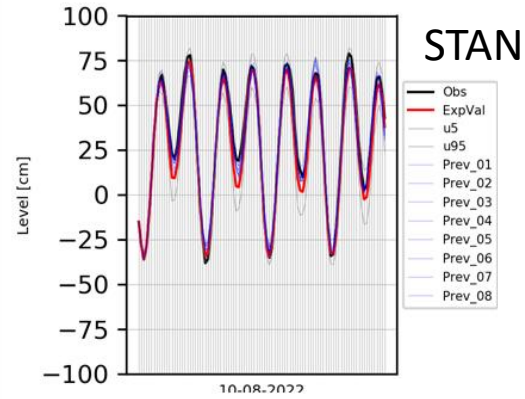
Application 2

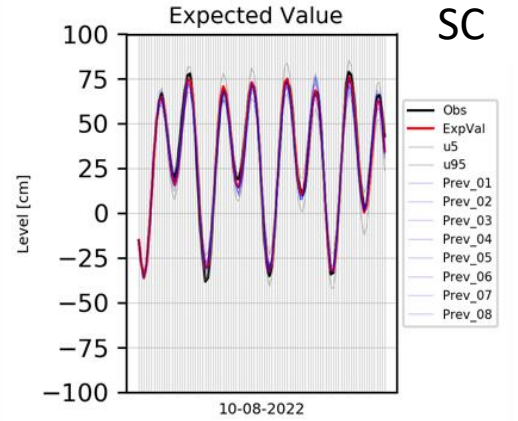
Calibration Period 2019-2022

Comparison between Standard Configuration and Seprated Components (SC) 15.12.2022 and 10.08.2022



