A real-time monitoring system and an early warning system implemented

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PART A

Real-time monitoring system

CHAPTER 1

Introduction

The *real-time monitoring system* for the Veneto coastline is implemented inside the same web application where *the dynamic maps of flooding* is (reference D.5.4.1).
The web application's HomePage is dedicated to data visualization and data interrogation regarding sea levels, tidal forecasts and the flooding forecasts for the Venice city (*the dynamic maps of flooding)*; otherwise the *real-time monitoring system* pages content focus on the time course of the forecast events along the Veneto coastline and performs dynamic auto-updates based on geographic grid forecasts formulated by the forecasting system active on the portal iws.seastorms.eu.
The web app is publicly available at the website https://stream.seastorms.eu/ managed by City of Venice - Centro Previsione e Segnalazione Maree.

CHAPTER 2

Real-time monitoring system

The real time monitoring system allows to monitor the trend of one or more forecast events affecting the Veneto coasts through a monitoring charts displaying various data, such as wave mean direction, period and high and through a dynamic map based on the forecasting system active at Centro Maree on iws.seastorms.eu.

2.1 Overall architecture

The development was carried out inside a Django Framework (version 3.0.06). A vector tile server, Martin, was used to compact and make more efficient the map rendering of the vector tiles containing the geographic data on the client side application. The graphical user interface (GUI) was implemented using the REACT library, specifically using MATERIAL-UI components for faster and easier web development. Build your own design system, or start with Material Design. The coastal zones map was integrated and customized using MapLibre, an open-source JavaScript library. The charts were implemented with EChart React, a JavaScript library that combines the functionality of ECharts, a popular data visualization library, with the flexibility and ease of use of React. It provides React components that wrap the ECharts library, enabling developers to easily integrate interactive and dynamic charts into their React applications. The final layout of the new Web App was customized according to the visual identity of the STREAM project.

2.2 Data harvesting

The geospatial data for the Veneto coastal zones were provided by UniTS, along with the coastal zones geometries were provided also an offshore point for each coastal zone on which the data for wave models will be collected. The real time sea levels data are collected through a semi-automatic harvesting procedure that uses periodic Celery tasks to interrogate Open data site and update the Web App.

The forecasted tidal levels are published from Comune di Venezia on the Open data site, from these endpoints the forecast models are gathered.

Data from two forecast models Pelmo and Shymed were also collected in order to forecast the events along the Veneto coastline. Shymed (SHYFEM on MEDiterranean) is the current operational model at CPSM. This system, based on the SHYFEM model, updates previous systems that are no longer operational. It operates with a computational grid, extended to the Mediterranean and addition of astronomical tide locally. In addition, there are three versions with various wind stress formulations and different corrections of the forecast wind. The forecast is emitted every 12 h, but every hour the forecast is updated by means of a one-dimensional Kalman filter, using the latest observations. For more information on the Shymed forecast model see: M. Bajo and G. Umgiesser, “Storm surge forecast through a combination of dynamic and neural network models,” *Ocean Modelling,* vol. 33, no. 1, pp. 1–9, Jan. 2010, doi: 10.1016/j.ocemod.2009.12.007.

Pelmo is an operational system purposely developed to forecast wind waves in the semi-enclosed Adriatic Sea, with special focus on the northern part of the basin, with the explicit aim of target sea storms that represent a threat to the coastal cities. It is based on the state-of-the-art WAVEWATCHIII® model. For more information about Pelmo forecast model see:

F. Barbariol et al., “Wind-wave forecasting in enclosed basins using statistically downscaled global wind forcing” Frontiers in Marine Science, vol. 9, 2022, https://www.frontiersin.org/articles/10.3389/fmars.2022.1002786. Both models are published at the THREDDS data server of City of Venice, beyond authentication and are queried on a regular basis.

2.3 MeasurementPage on the Web App

In the Web App MeasurementsPage (Fig.1) are visible the chart regarding the wave direction mean, the wave high mean and the wave period mean. The three line charts display the data for Malamocco buoy and Cavallino buoy collected from Comune di Venezia on the Open data site. The x-axis reports the data time coverage and on the y-axis the unit of measure is displayed.

