

Wave Modeling in the Mediterranean Sea: hindcast, forecast and climate projection for engineering applications

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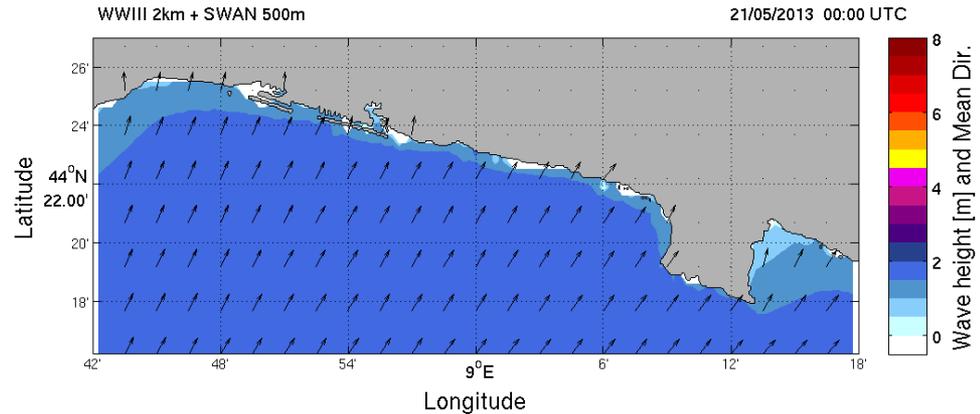
giovanni.besio@unige.it

Modellazione dei processi fisici del mare

Modellazione fisica



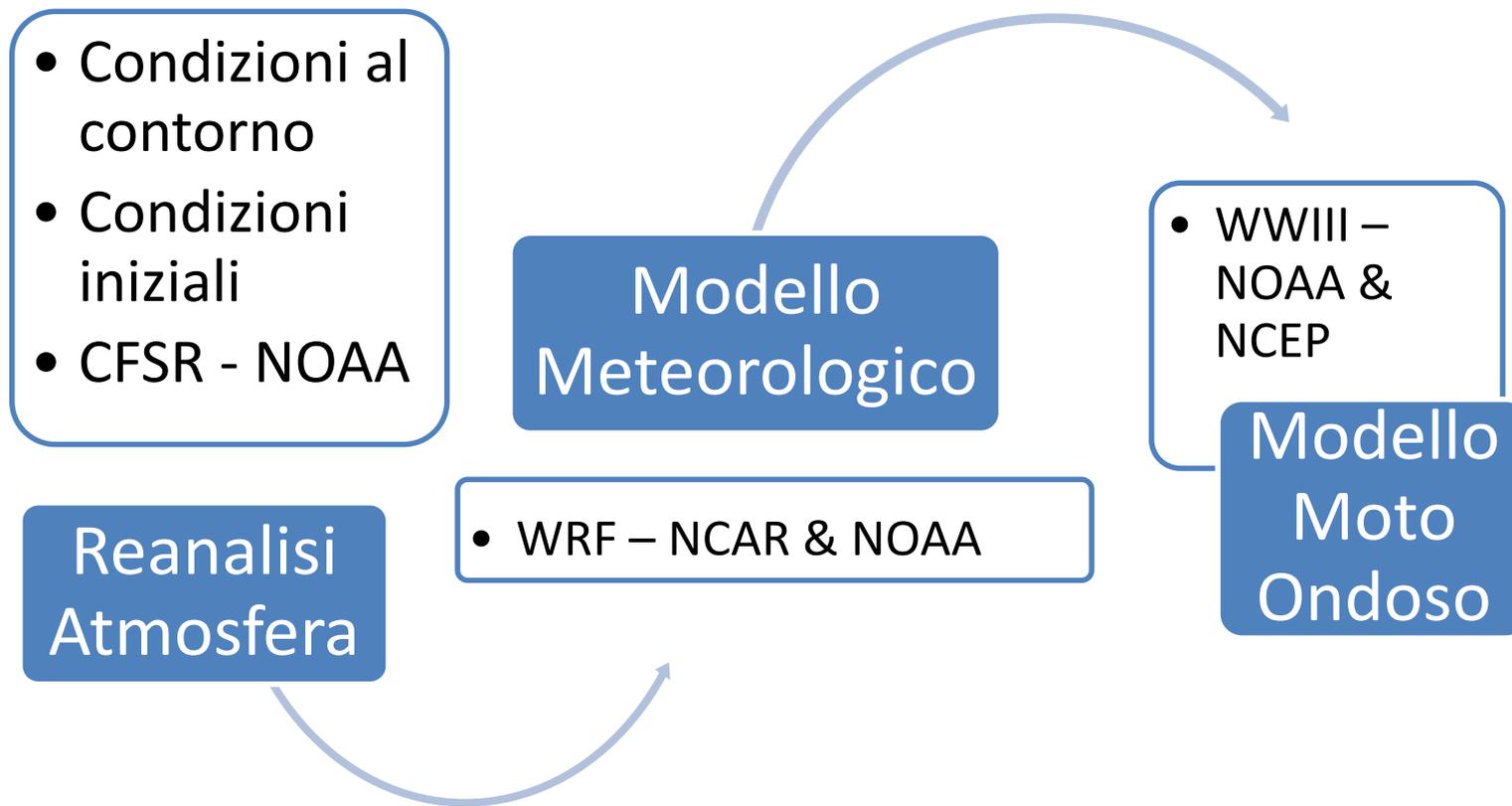
Modellazione numerica



Difficoltà nel reperimento di dati meteo-marini per la valutazione delle sollecitazioni ambientali



Catena modellistica

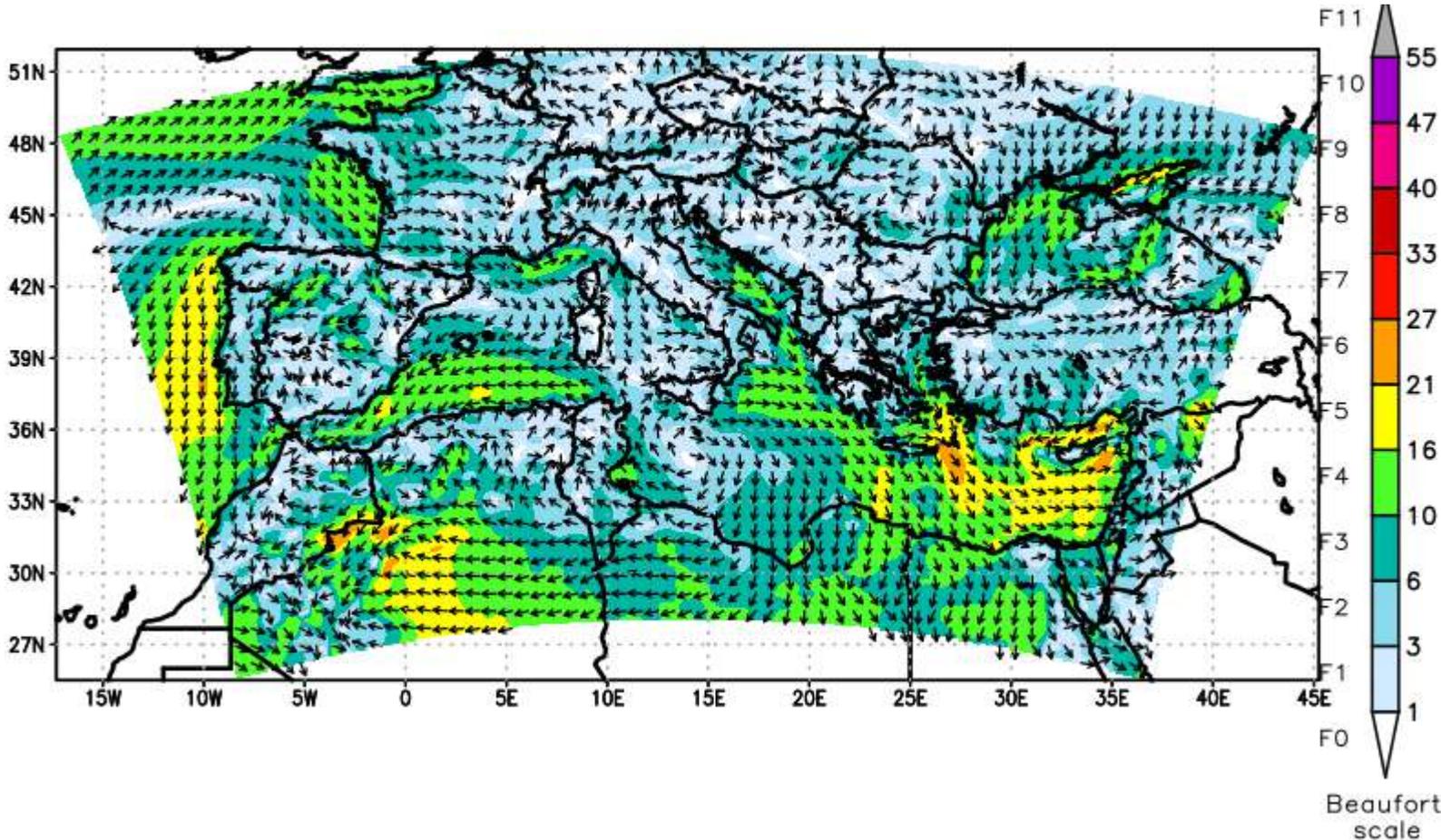


Catena modellistica

Modello Meteorologico

Forzanti prese dal Global Forecast System (GFS) in previsione e dal Climate Forecast System Reanalysis (CFSR) a una risoluzione di 0.5° ogni 24 ore per la previsione e la reanalisi rispettivamente

Le condizioni sul contorno vengono imposte ogni tre ore, mentre le condizioni iniziali ogni 24



Catena modellistica

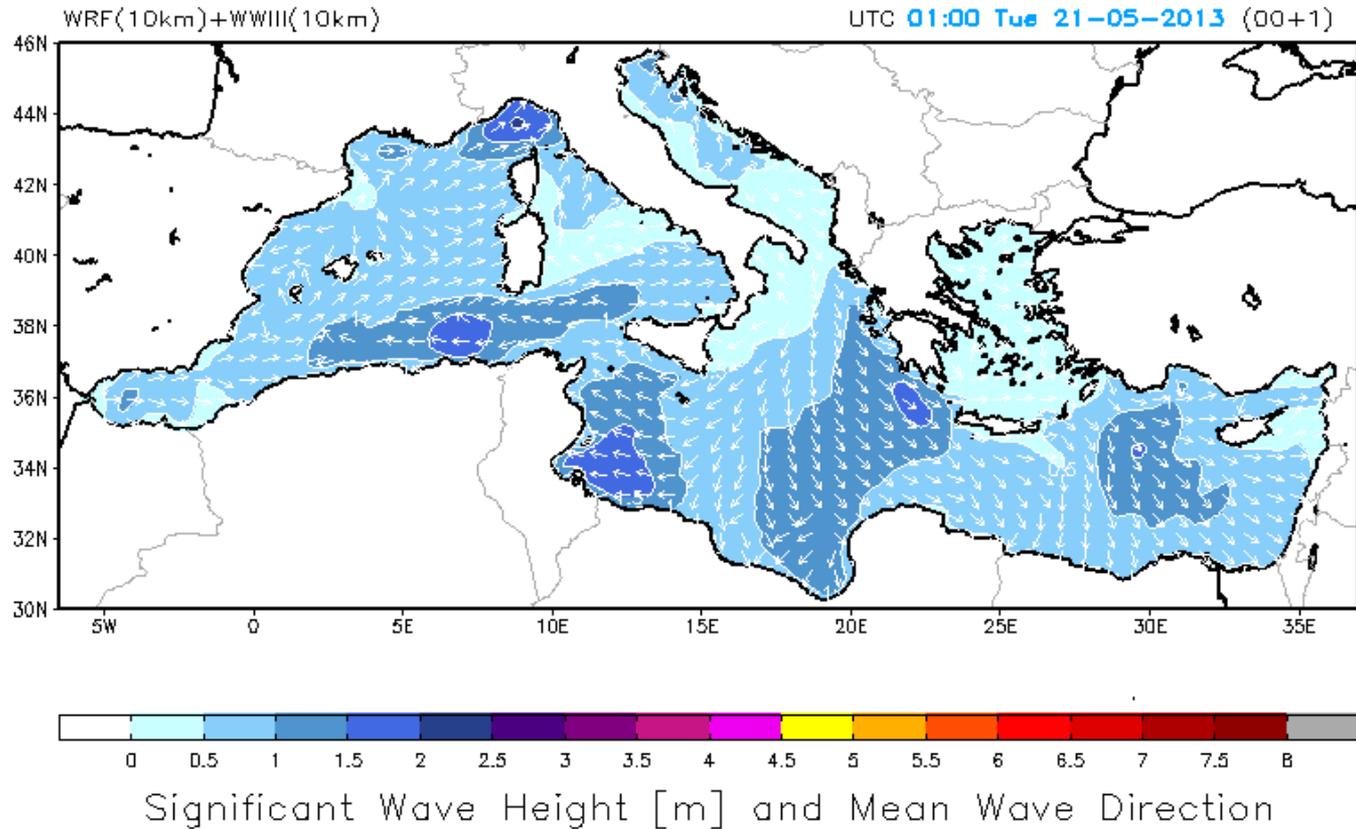
Modello d'onda WWIII
con risoluzione 0.1°
nel Mediterraneo

Modello spettrale di
terza generazione, in
grado di descrivere la
crescita, smorzamento
ed effetti non lineari
all'interno dello
spettro

La forzante consiste
nei campi di vento a
10 metri su base
oraria ottenuti con il
modello atmosferico

Uscite orarie su tutto il dominio per quanto riguarda le grandezze integrate sullo spettro. Gli spettri sono salvati in corrispondenza dei punti boa (RON e REDXET)

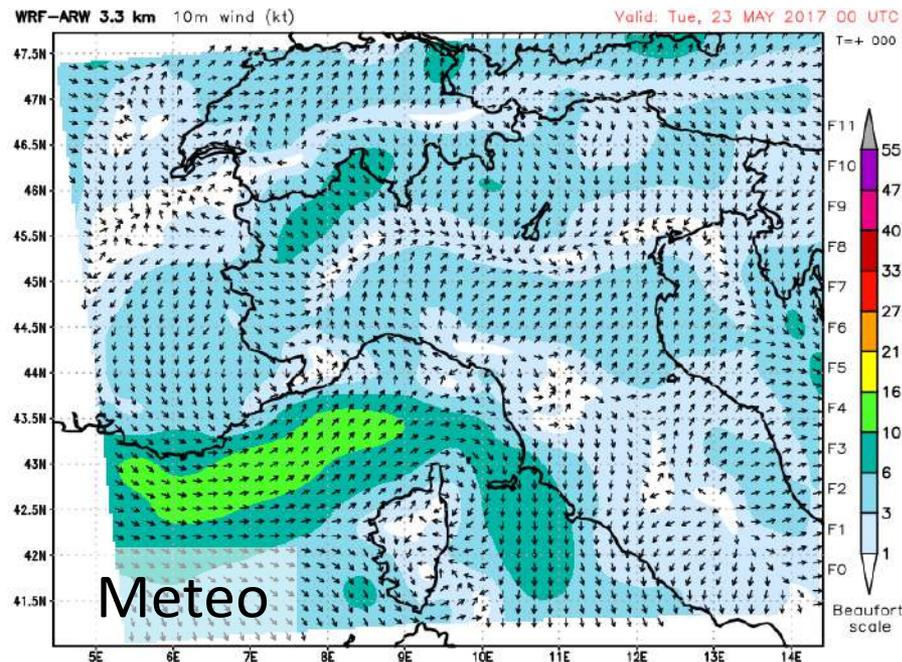
DICCA – University of Genoa



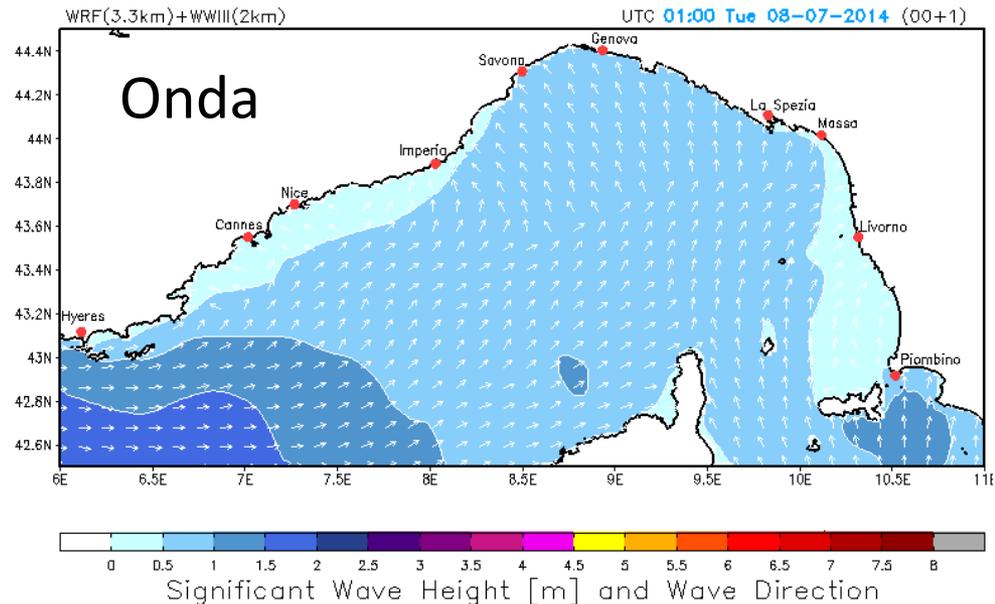
Catena modellistica

In previsione viene realizzato un downscaling a circa 3.3km per la componente meteorologica e a 2km per quella ondoso nel bacino dell'alto Tirreno

2 corse al giorno
(0.00 & 12.00 UTC)