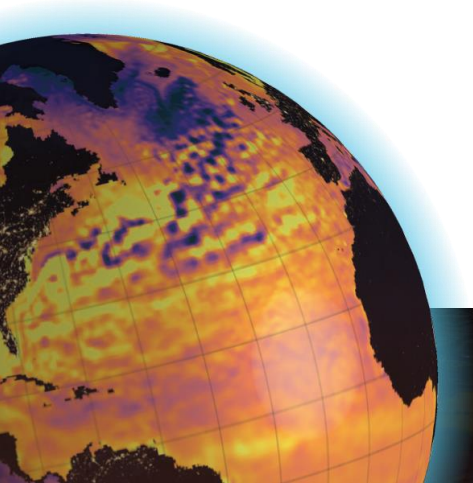






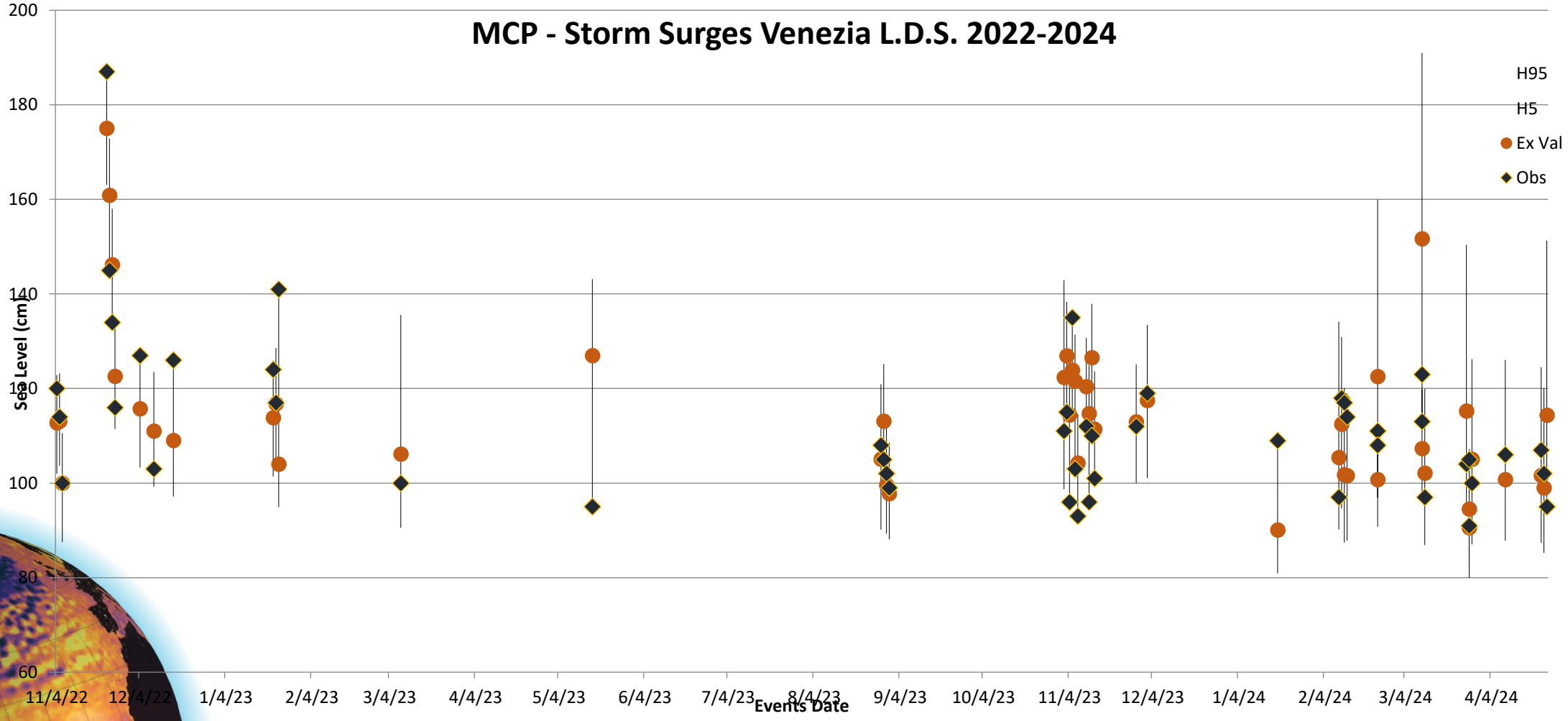
What are we talking about…

- Sea Level: how to forecast and why
  - “ACQUA ALTA” in Venice
- …needing a probabilistic forecast
- Model Conditional Processor v1.0 and v2.0
- Results
  - Analysis of performance
  - Analysis of forecast for the events: 15.12.2022 and 10.08.2022
  - Analysis of storm surges events