Fig. 1 MeasurementsPage with the three charts. From the top Wave direction mean, Wave high mean and Wave period mean.

The data shown in each chart can be downloaded in .cvs format using the proper download button located on the bottom right of each chart (blue arrow).

On the same page using the date picker placed on the top left is possible to select time period coverage displayed on chart (Fig.2).

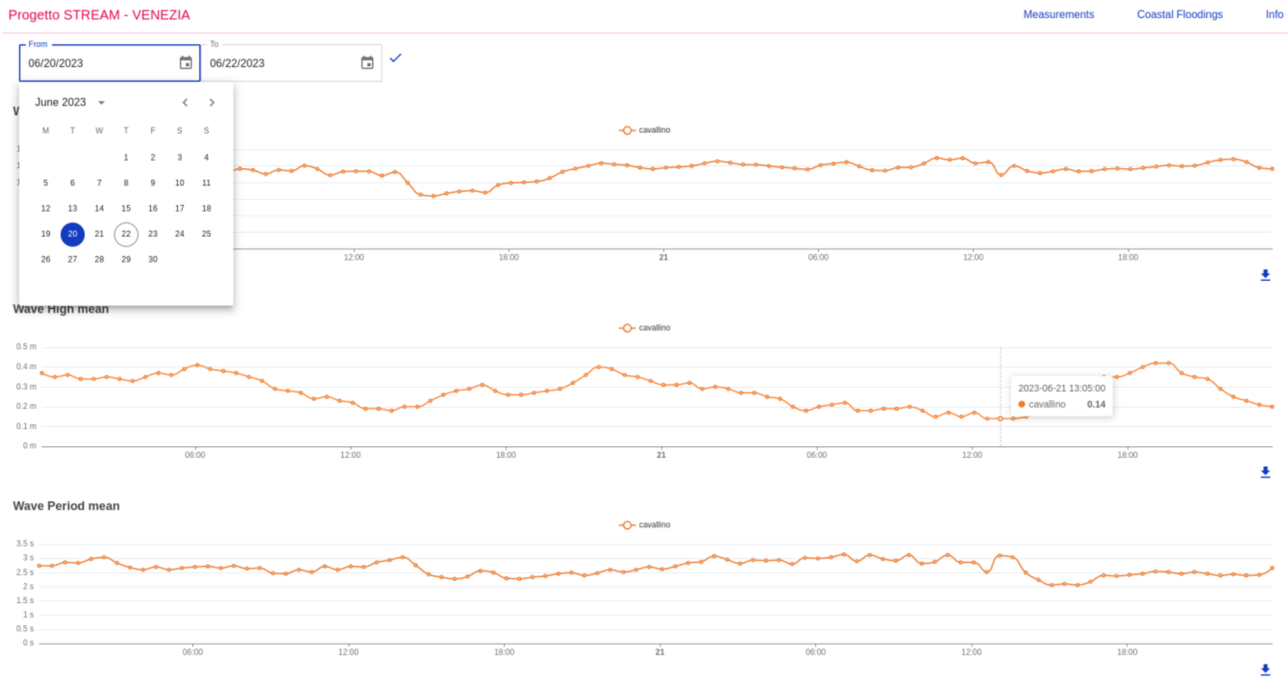

Fig. 2 MeasurementsPage with the three charts. On top left the date picker where it is possible to select the time period start and end date to dynamically change the charts.

2.4 CoastalPage on the Web App

The Web App CoastalPage (Fig.3) the page is divided between two components. On the left the coastal dynamic map of storm surge warning thresholds for the Veneto coast.