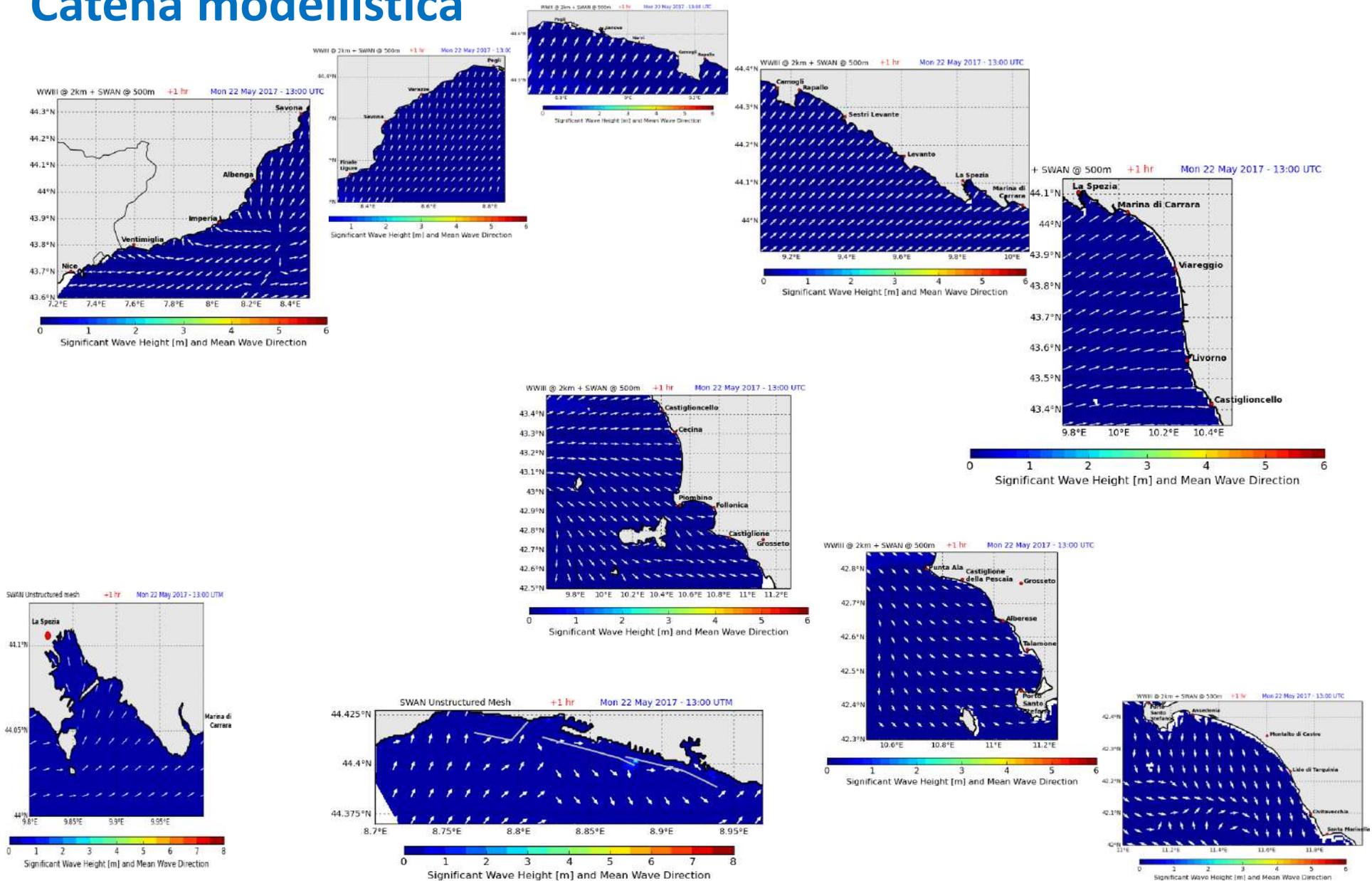


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In previsione le simulazioni sono estese a 5 giorni con uscite orarie

Catena modellistica





MeteOcean Wave Forecast ... x +
www.dicca.unige.it/meteocean/ Google



Dipartimento di Ingegneria
Civile, Chimica e Ambientale

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- MeteOcean
- Model & Services
- Wave Forecast
- Weather Forecast
- Regatta
- Webcams
- Publications
- People
- Hindcast 1979-2010

YOUR SPOT

Select your spot to view the forecast's graph

Italy
Liguria
Genova

GRAPHS TABLE

Harbour entrance forecast

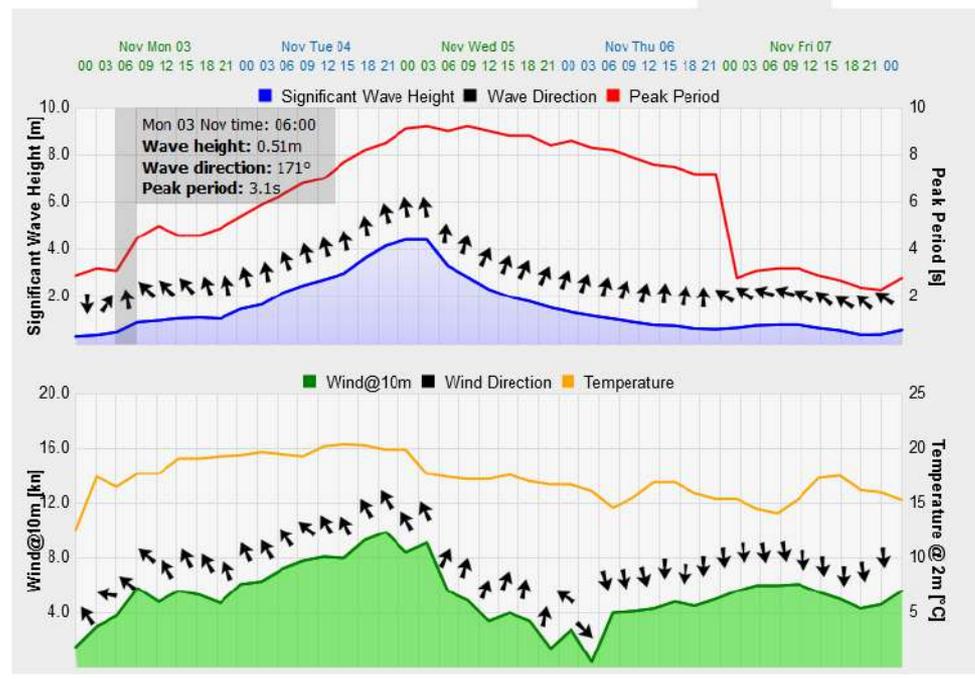
Savona
Genova
La Spezia



MeteOcean
Like 157

23,830	82
796	69
395	55
262	48
222	47
200	45
185	35
104	34
94	33

FLAG counter



NEWS

- 01/07/2014 We are famous! We have been interviewed!
- 01/07/2014 Weather and Wave forecast @ 5 days with 2 runs per day (00:00 and 12:00 UTC)
- 26/11/2013 Wave hindcast 1990-2010 for the whole Mediterranean basin available at a 0.1° resolution
- 16/05/2013 Last mile propagation for Ligurian Coast Available

WAVE FORECAST AND HINDCAST

Validazione e Ottimizzazione

Il modello WavewatchIII è stato validato e ottimizzato sulla base dei dati delle reti di boe italiane, francesi, greche e spagnole

Utilizzo di diversi termini sorgente

- Ardhuin et al. (2010), conosciuti come ACC350
- Tolman & Chalikov (1996)
- Bidlot et al. (2005)

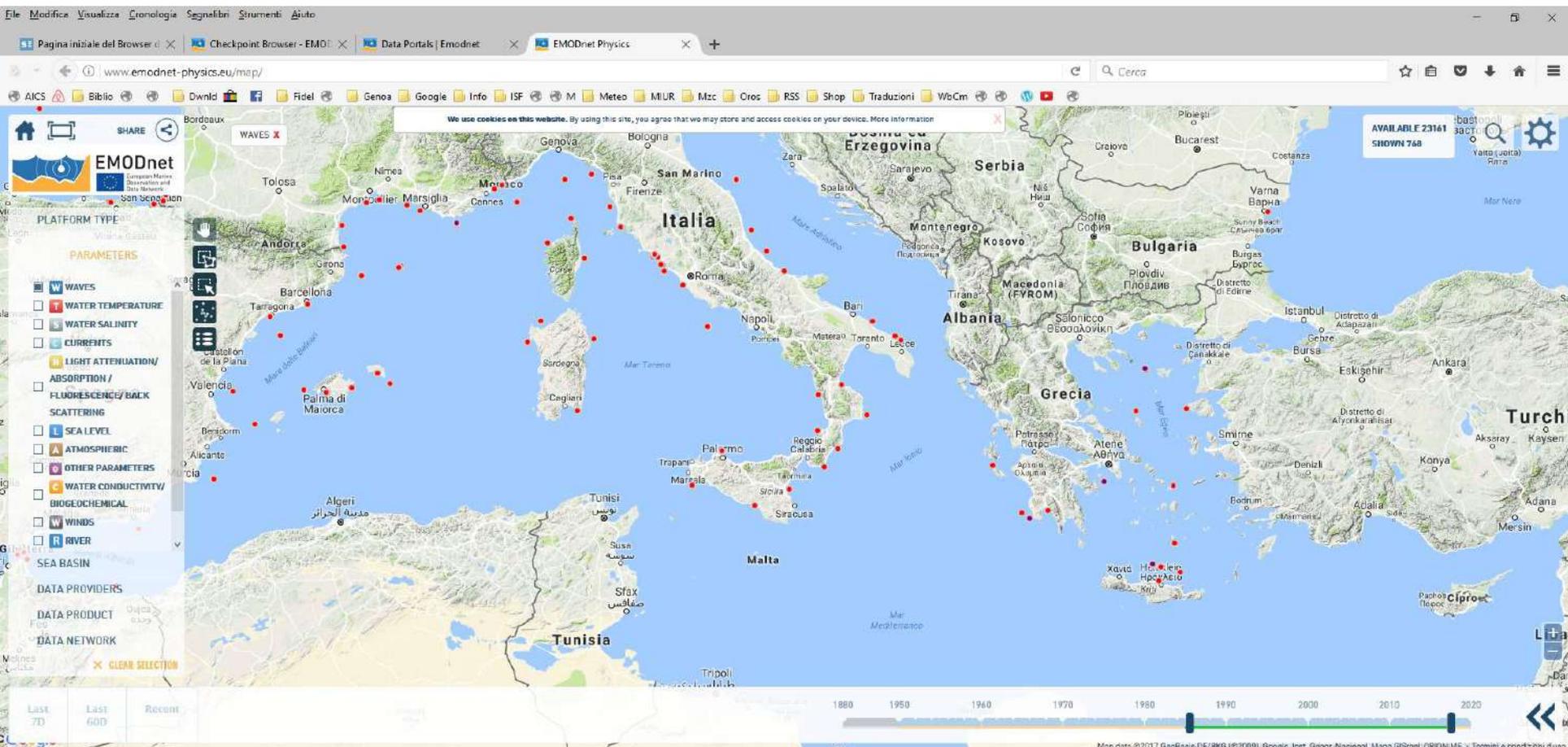
$$\frac{\partial N}{\partial t} + \frac{1}{\cos \phi} \frac{\partial}{\partial \phi} \dot{\phi} N \cos \theta + \frac{\partial}{\partial \lambda} \dot{\lambda} N + \frac{\partial}{\partial k} \dot{k} N + \frac{\partial}{\partial \theta} \dot{\theta}_g N = \frac{S}{\sigma}$$

Analisi di sensitività per la parametrizzazione ACC350 (41 scenari)

Confronto con utilizzo di diversi modelli atmosferici (WRF vs BOLAM)

Analisi degli effetti della risoluzione del modello atmosferico e del modello del moto ondoso (serve sempre aumentare la risoluzione???)

Validazione e Ottimizzazione



Validazione e Ottimizzazione

Indicatori statistici utilizzati

Bias normalizzato (NBI) $NBI = \frac{(\bar{S} - \bar{O})}{\bar{O}}$

Errore quadratico medio normalizzato (NRMSE) $NRMSE = \sqrt{\frac{(S - O)^2}{\bar{O}^2}}$

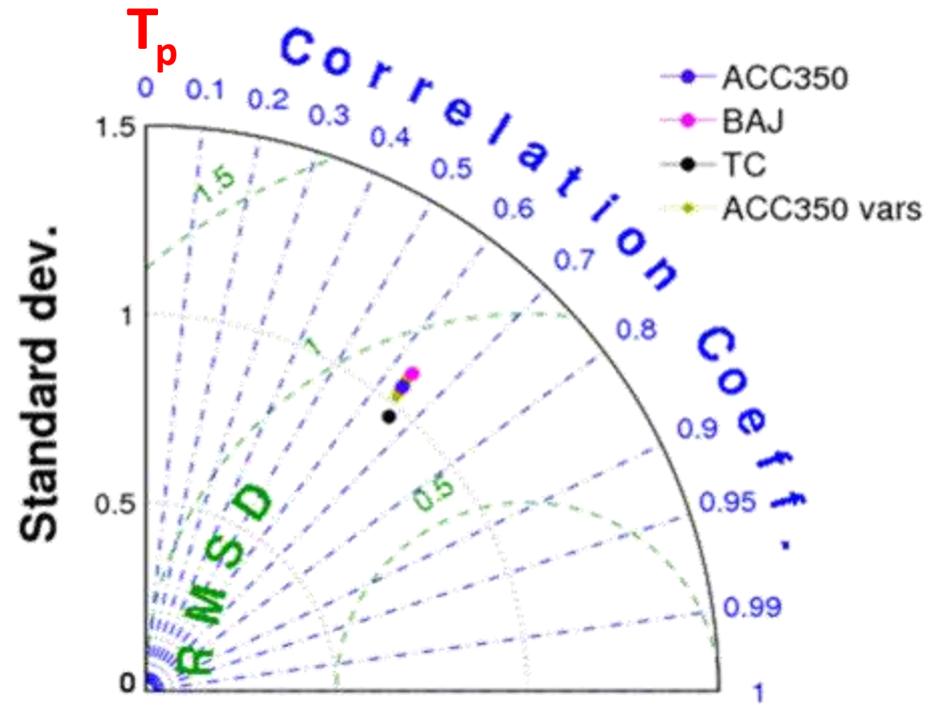
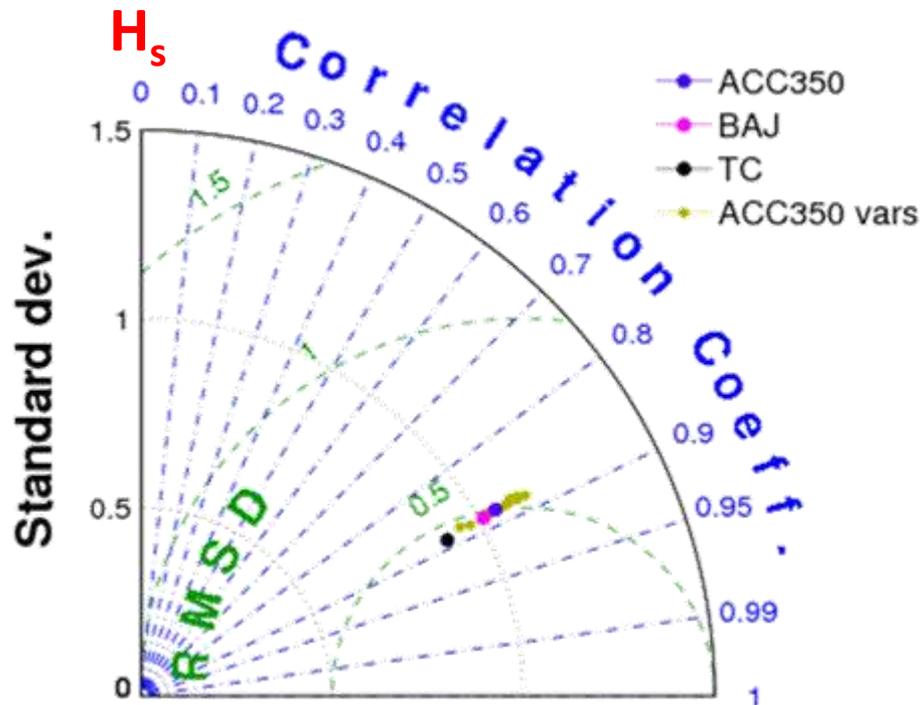
Errore quadratico medio (RMSE)

$$RMSE = \sqrt{(S - O)^2}$$

Correlazione (ρ)

$$\rho = \frac{\sum (S_i - \bar{S})(O_i - \bar{O})}{N\sigma_s\sigma_o}$$

Diagrammi di Taylor per H_s e T_p



Forecast

Storm Hazard Index

Besio, G., Donini, L., Gallino, S., Onorato, L. 2015 A prompt index for sea storm hazards, SCACR Proceedings, pp. 385-395

Indice pericolosità moto ondoso utilizzabile in condizioni operative di previsione (in collaborazione con ARPA Liguria)

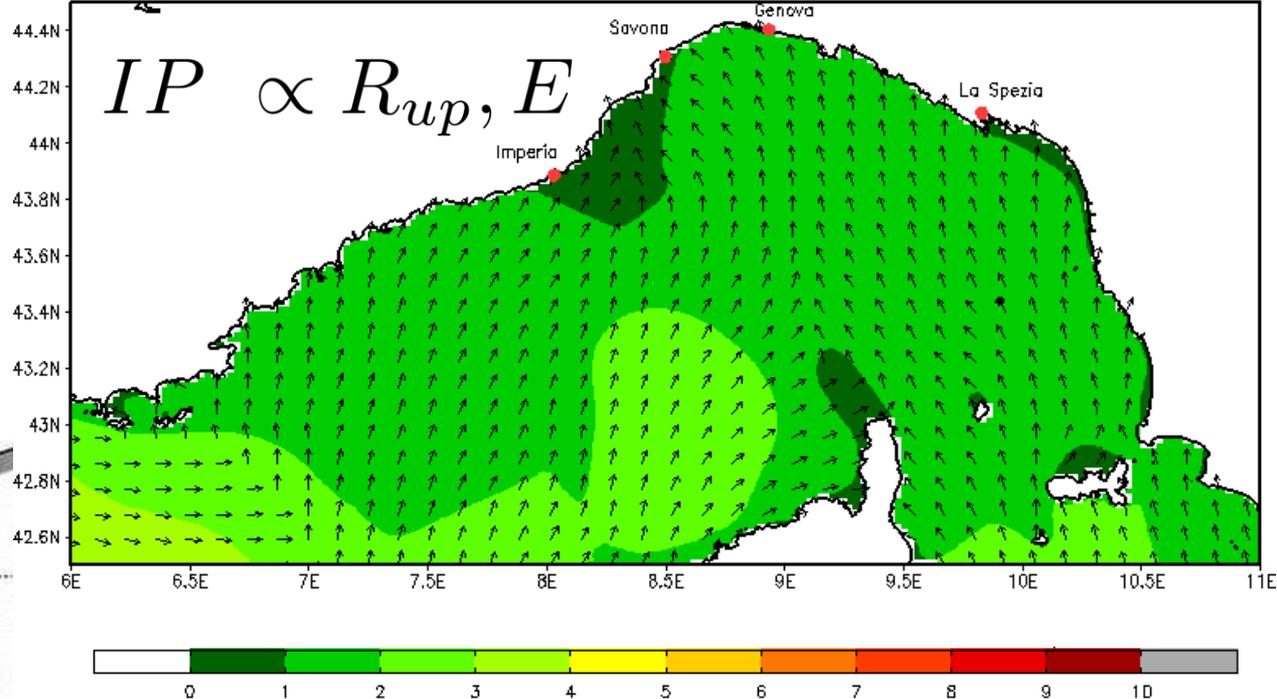


Prerequisiti: indicazioni di pericolosità (protezione civile)
senza carico computazionale