Storm surges Events

Extreme events in the period 2022-2024
Alert Bulletin



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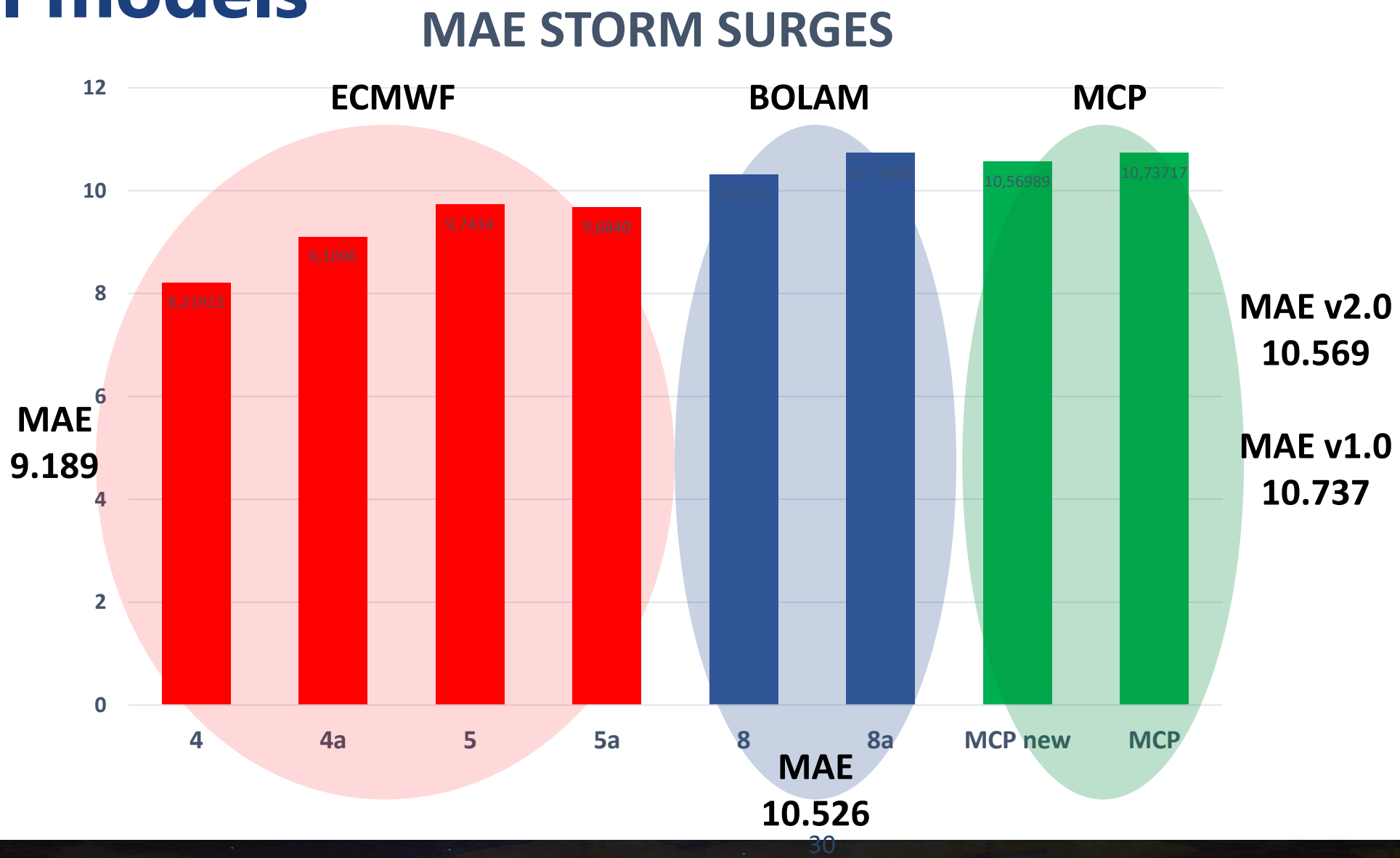
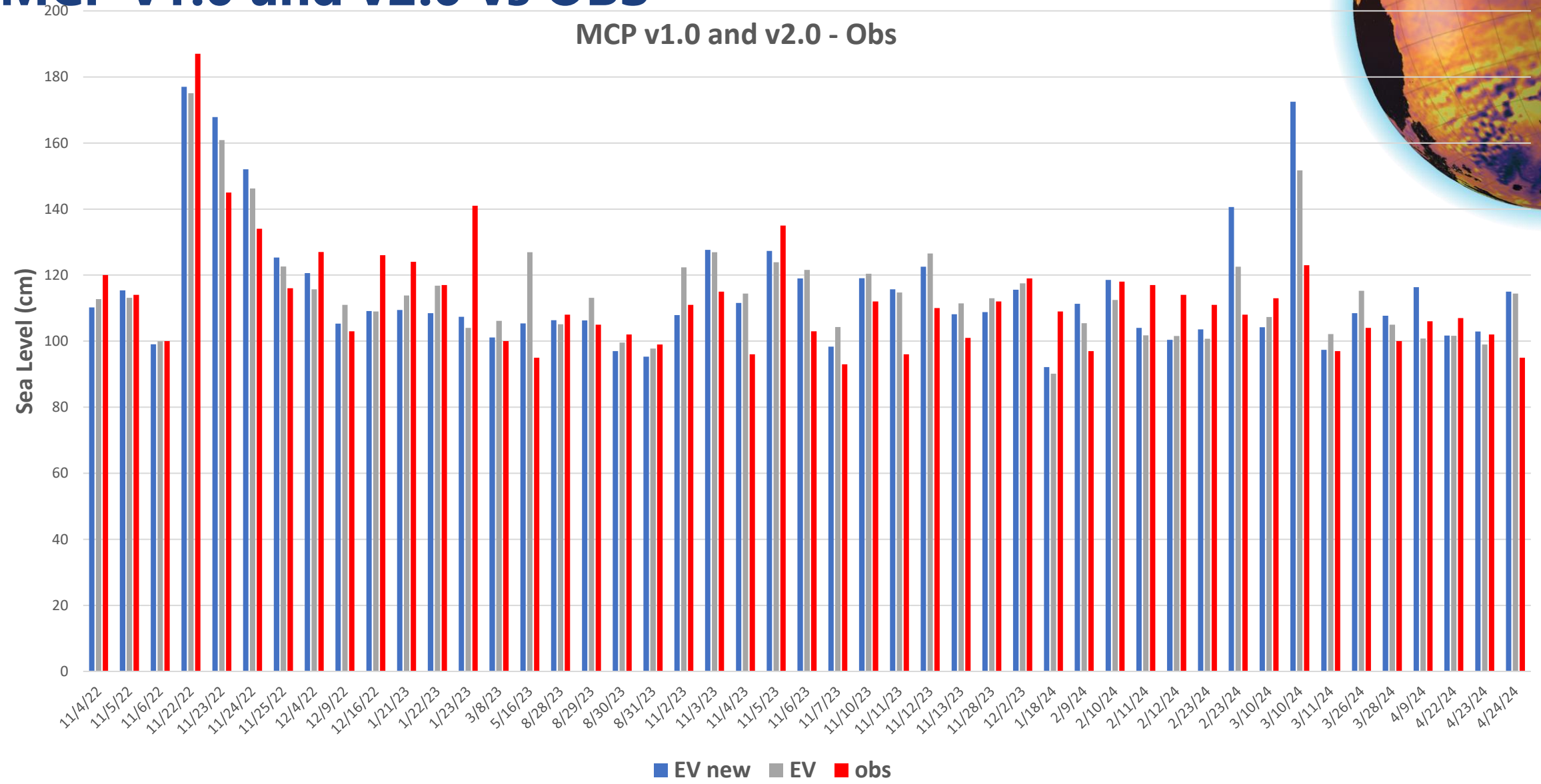
MAE all models

MAE BOLAM, ECMWF, MCP



MCP v1.0 and v2.0 vs OBS



European Commission

Copernicus Marine Service

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INTERNATIONAL OCEAN GOVERNANCE
EU COMPONENT TO GLOBAL OCEAN OBSERVATIONS

MERCATOR OCEAN INTERNATIONAL

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Canada