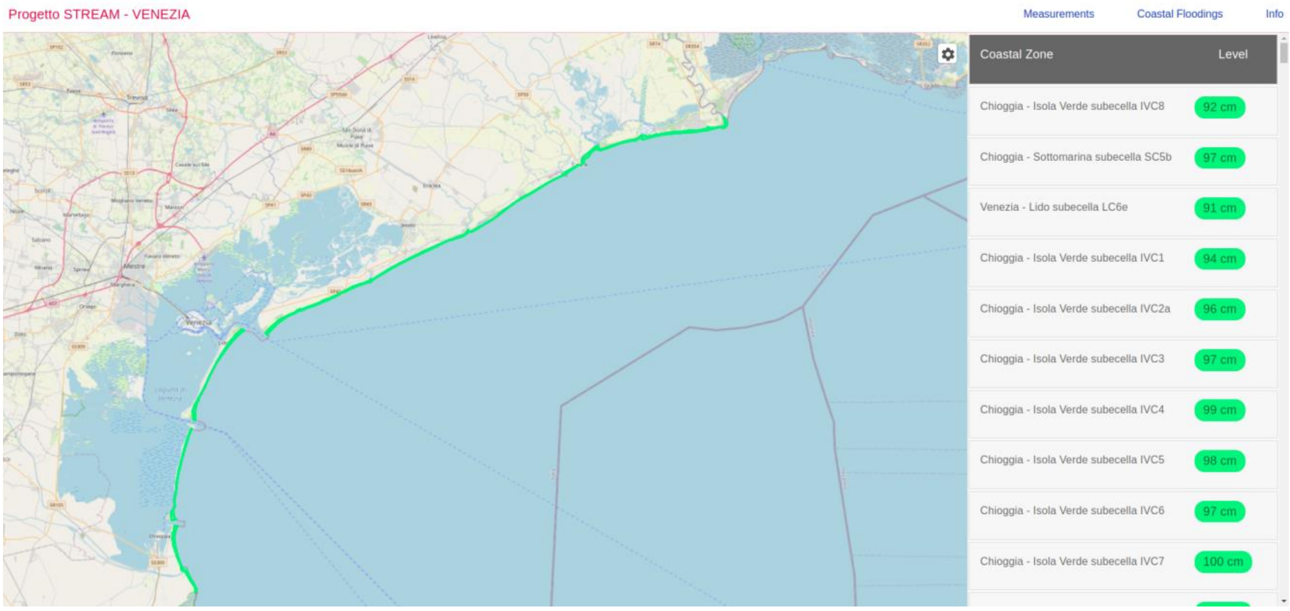

Fig.3 CoastalPage. On the map the geometry of the Veneto coastal zones, on the left the table with the same coastal zones and the score given by the sum of the sea level and the wave high. The zones in this page are color coded: green not affected by the forecasted event, yellow little affected by, orange affected by and red heavily affected by the event.

Based on the data collected during the project and made available through the geoportal section of I-FLOOD infrastructure (iws.seastorms.eu) and the forecast models published by THREDDS data server of the city of venice (thredds.comune.venezia.it) the map is able to show an overview of the entire coast levels of warning, in relation to the expected conditions of the sea through a color scale from green to red where green means ‘not affected by the forecasted event’ and red is ‘heavily affect by the forecasted event’.

2.5 Using the mobile Web App

The mobile version contains the same features of the Web App. The mobile version is possible to access both the MeasurementPage and the CoastalPage and use all the functions available in the Web App mentioned above.