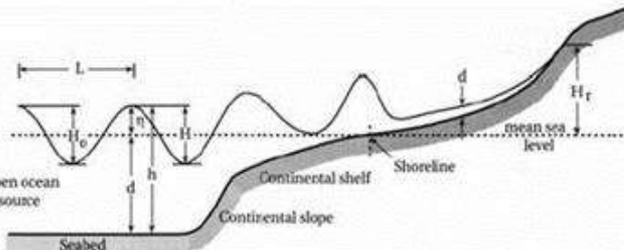
Filosofia

Il pericolo per strutture e persone nelle aree costiere è provocato principalmente dalla risalita del moto ondoso (run-up) sulla spiaggia

WRF(3.3km)+WWIII(2km) UTC 22:00 Tue 28-10-2008 (00+70)



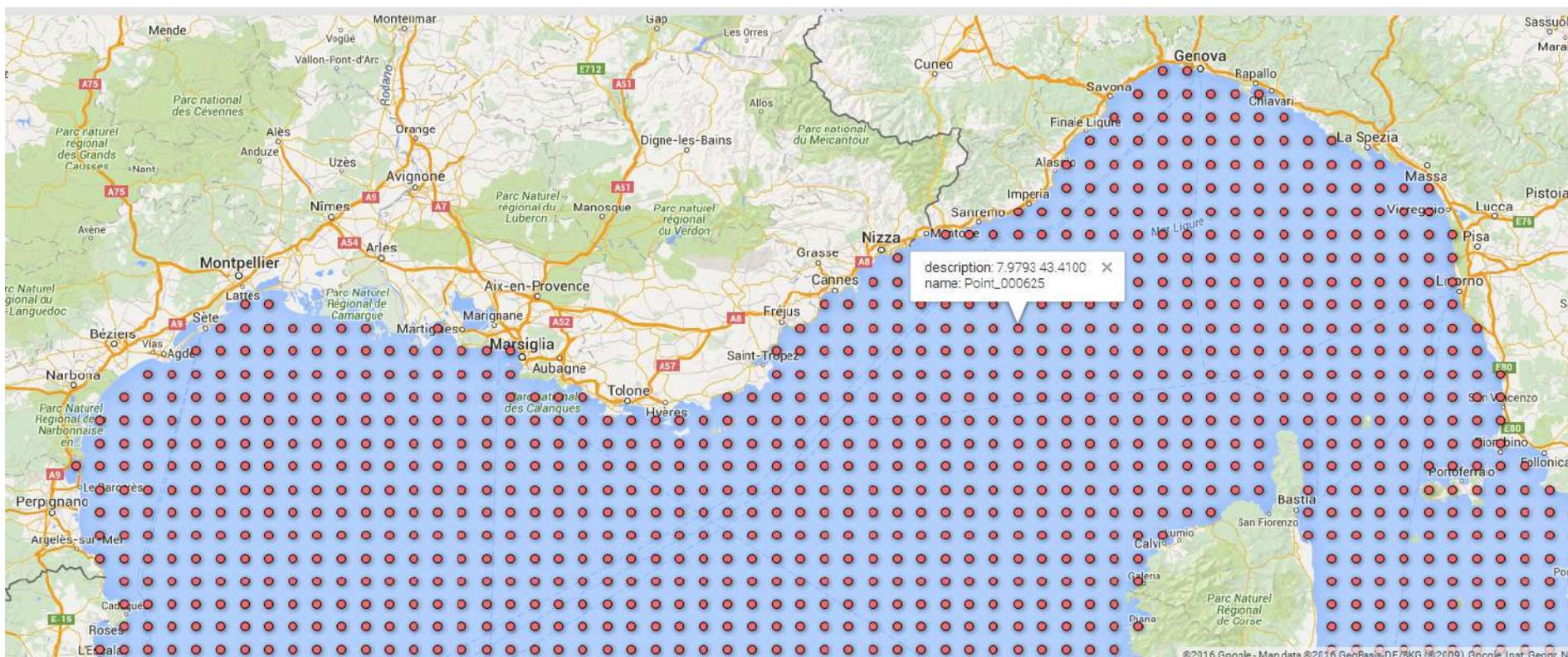
$$IP \propto R_{up}, E$$



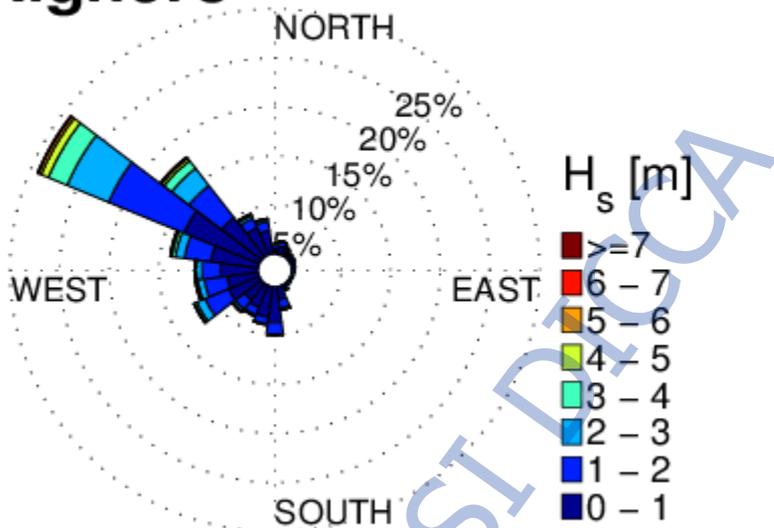
Coastal Sea Storm Hazard Index

Hindcast 1979-2018

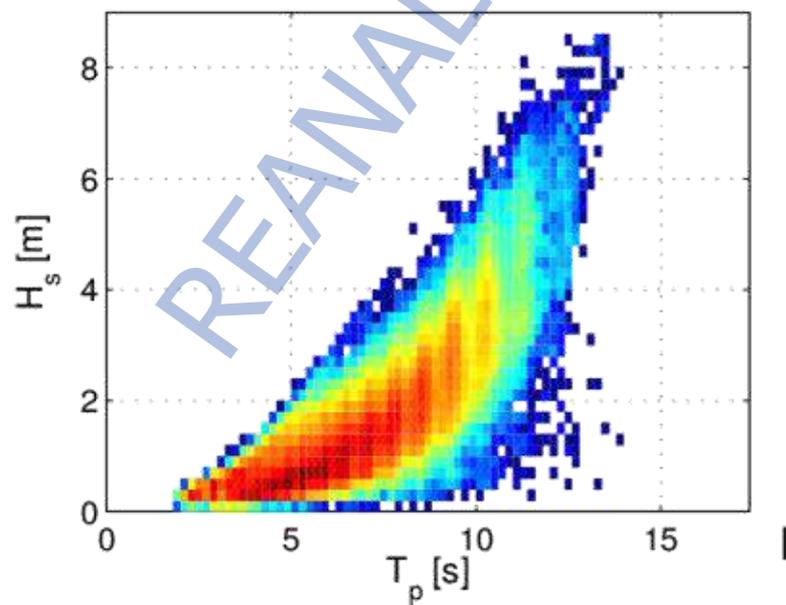
La catena modellistica è stata utilizzata per realizzare una re-analisi delle condizioni meteo-marine per il periodo compreso tra Gennaio 1979 e Dicembre 2018



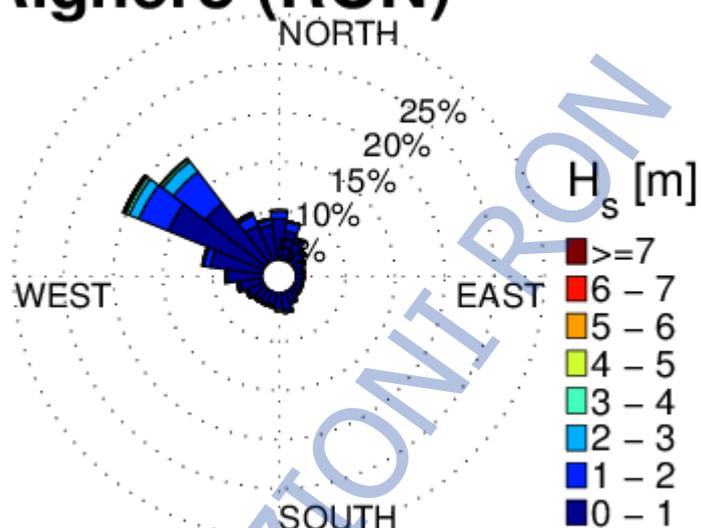
Alghero



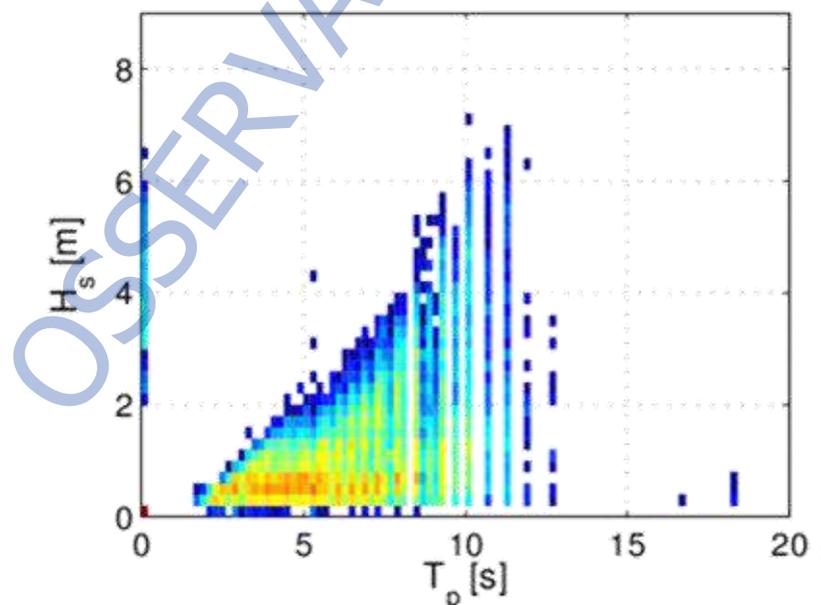
Alghero



Alghero (RON)



Alghero (RON)

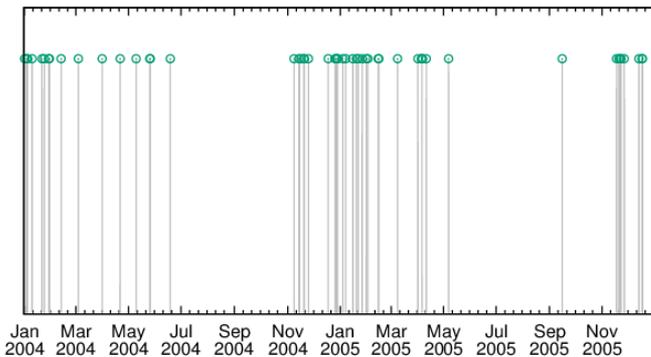


CLIMA ONDOSO SIMULATO vs RON

Hindcast 1979-2018

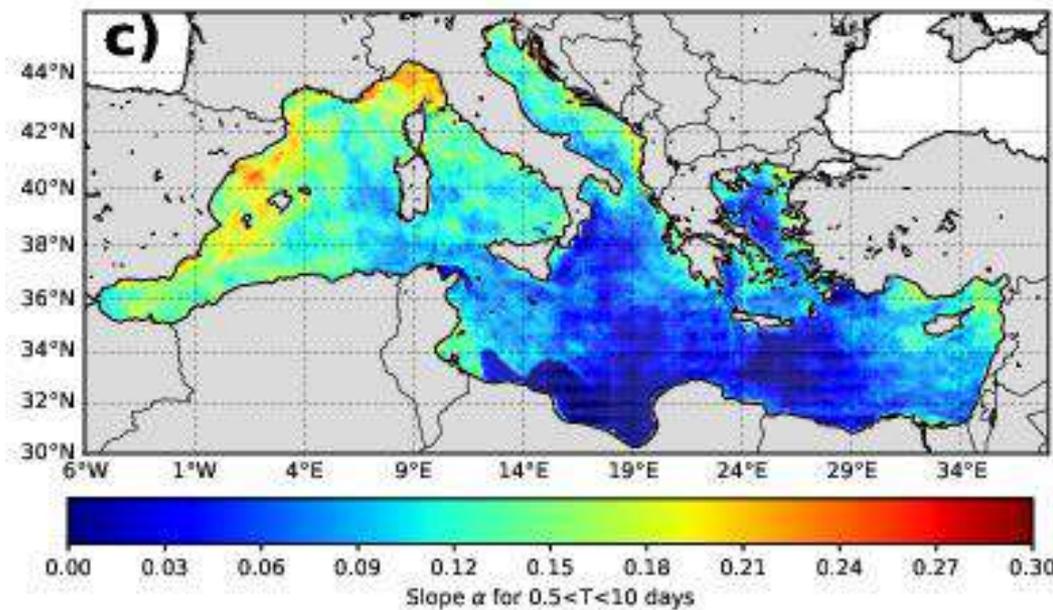
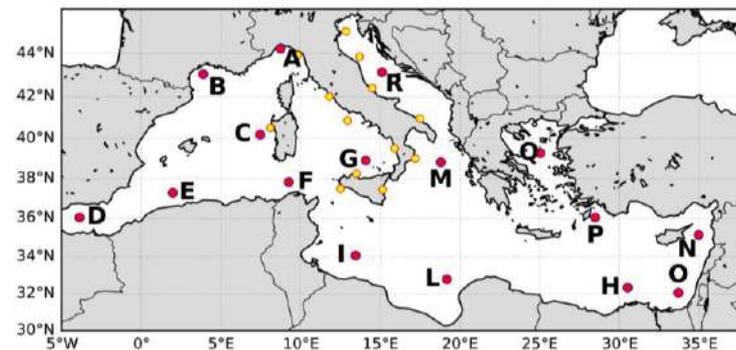
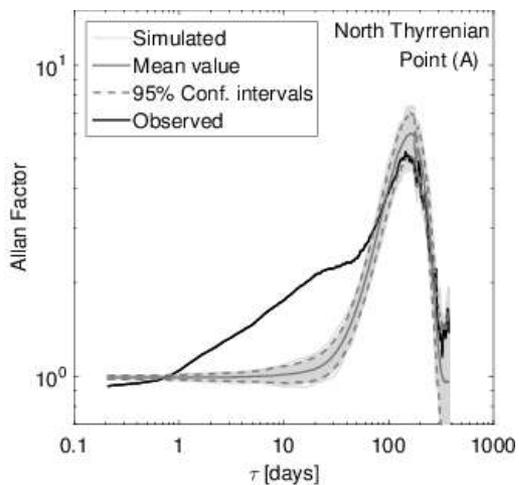
Storm Clusters

Besio, G., Briganti, R., Romano, A., Mentaschi, L. & De Girolamo, P. 2017.
Time clustering of wave storms in the Mediterranean Sea *Natural Hazards Earth System Science*, **17**, pp. 505-514



$$AF(\tau) = \frac{\langle [N_{k+1}(\tau) - N_k(\tau)]^2 \rangle}{2 \langle N_k(\tau) \rangle}$$

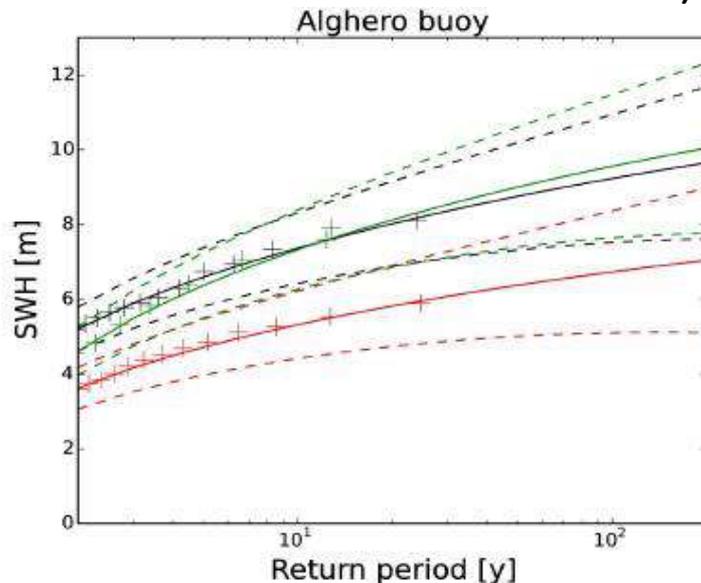
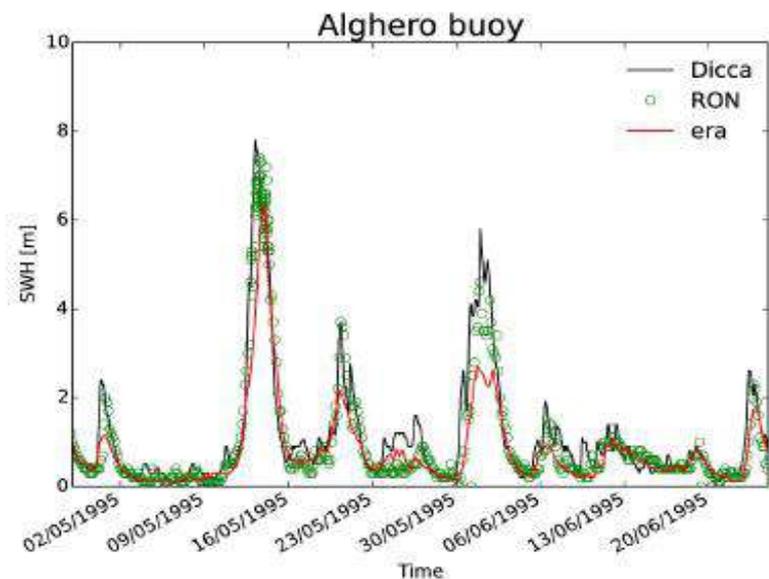
$$AF(\tau) = 1 + \left(\frac{\tau}{\tau_1} \right)^\alpha \text{ Allan Factor}$$



Hindcast 1979-2018

Extreme Value Analysis

Le basi di dati sono state confrontate in corrispondenza di sei boe virtuali dislocate nel bacino del Mediterraneo (sottobacini con diversi climi ondosi)



Confronto dati con RON (affidabilità ricostruzione dati)

- dettaglio su un periodo di due mesi (Aprile - Giugno 1995, boa di Alghero): buona correlazione tra SWH ricostruite ed osservate sia durante le calme che durante le condizioni di mare più severe
- serie ECMWF: tendenza a sottostimare i valori altezza d'onda durante le fasi maggiormente energetiche delle mareggiate: scarti oscillanti tra una differenza di circa un metro fino a tre metri

Hindcast 1979-2018

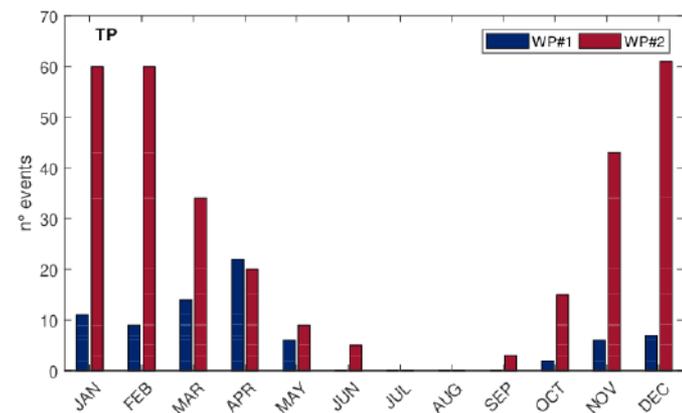
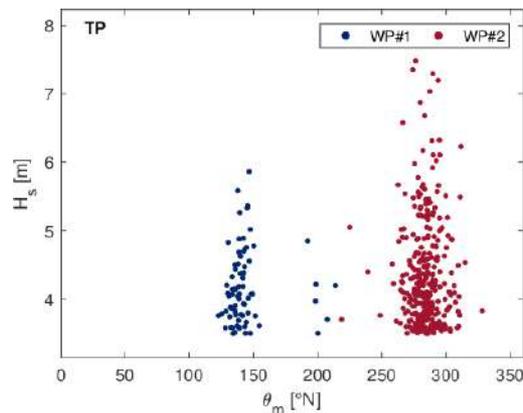
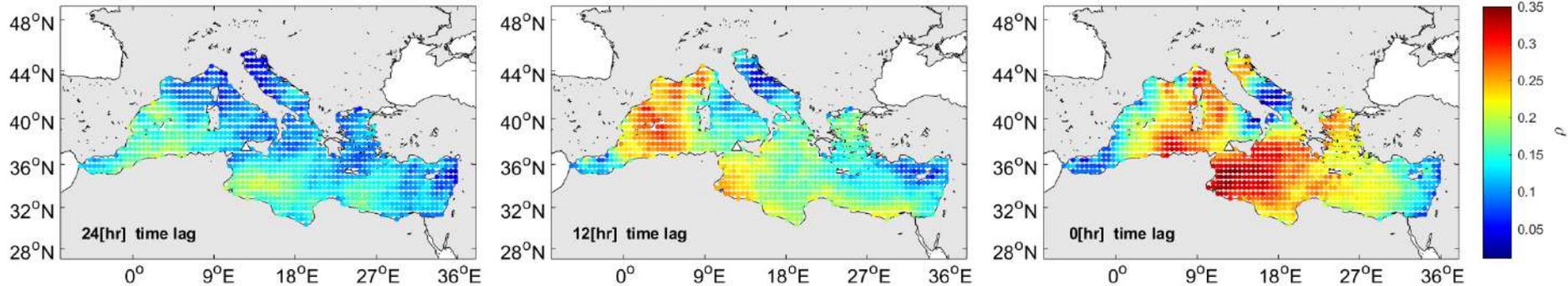
Extreme Value Analysis and Weather Pattern

Selection of surface wind fields for weather pattern classification

$$\rho(i,j,\Delta t) = \max_{0 \leq \theta < 2\pi} \{ \rho(H_s; u(i,j,\Delta t, \theta)) \}$$

$$u(i,j,\Delta t, \theta) = u_x(i,j,\Delta t) \cos(\theta) + u_y(i,j,\Delta t) \sin(\theta)$$

i, j : wind node
 Δt : time lag
 θ : referring direction



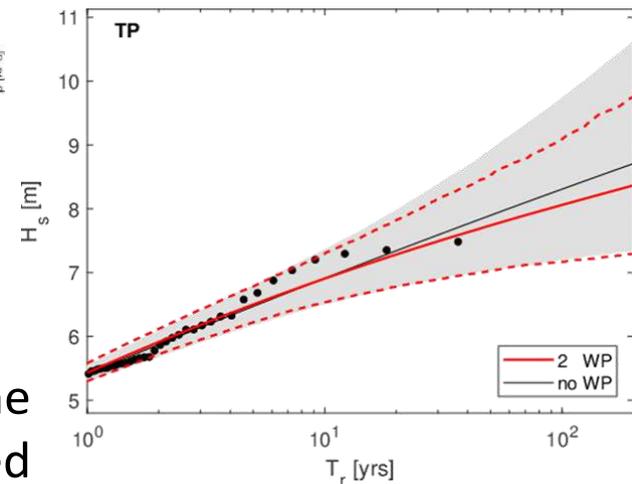
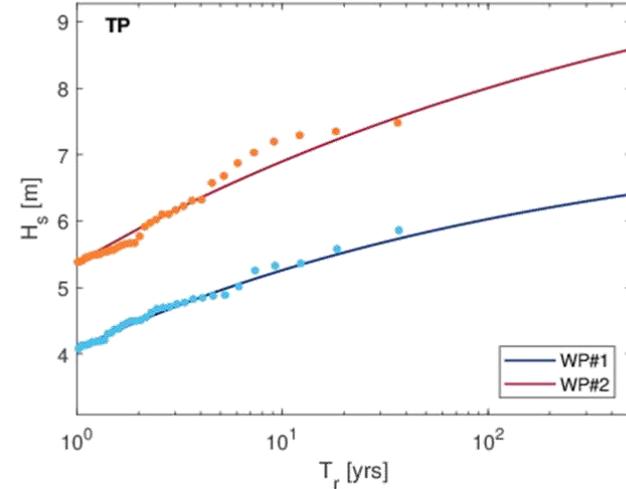
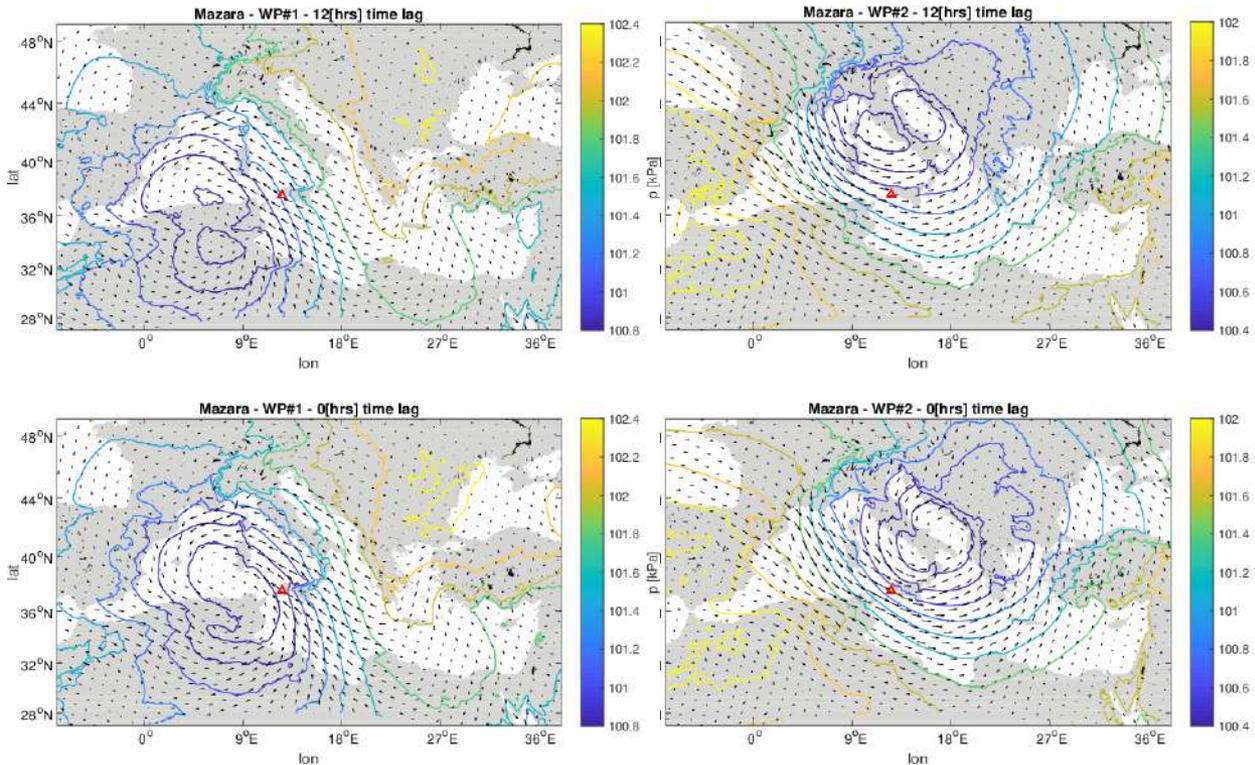
Hindcast 1979-2018

Mean Sea Level Pressure Fields and Extreme Levels

Extreme Value Analysis and Weather Pattern

WP1

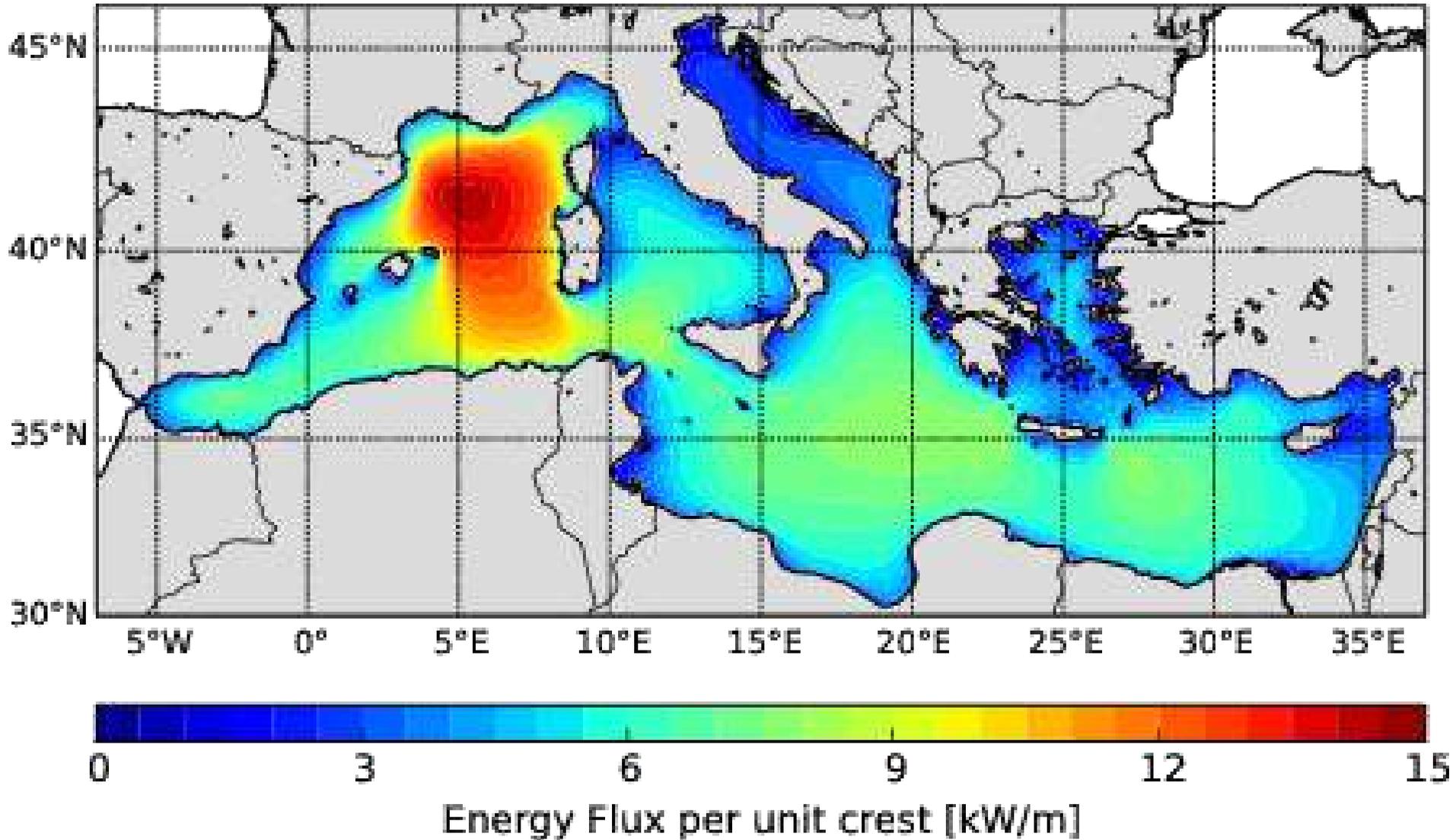
WP2



The empirical curve match well the analytical one
and the IC are considerably reduced

Hindcast 1979-2018

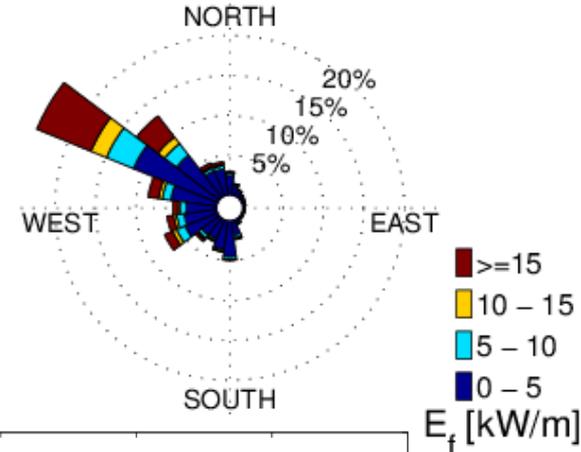
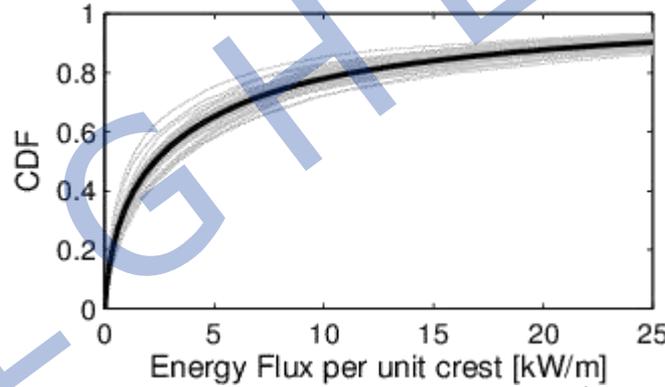
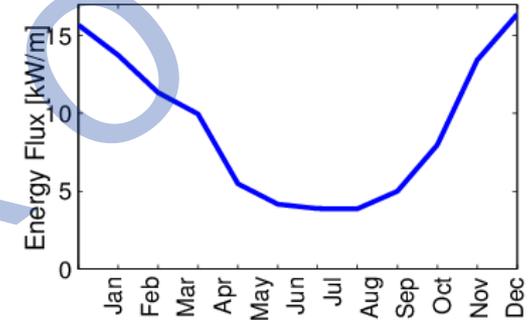
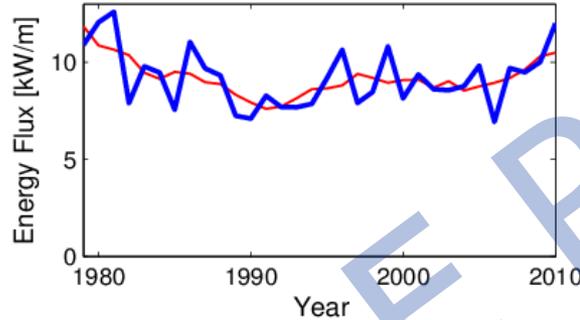
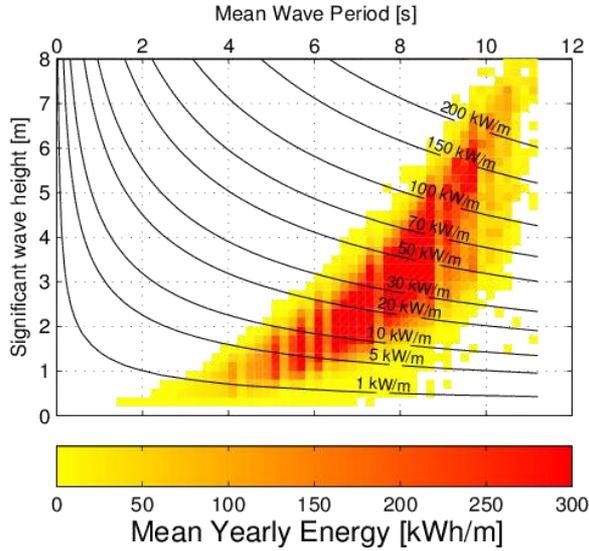
Wave Energy Exploitation