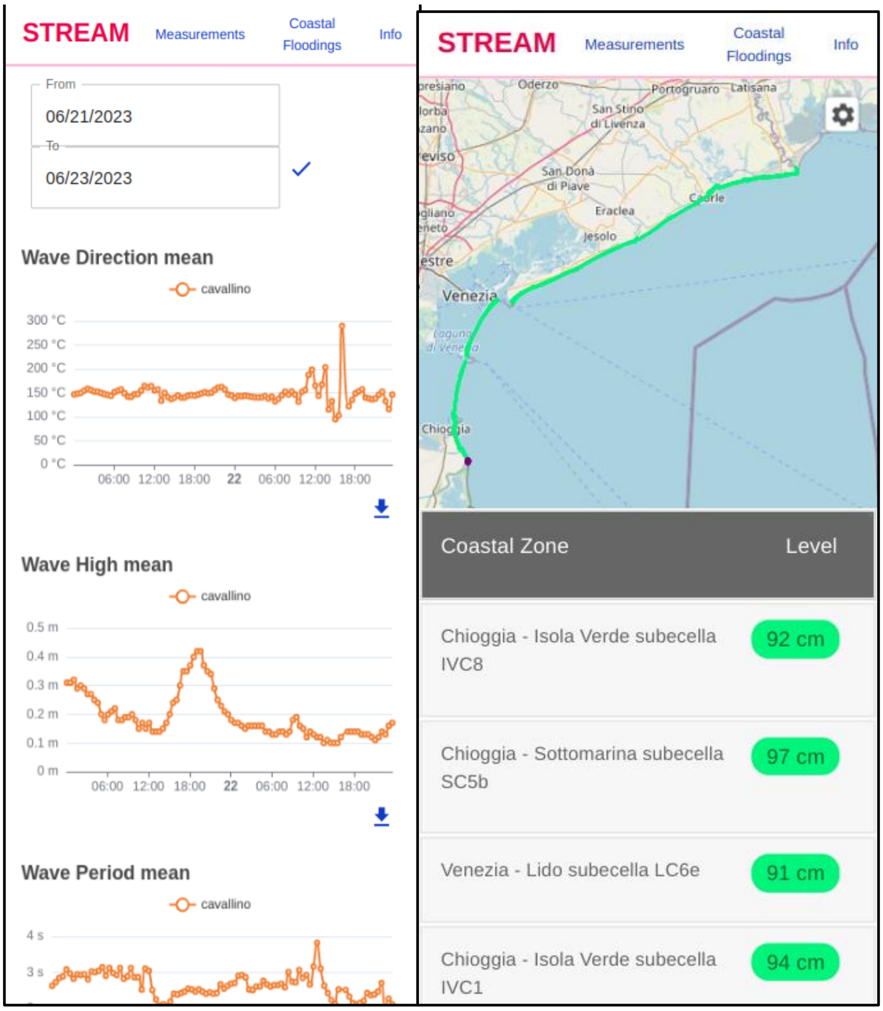

Fig 4. On the left the MeasurementsPage mobile version layout and on the right the CoastalPage mobile version layout.

Hovering the mouse over the coastal zones table list the selected coastal zone highlighted itself on map (Fig.6) making possible the geolocalization of the selected zone on map.

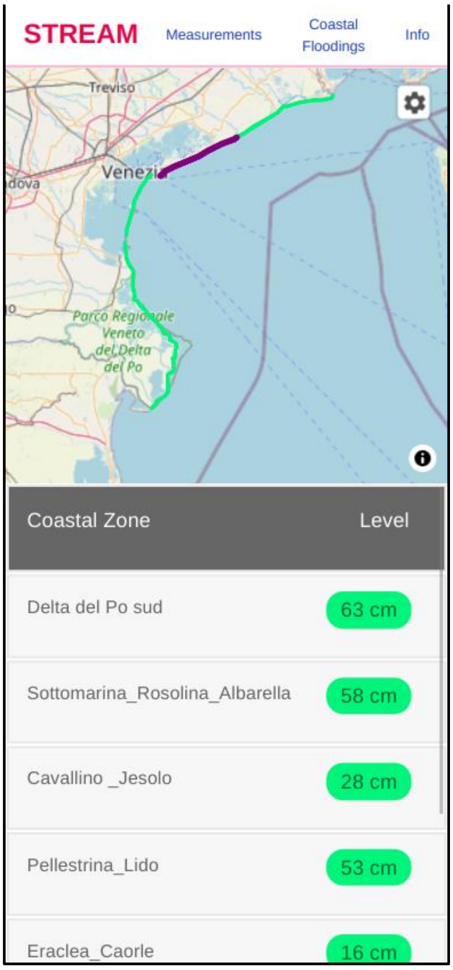

Fig.6 The selected zone highlighted in purple on the map.