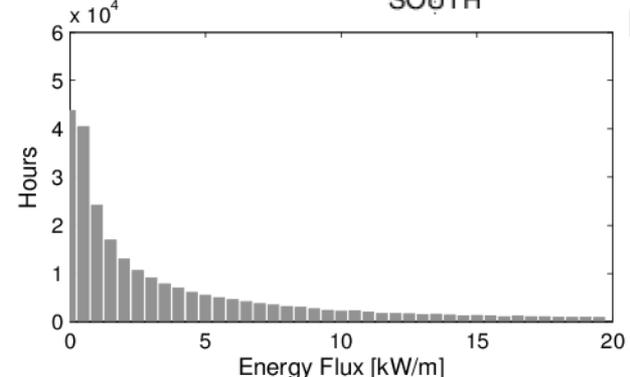
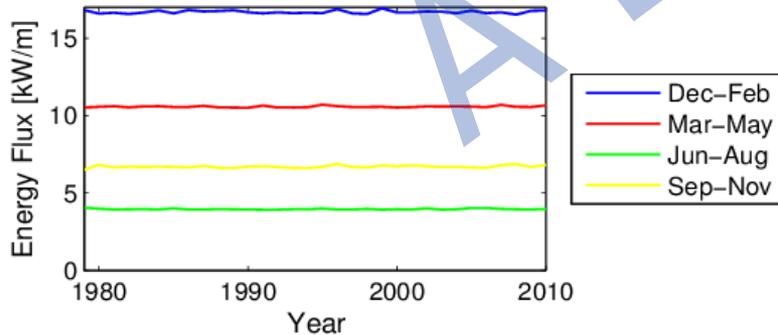
Hindcast 1979-2018

Wave Energy Exploitation

Besio G., Mentaschi L., & Mazzino A., 2016. Wave energy resource assessment in the Mediterranean Sea on the basis of a 35-year hindcast, *Energy*, 94



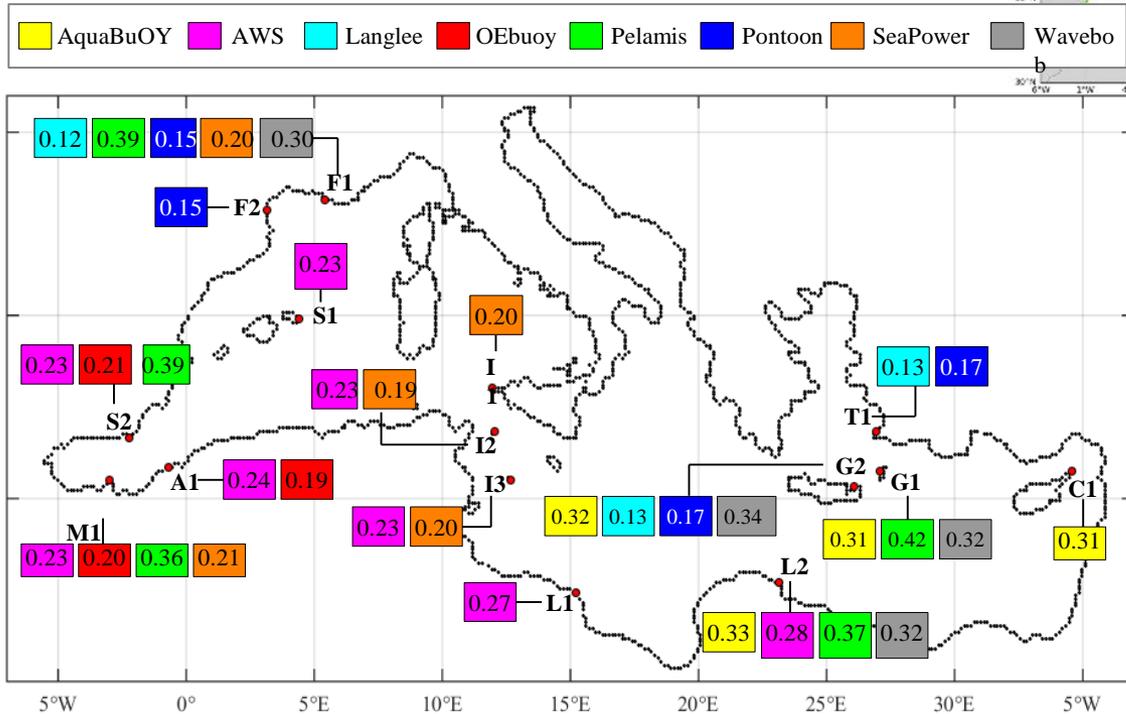
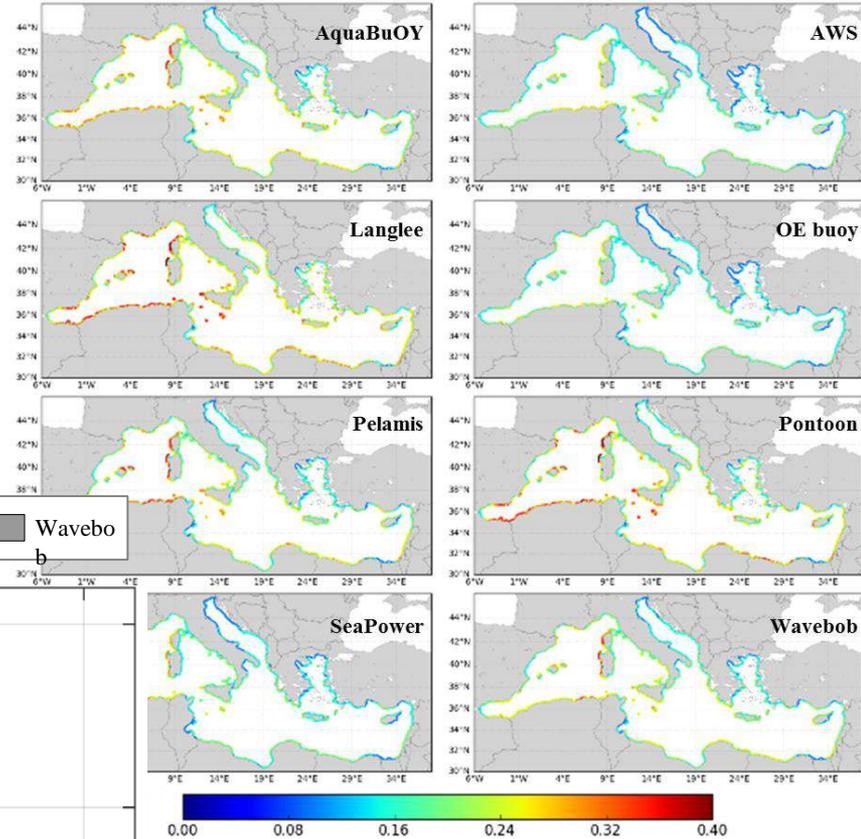
Stime di dettaglio per un qualsiasi punto all'interno del Mediterraneo



Hindcast 1979-2018

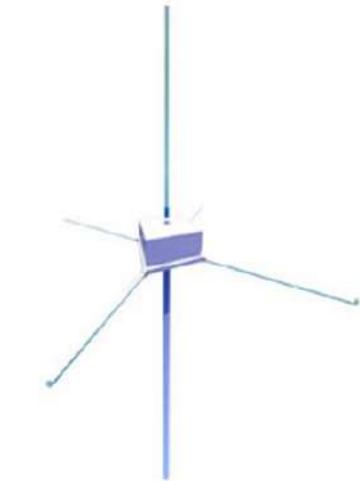
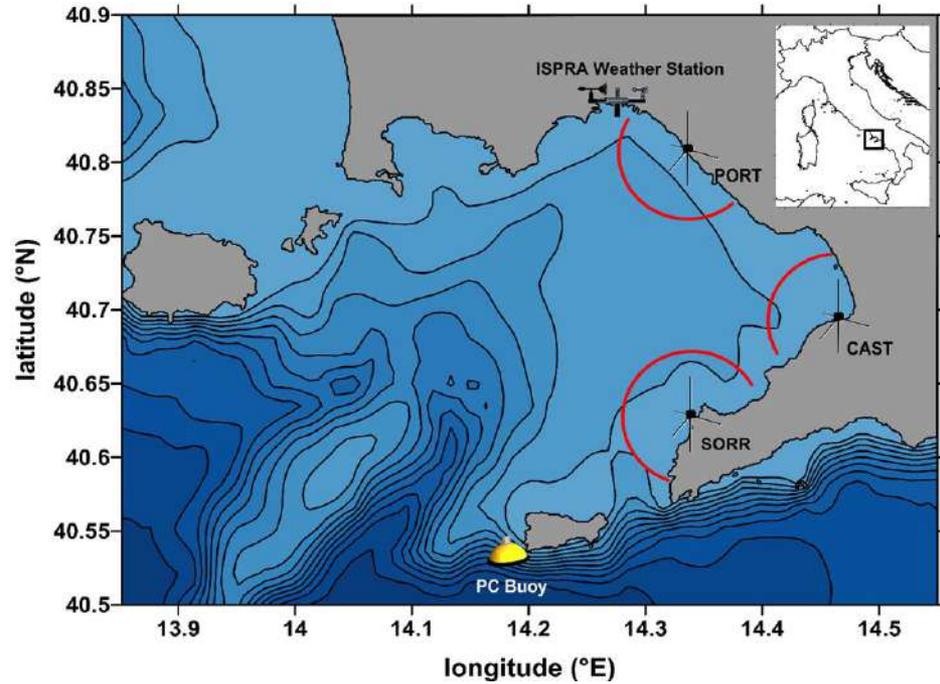
Bozzi, S., Besio, G. and Passoni, G. 2017. Wave power technologies for the Mediterranean offshore: scaling and performance analysis. Submitted to Renewable & Sustainable Energy Reviews

Wave Energy Exploitation



Hindcast 1979-2018

Radar + Numerical Models

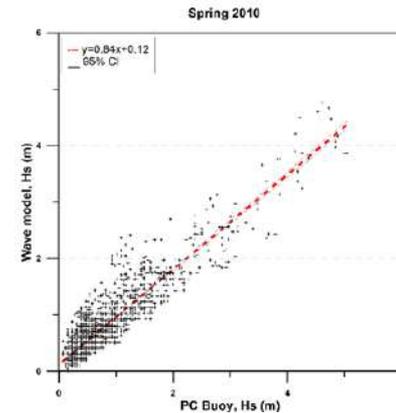
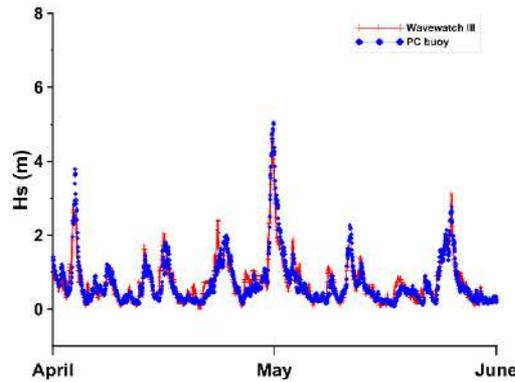
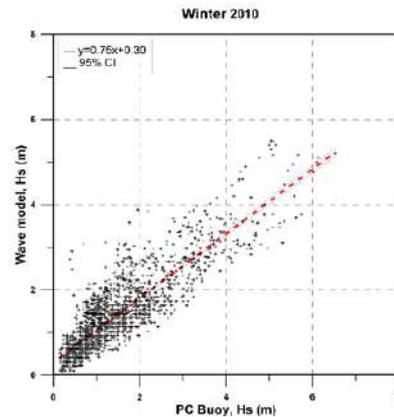
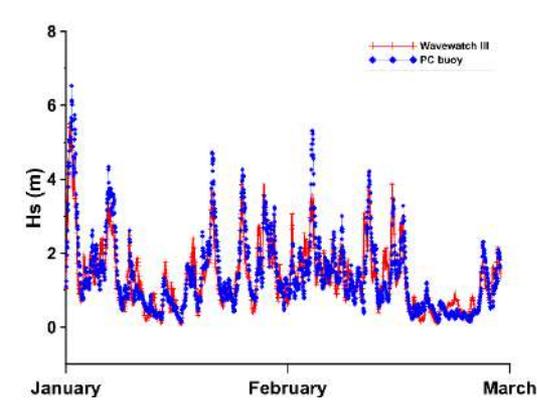


SeaSonde HF Radar Codar



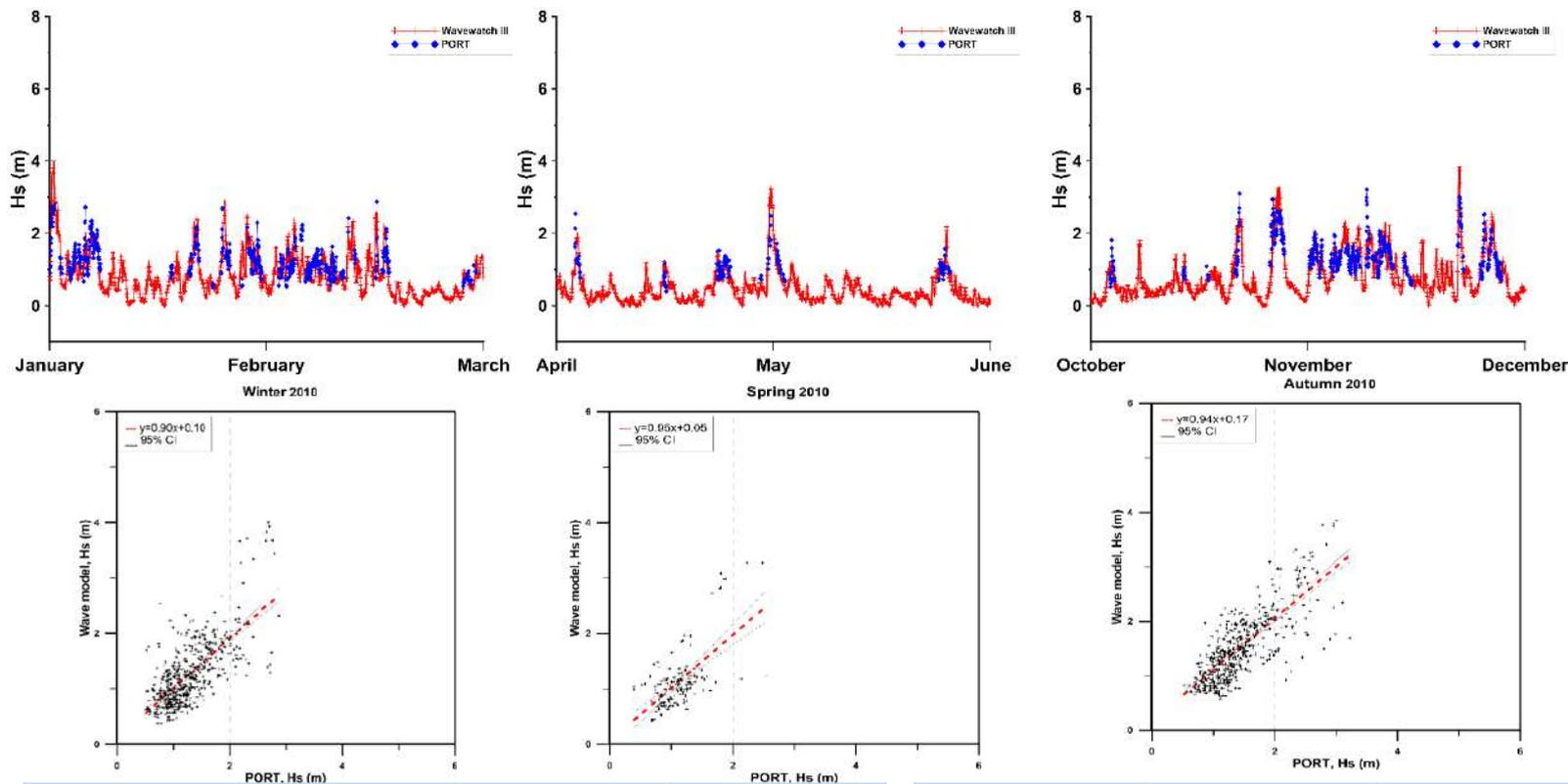
SEAWATCH Wavescan Buoy

WWIII vs PC buoy



Hindcast 1979-2018

Radar + Numerical Models



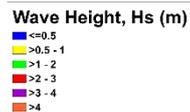
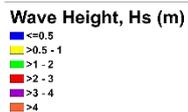
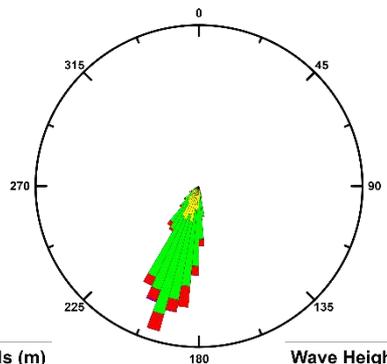
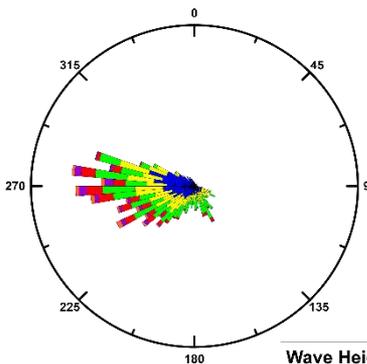
WW3/ PC buoy	r	RMSE	HH
Winter	0.87	0.4	0.3089
Spring	0.91	0.2	0.2798
Summer	0.89	0.2	0.3019
Autumn	0.89	0.4	0.2760

WW3/HF PORT	r	RMSE	HH
Winter	0.7	0.4	0.3092
Spring	0.62	0.41	0.3510
Summer	0.67	0.39	0.3045
Autumn	0.78	0.39	0.2531

Hindcast 1979-2018

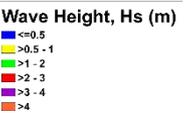
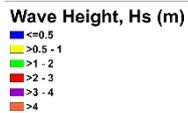
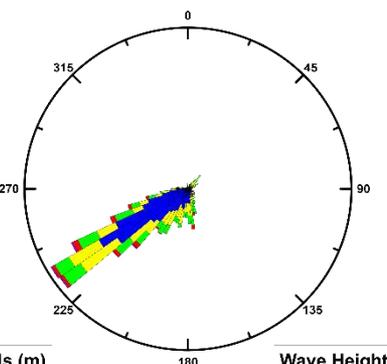
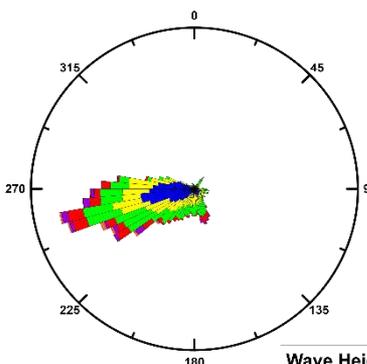
Wave roses (PC buoy) - 2010

Wave roses (PORT) - 2010



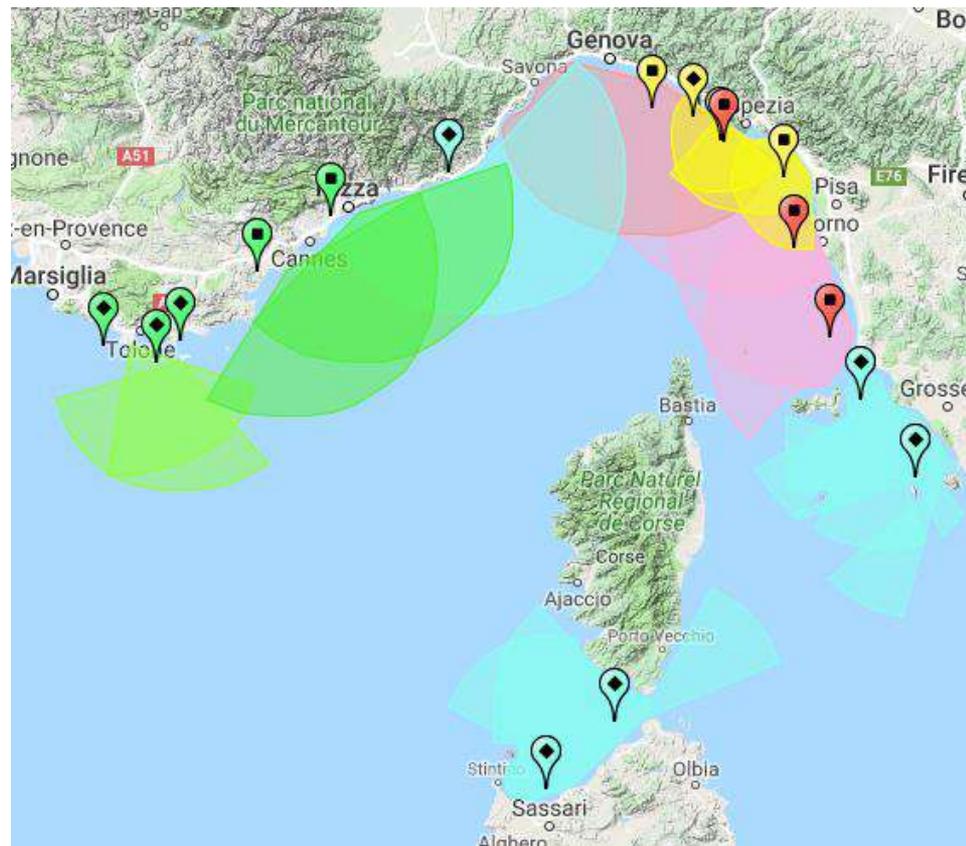
Wave rose (WW3) - 2010

Wave roses (WW3) - 2010

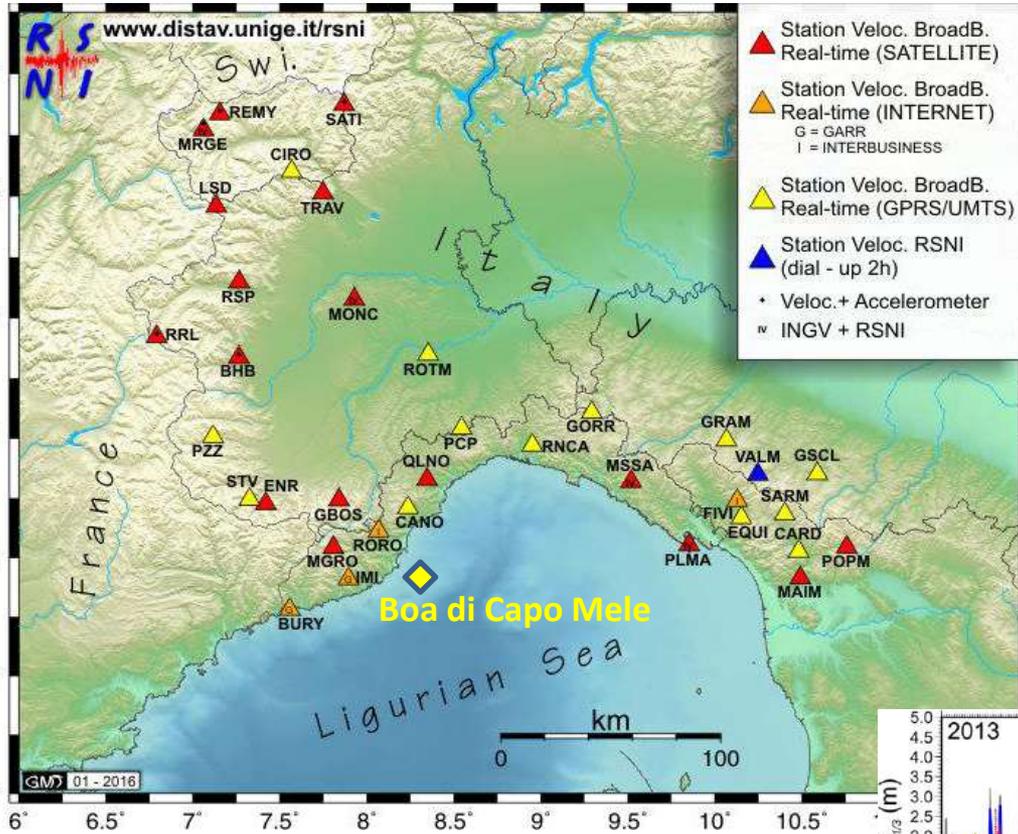


Radar + Numerical Models

Saviano, S., Uttieri, M., Besio, G., Zambianchi, E. 2017. Wave measurements and models in the Thyrrenian Sea. EGU General Assembly



Hindcast 1979-2018

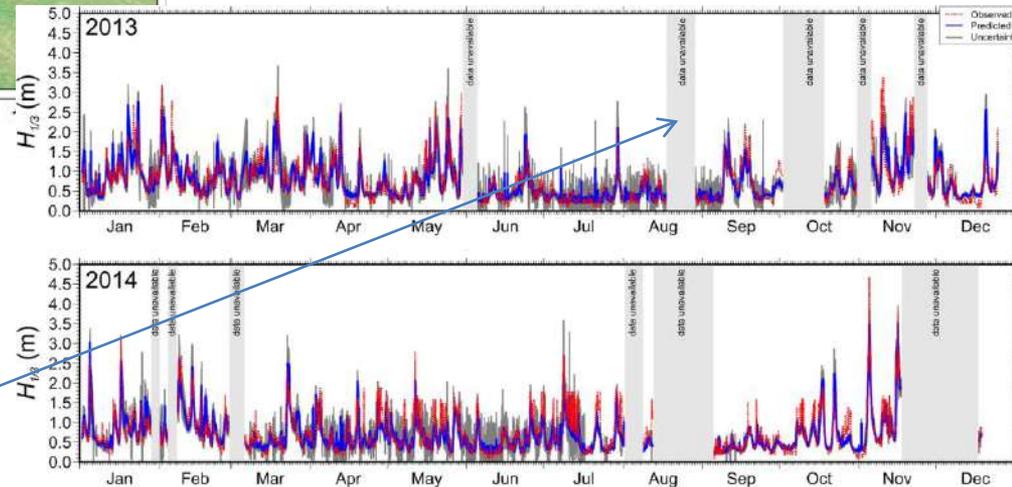


Simosgrafi + Numerical Models

Ferretti, G., Scafidi, D., Cutroneo, L., Gallino, S., & Capello, M. 2016. Applicability of an empirical law to predict significant sea-wave heights from microseisms along the Western Ligurian Coast (Italy). Continental Shelf Research, 122, 36-42.

- Necessità di punto di misura
- Presenza di buchi dovuti a telesismi
- Mancanza di informazione sulla direzione

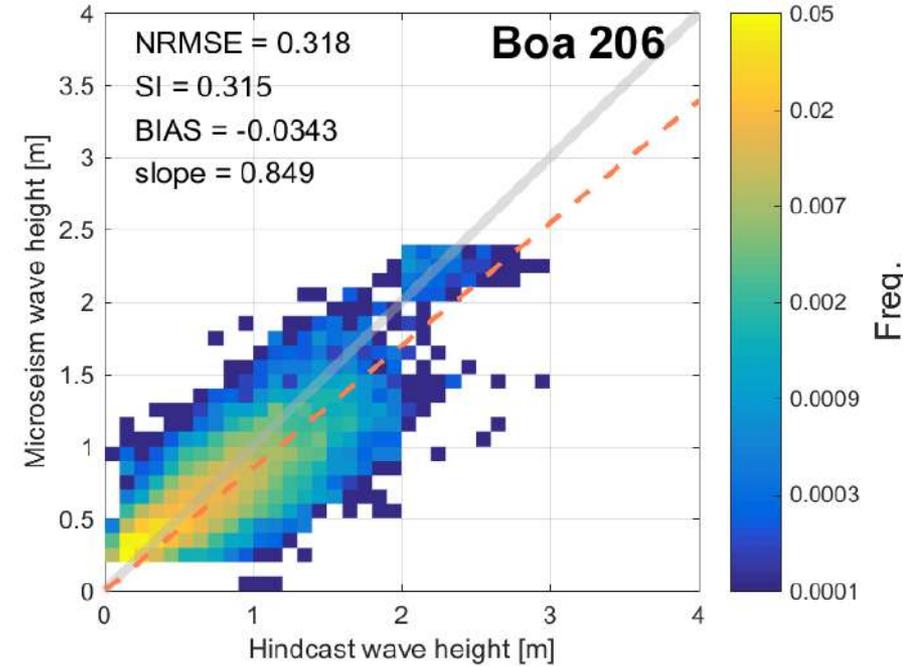
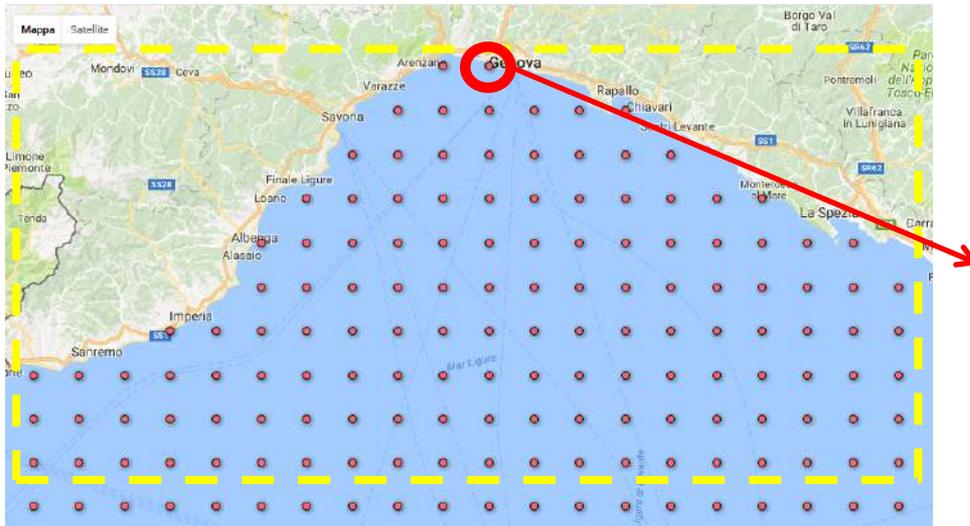
Telesisma



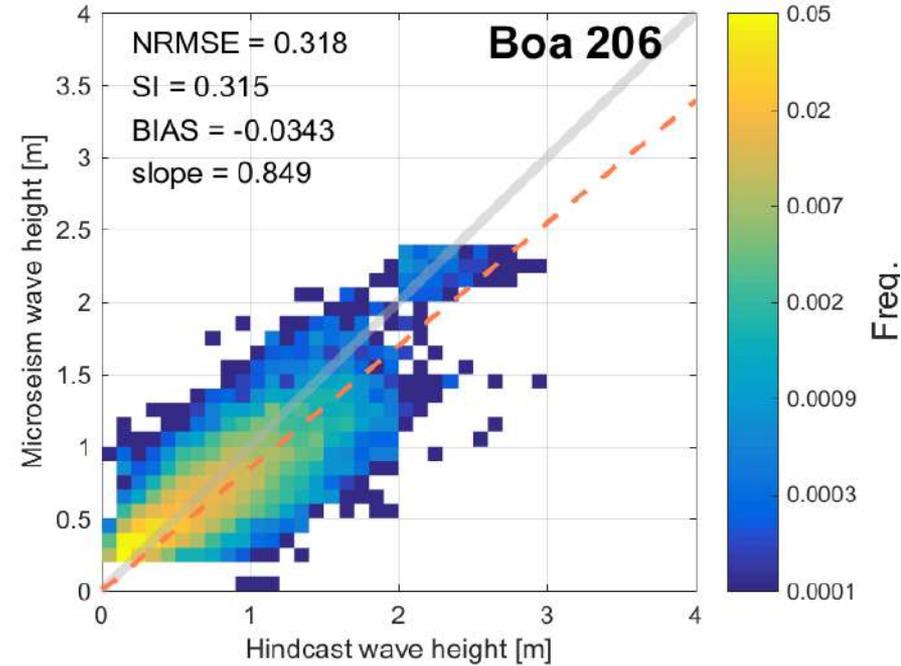
Hindcast 1979-2018

Simosgrafi + Numerical Models

Hindcast come serie di riferimento
Regionalizzazione



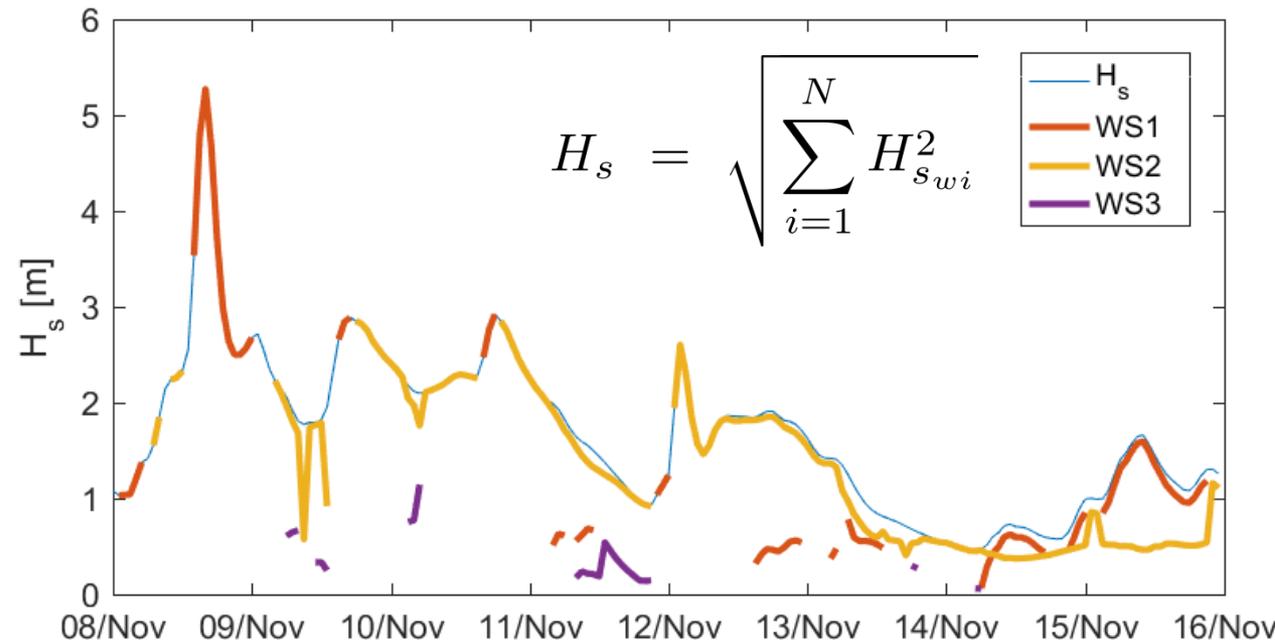
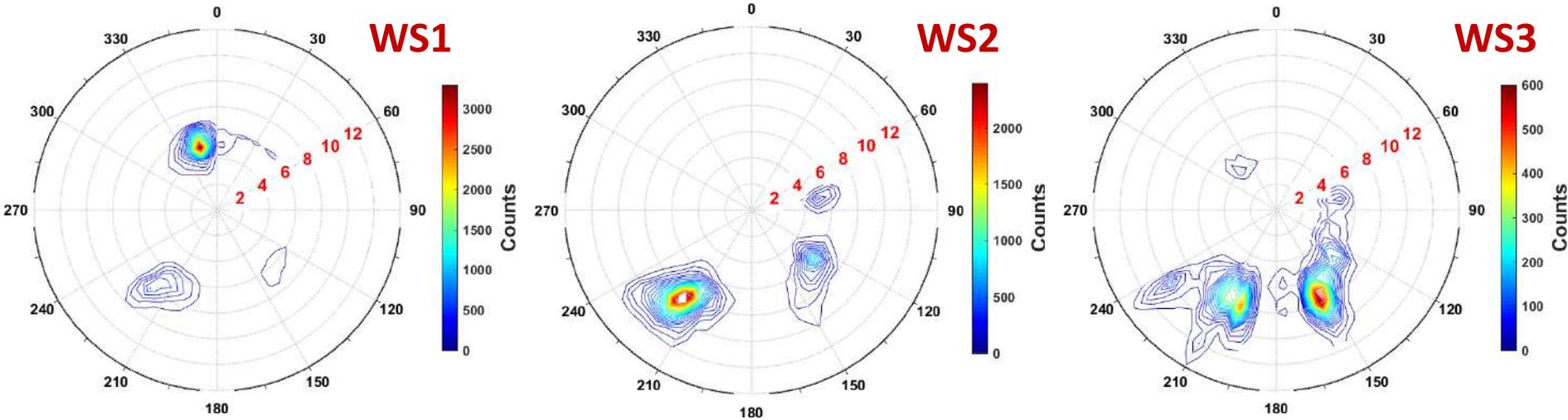
Procedura
automatica
rimozione
telesismi con
analisi statistica
mareggiate del
passato