Part B

Early Warning System

CHAPTER 3

Early warning proposed

3.1 Introduction

Italy has about 8.300 km of coastline, most of which are densely populated and used for tourism, but also home to important historic centers with a valuable architectural and cultural heritage, as well as port and industrial activities, and not last natural areas of great value. Many are the storm events that come across the coast, causing damage to people and things.
Despite the importance of the coastal sector, nowadays only a few Italian regions bathed by the sea are equipped with a warning system for the risk of storms (coastal flood early warning system) that allows a forecast and a timely recognition of the imminent risks, to alert people and allow them to save people and things. These warning systems are based on knowledge of the specific meteorological characteristics of past events impacting the territory, for the identification of critical thresholds exceeded which the coast must be put in a state of attention. The Veneto Region has developed several warning systems, such as weather, plumbing, or the more specific "Acqua Alta" but is still lacking a real storm warning system. Its coastline stretches for about 150 km, most of which is a tourist destination. A storm warning system would limit the impact of particularly dangerous events on the coast.
As already mentioned, in Italy only some regions have already defined these protocols and it is on the example of them, described in Activity 4, that we have been based on the creation of a coastal storms warning system specific to the Veneto Region.

3.2 Historical Coastal Storms Data for the Veneto Region

The methodologies identified by the other regions are to identify a threshold of significant wave height (Hs) or combined significant wave/ sea level that allows to distinguish a coastal storm from the "ordinary" waves. The analysis of the sea condition data must then be related to that one of the events of the past by identifying critical thresholds, exceeded which the storms have had harmful impacts on the coast.

3.2.1 Data origin

The identification of critical alert thresholds is based on the activity of creating an archive of data relating to coastal storm events affecting the Venetian coasts for the period between 1980 and 2022, whose results are merged into the SeaStorms database. The creation of this archive required a precise research work that included the following steps:

(i) recognition of existing projects, archives / databases concerning the Veneto region or the surrounding areas:

a. Catalogo SeaStorms Atlas catalogue https://seastorms.eu/sea_storm_atlas/segment/list;
b. FloodCat database www.mydewetra.org,
c. MICORE historical coastal storms catalogue (https://ambiente.regione.emilia-romagna.it/it/geologia/geologia/costa/il-catalogo-delle-mareggiate),
d. in_storm catalogue from Emilia Romagna Region https://ambiente.regione.emilia-romagna.it/it/geologia/geologia/costa/in_storm-il-sistema-informativo-per-la-gestione-delle-mareggiate,
e. RiscKit catalogue http://risckit.cloudapp.net/risckit/#/,
f. Civil Protection of Veneto Region https://www.regione.veneto.it/web/protezione-civile.

(ii) Recognition from the press, blogs and websites, reports and scientific articles, official decrees of the Civil Protection (https://www.regione.veneto.it/web/protezione-civile/coordinamento-regionale-in-emergenza), identifying a series of high waters and storms with damage to Venice and the coasts of Veneto

(iii) Collection of physical data (waves, directions and levels), to be associated with each identified event. The data relating to the height and direction of the waves are extracted from the CNR-ISMAR Platform "Acqua Alta" (Pomaro et al, 2017 and 2018) while those of level, especially, from the Punta Salute mareograph and, in small part, from the recordings of the Platform (https://www.comune.venezia.it/it/content/centro-previsioni-%C3%A9-segnalazioni-m%C3%A0ree).

(iv) construction of a database consisting of two macro-compartments: PHYSICAL DATA and IMPACTS.

In this way, 79 storm events were identified for the coasts of the Veneto Region during the period considered.

3.2.2 Data analysis

The elaborations carried out on the physical data for the 79 identified events have allowed to define that most of the storms impacting on the Venetian coast are to be attributed to winds coming mainly from the first and second quadrant, that is winds of Bora-Levante and, above all, Scirocco (Fig. 1 A and B).