- Stima delle funzioni di trasferimento utilizzando pesi diversi a seconda dell'area di interesse
- Procedura elaborazione direzione provenienza del moto ondoso

Hindcast 1979-2018

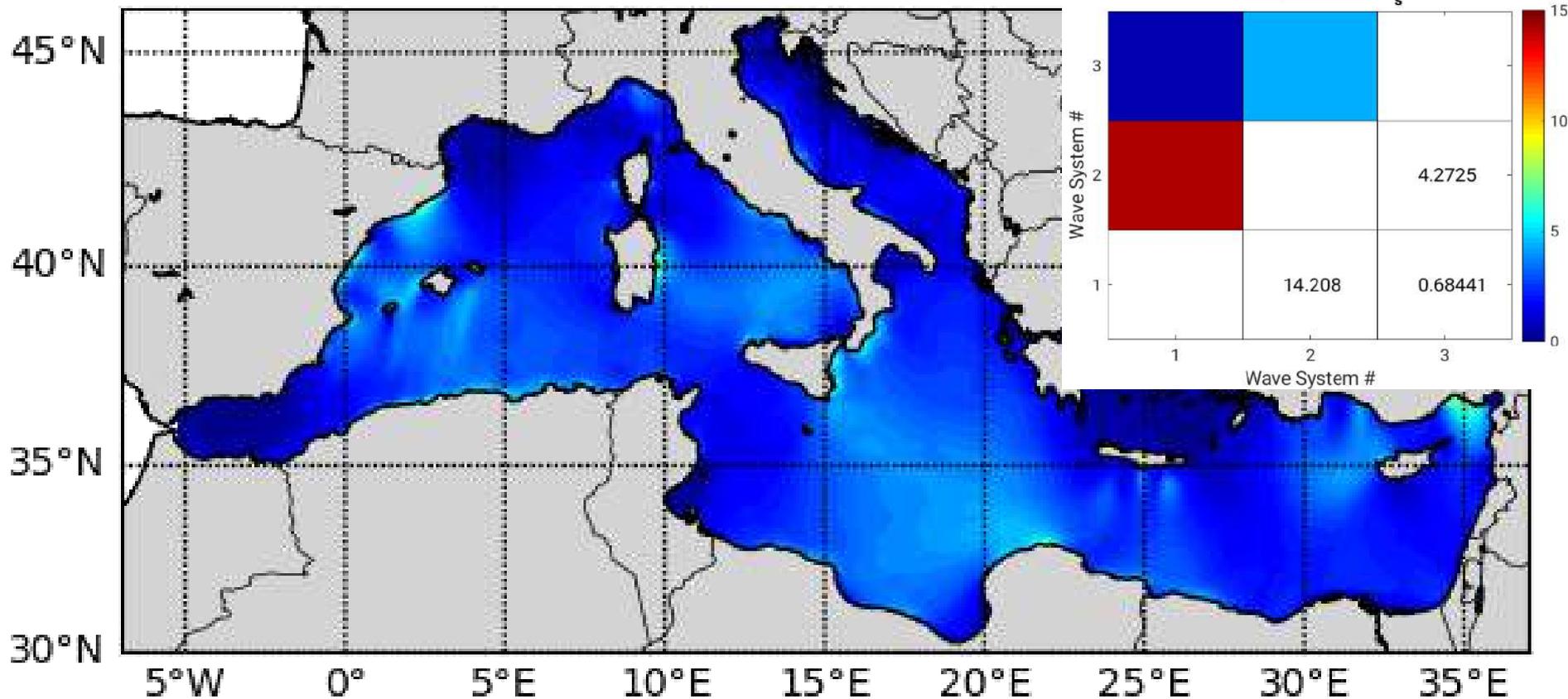
Wave Spectral Climate



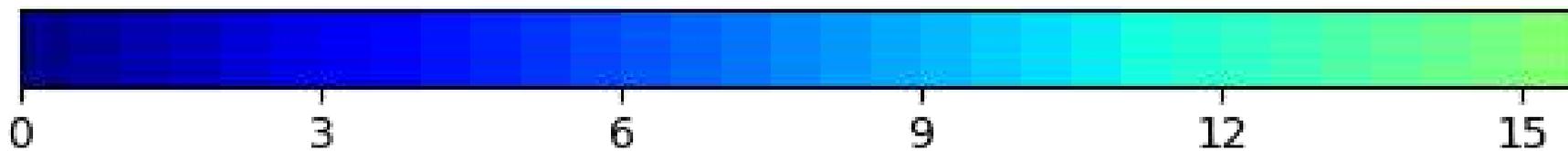
- Identificare i diversi sistemi di moto ondoso
- Regime dei litorali
- Sicurezza Marittima

Hindcast 1979-2018

Wave Spectral Climate

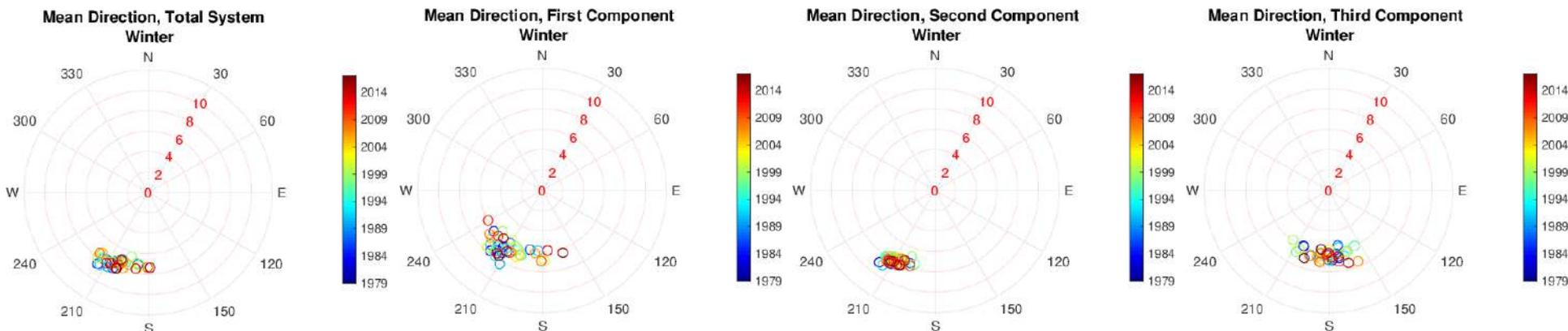


Crossing sea probability SW1-SW2

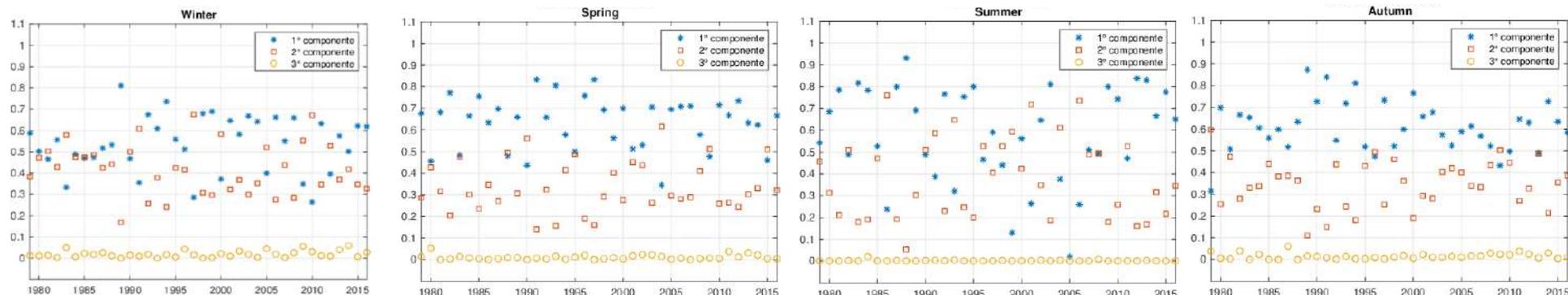


Hindcast 1979-2018

Wave Spectral Climate



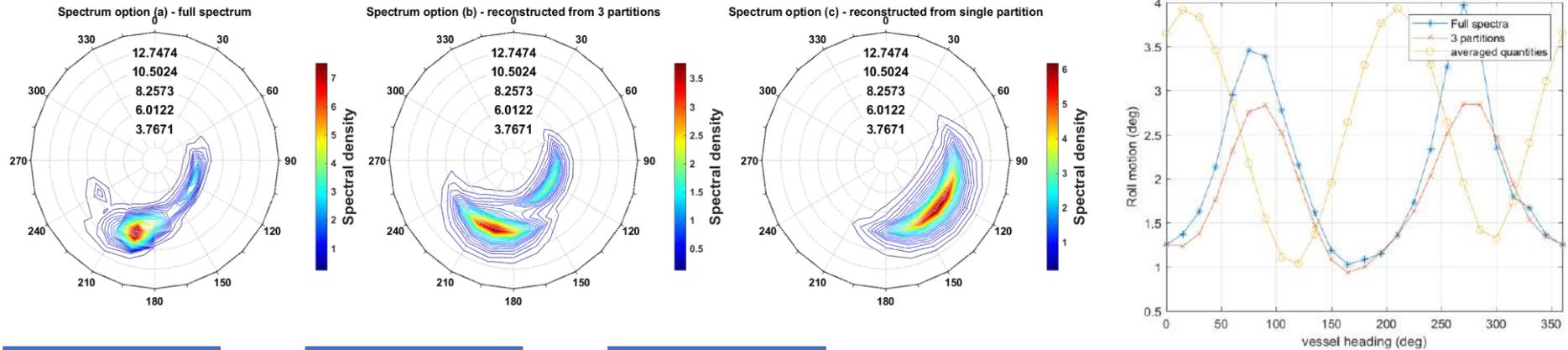
Seasonal Direction Distributions & Rate of spectral energy



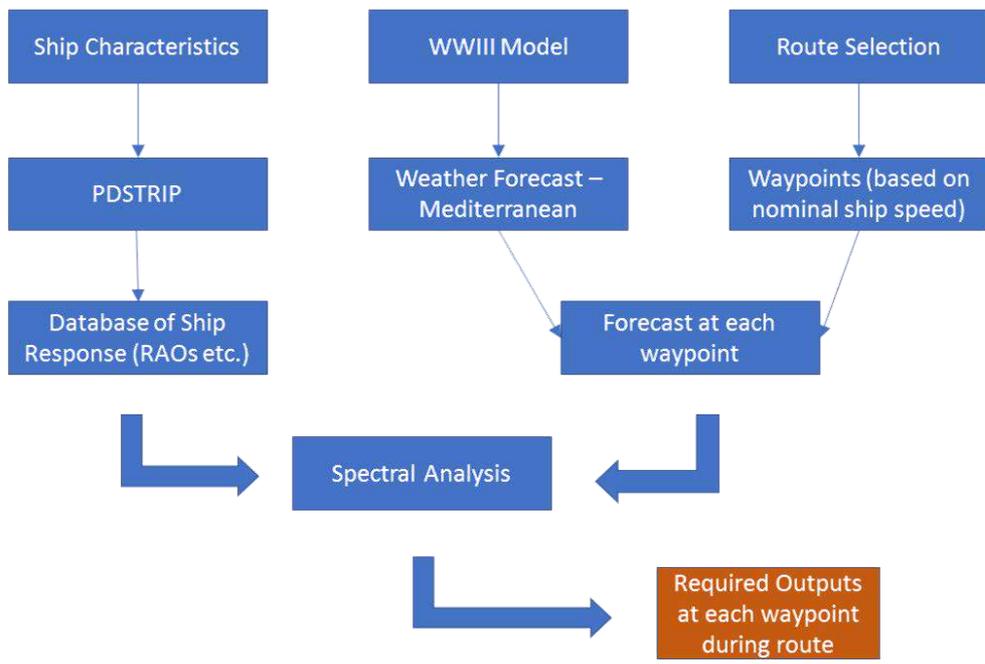
Hindcast 1979-2018

See Keeping – Weather Routing

Spentza, E., Besio, G., Mazzino, A., Gaggero, T., Villa, D. 2017. A ship weather-routing tool for route evaluation and selection: influence of the wave spectrum. Proc. of IMAM Conference



Importanza bontà dati meteo per scelta rotte ottime (sicurezza del carico, confort, velocità, consumi)



Forecast

Spectral Forecast

Valid for 2018-10-28 12:00

UTC 2018-10-27 00:00 + 036 hrs

$H_s = 2.537$ m

$T_{-10} = 6.94$ s

$T_{01} = 6.30$ s

$T_{02} = 5.88$ s

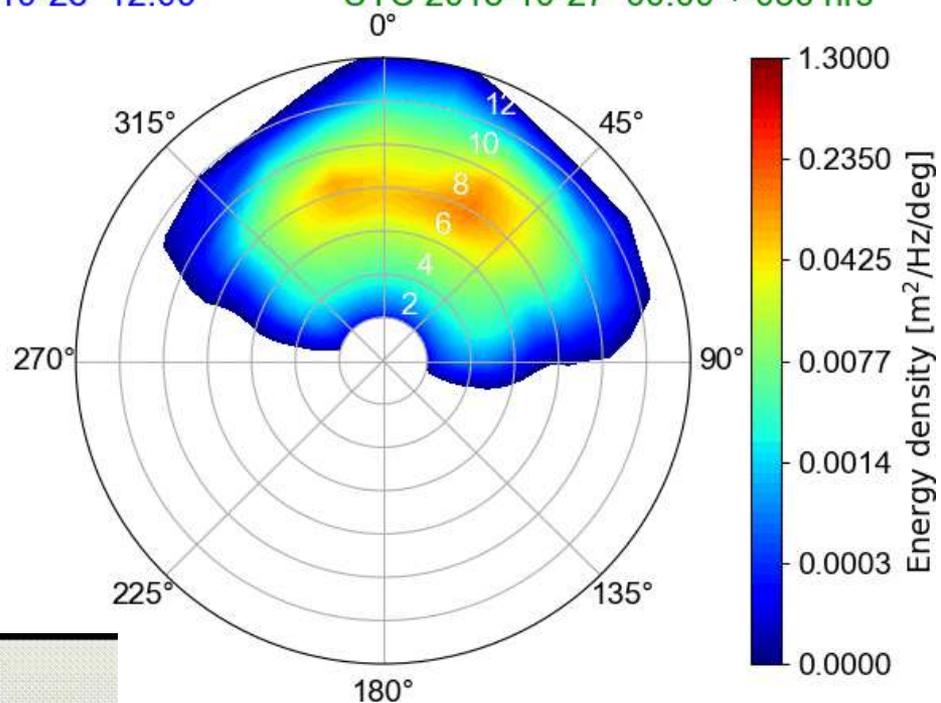
$Dir_p = 30.00$ ° N

$Dir_m = 12.98$ ° N

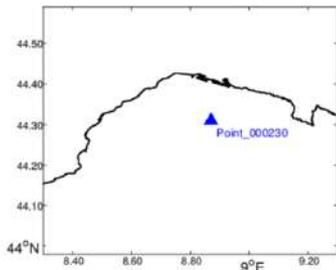
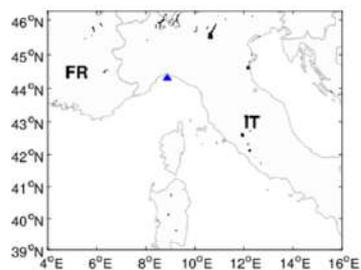
$Spr_{Dir} = 4.63$ °

Lat 44.2866 ° N

Lon 9.2631 ° E



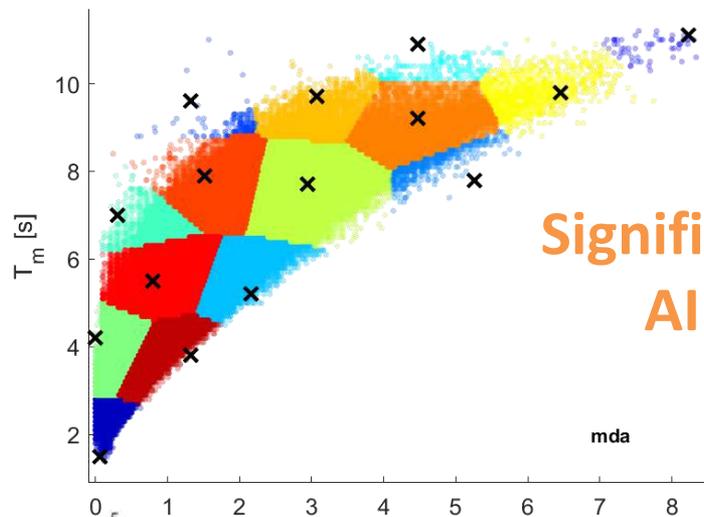
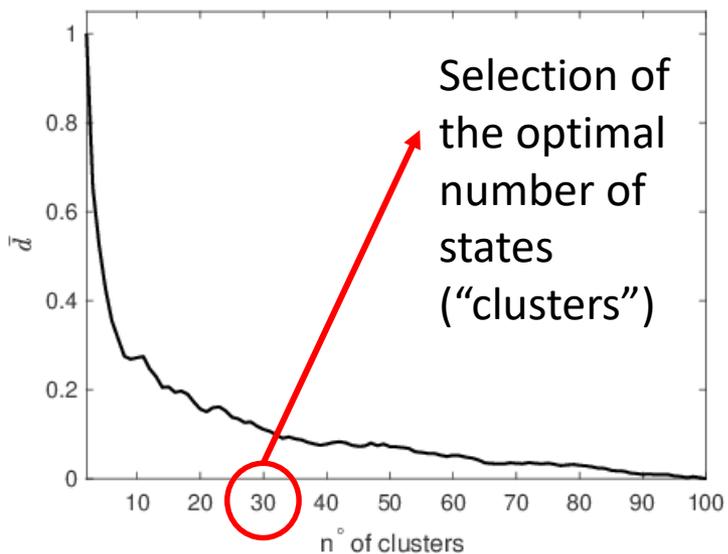
Hindcast 1979-2018



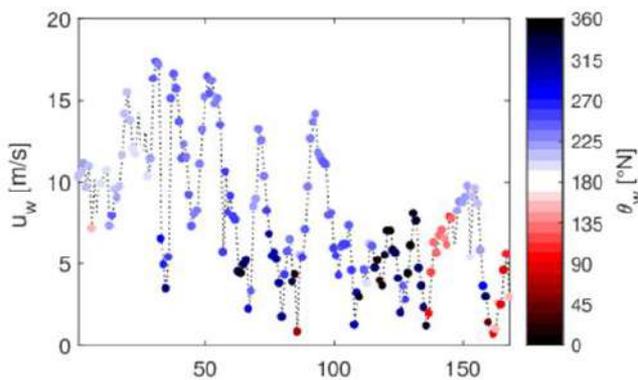
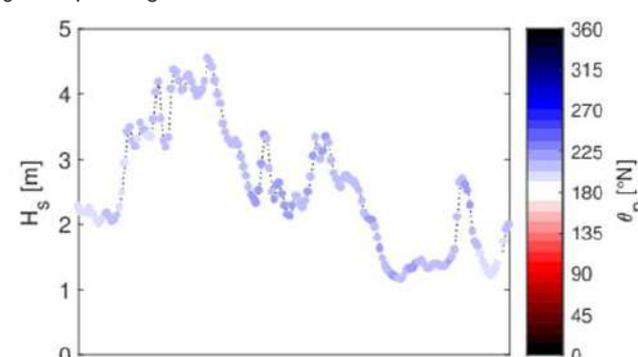
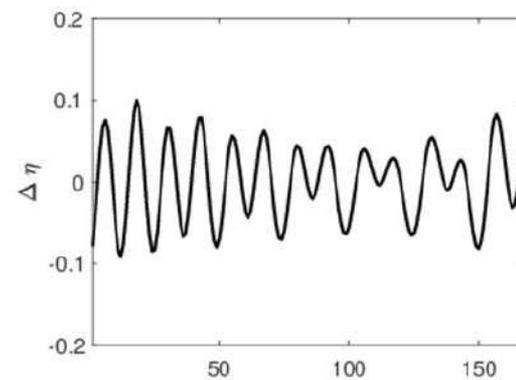
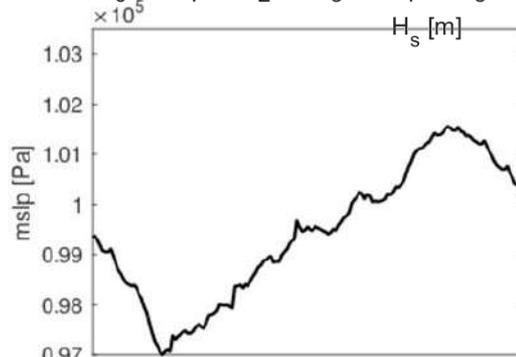
$$X_{n,V} = \begin{bmatrix} x_{1,1} & \dots & x_{1,V} \\ \vdots & \ddots & \vdots \\ x_{n,1} & \dots & x_{n,V} \end{bmatrix}$$

$n \rightarrow$ number of states

$V \rightarrow$ number of variables

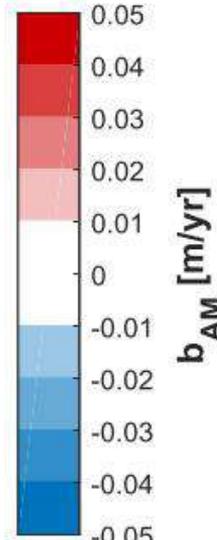
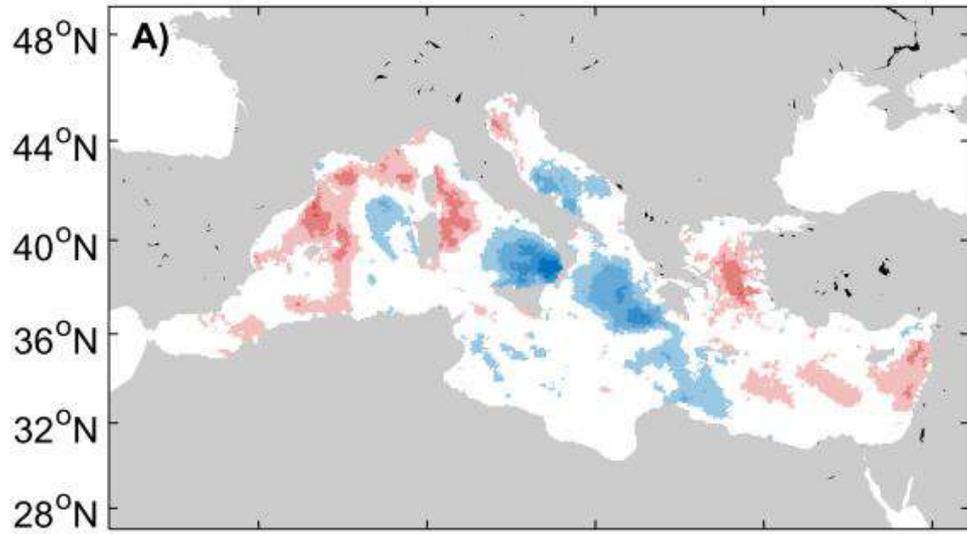


Significant Scenarios –
AI for Probabilistic
Forecasting

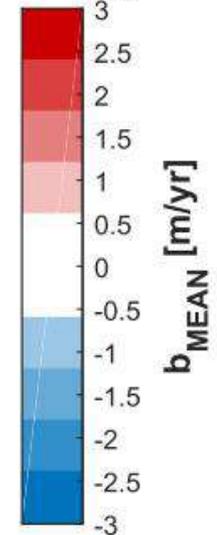
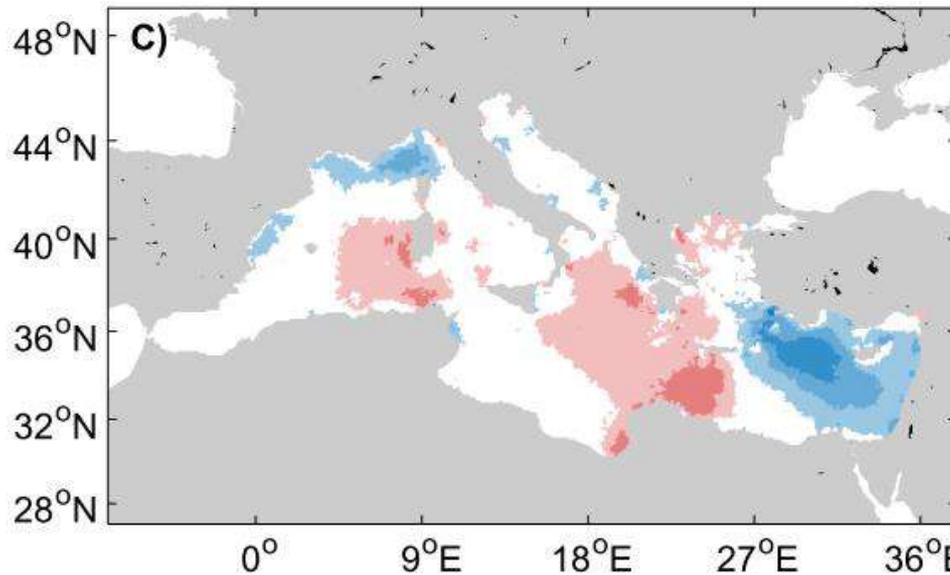


Hindcast 1979-2018

Long Term Trend



AM data



MEAN data

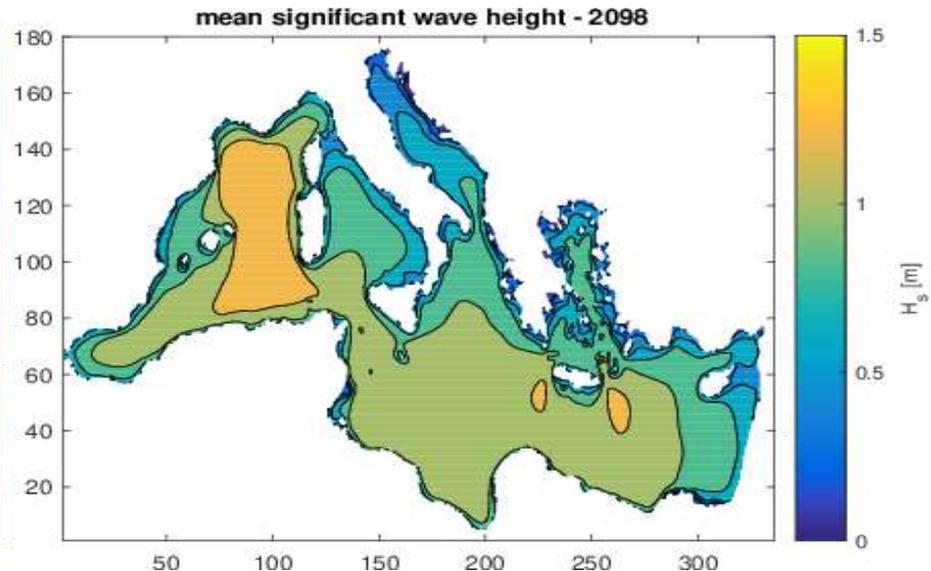
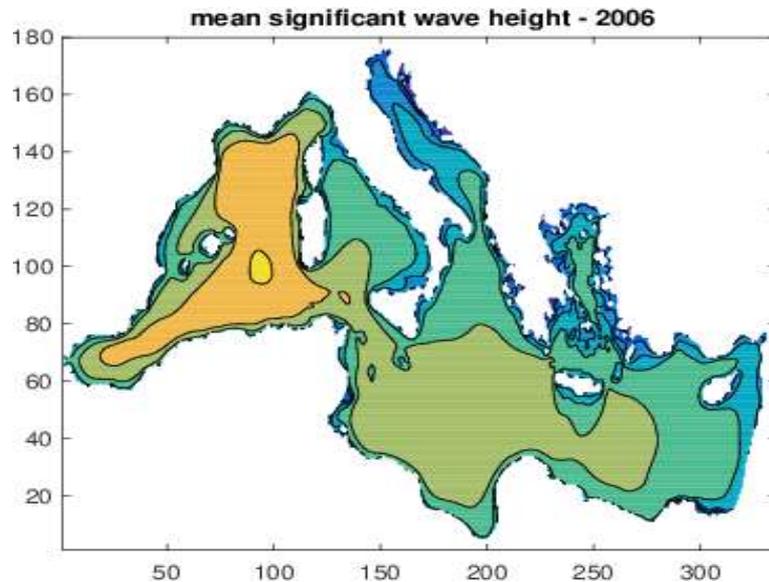
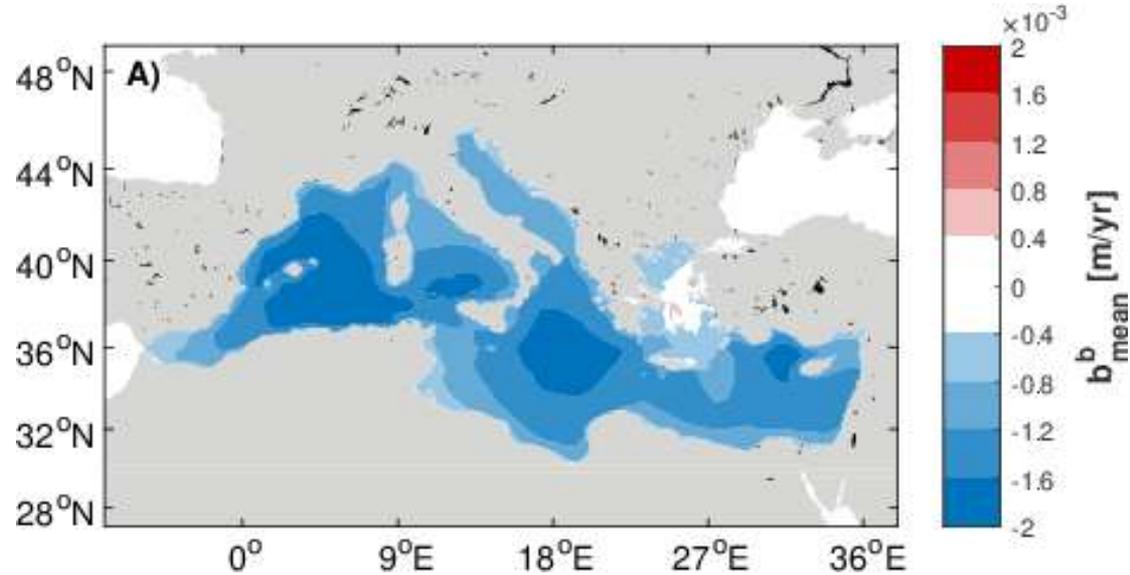
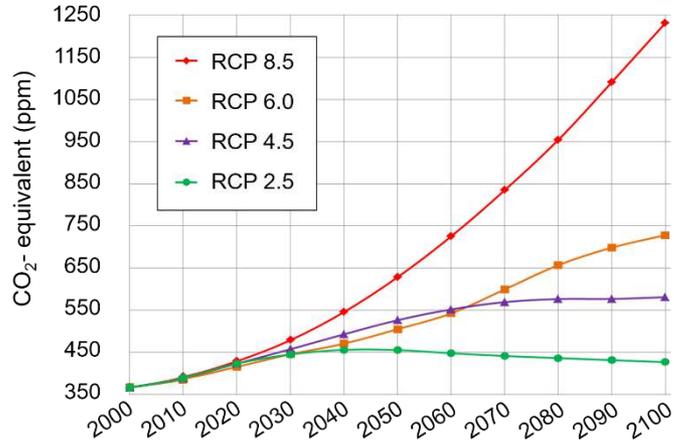
Theil-Sen (1992)

Climate Change Projection

Long Term Trend – RCP8.5

IPCC AR5 Greenhouse Gas Concentration Pathways

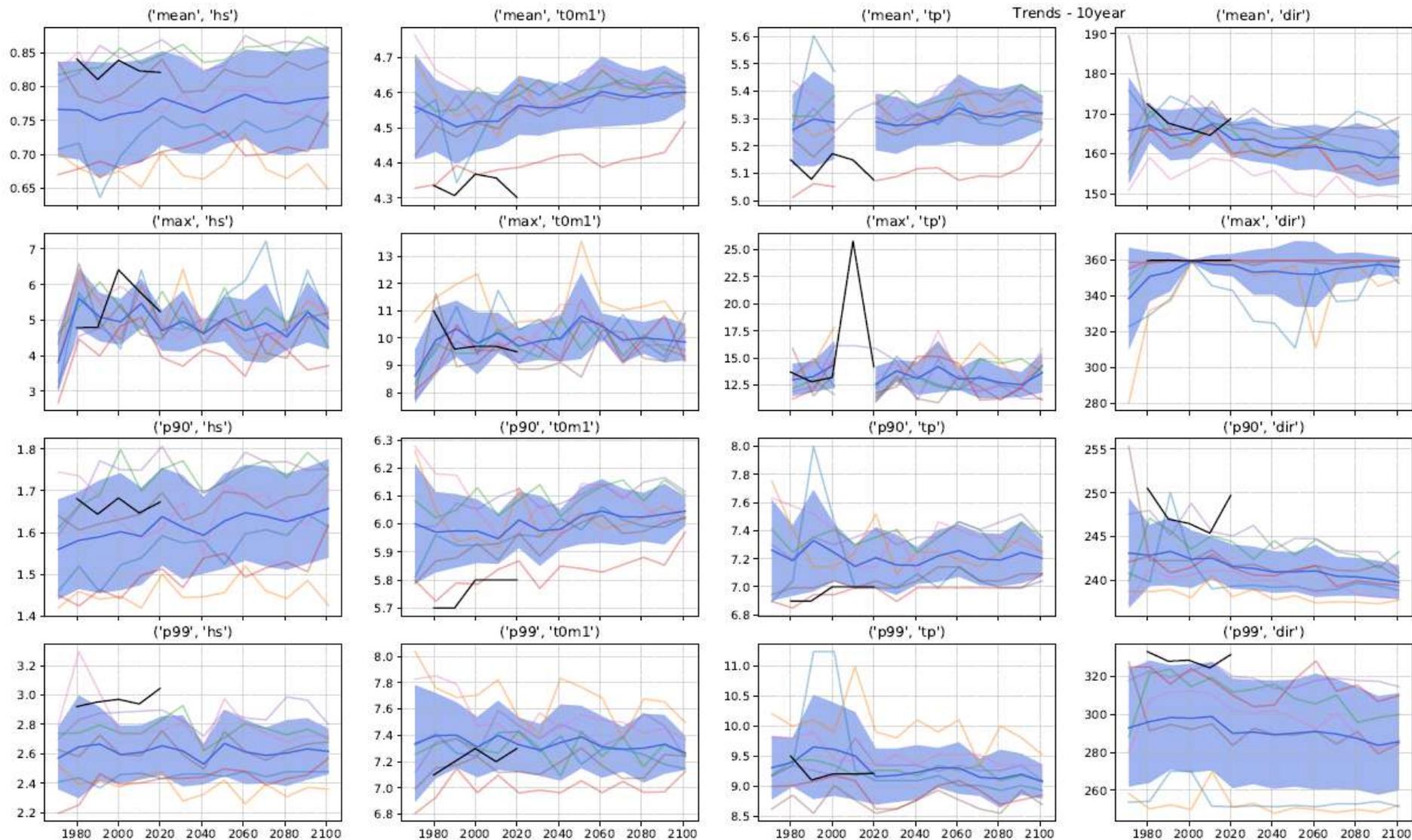
Representative Concentration Pathways (RCPs) from the fifth Assessment Report by the International Panel on Climate Change



Climate Change Projection

Long Term Trend – RCP8.5

CLMcom-CanESM2 CLMcom-MIROC5 SMHI-MPI-ESM-LR SMHI-NorESM1-M SMHI-CNRM-CM5 SMHI-IPSL-CM5A-MR SMHI-HadGEM2-ES ensemble mean hindcast



Progetti



Sistema transfrontaliero per la sicurezza in mare COntro i rischi della navigazione e per la salvaguardia dell'ambiente MARino



MANagement des Risques de l'Erosion cotière et actions de GOuvernance Transfrontalière



GEstione dei REflui per il MIglioramento delle Acque portuali

Stop alle PLASStiche in H2O



asSistenza alla Navigazione per l'Accesso ai Porti in Sicurezza



Partners Istituzionali



Partners Commerciali