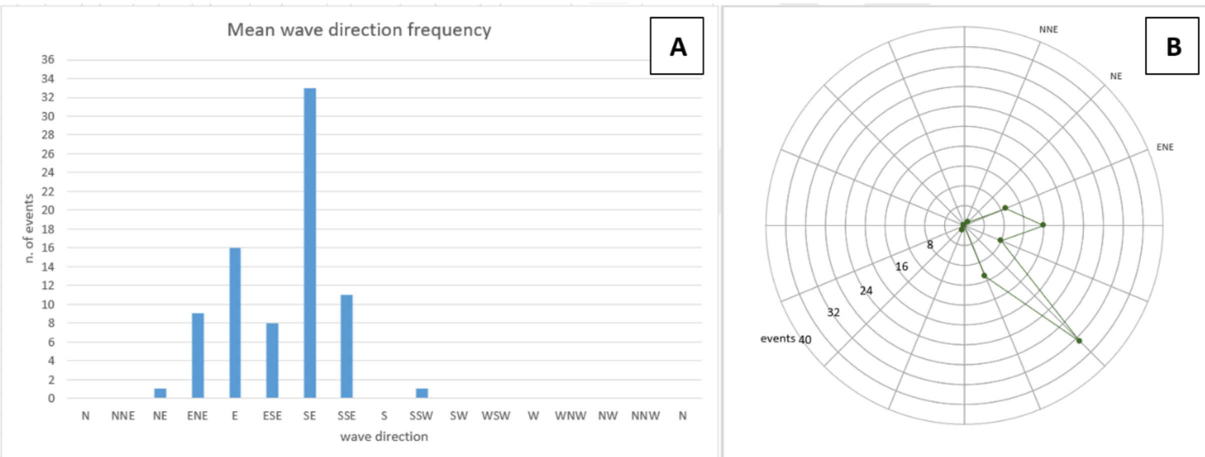

Fig. 1 A and B Average wave/wind direction frequency for the 79 events identified between 1980 and 2022.

Fig. 2 shows the frequency of the maximum significant heights (Hsmax) reached during the selected events. It can be noted that the most frequently reached Hsmax are those corresponding to the range between 2.5 - 3 m.

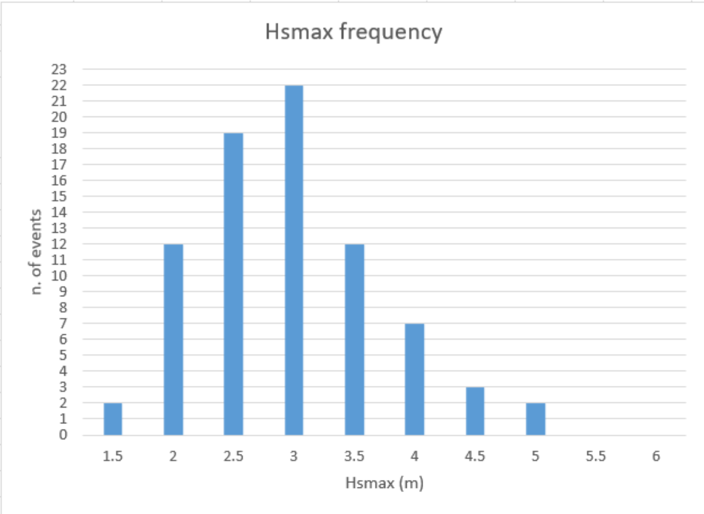

Fig. 2 Frequency of the maximum Hs for the 79 events selected between 1980 and 2022.

The water level values most frequently reached during coastal storms event covered the range between 110 and 120 cm (Fig. 3).

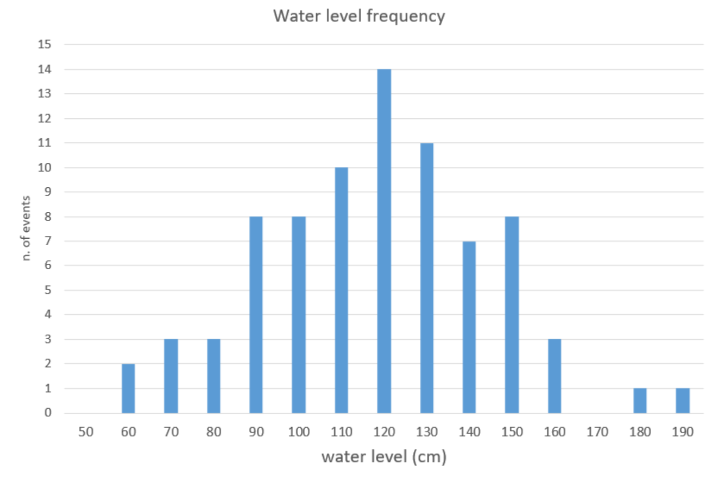

Fig. 3 Frequency of water level for the 79 events identified between 1980 and 2022.

Total water level values, this time only for storms detected between 1983 and 2022 (lack of hourly tidal level data between 1980 and 1983) show a higher frequency of events with a total level (therefore including Hs and tidal level) between 3.0-3.5 m (Fig. 4).

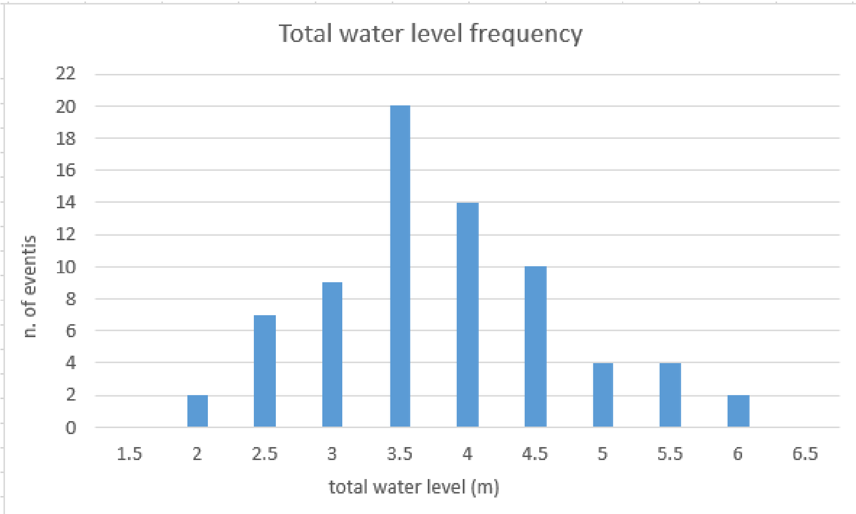

Fig. 4 Total water level frequency (including tidal and significant wave height) for events detected between 1983 and 2022.

Analyzing the sea condition data of the storms described in the official decrees of the Civil Protection (Tab. 2) and based on experience in other Italian regions, it was proposed a categorization of the impacts, attributing a color ranging from yellow, orange, red depending on the gravity of the damages (Tab. 2):

Tab. 1 Type of impact and color attribution.

Type of impact	Color attribution
waste beached	Yellow
coastal erosion lagoon silting washover	Orange
works of defense damages portual damages flooding	Red

To the storms identified and described in the decrees of the Civil Protection was attributed the same color of the impact that had caused the coast (Tab. 2).

Tab. 2 Storms described in the decrees of the Civil Protection of the Veneto Region and color assignment.

n. event	Event date	Hs max	Water level	Total water level	Worst damages	Color attribution
36	23-26/12/2010	2.43	144	3.70	embankment swept over	◆
37	31/10-1/11/2012	4.1	143	5.02	artificial cliff damages	◆
38	10-13/11/2012	2.85	149	4.33	artificial cliff damages	◆
40	16/05/2013	2.53	110	3.61	waste beached	◆
45	05-07/02/2015	3.76	124	4.45	portual structures damages	◆
47	14/09/2015	1.57	86	2.23	coastal erosion	◆
50	2-3/03/2016	2.92	100	3.36	coastal erosion	◆
52	16-17/6/2016	2.13	117	3.21	coastal erosion	◆◆
62	27-30/10/2018	3.97	156	5.23	VAIA event	
67	12-29/11/2019	3.22	187	4.50	ACQUA GRANDA event	◆
68	02-09/12/2020	3.37	138	4.21	balnear structures damages	◆
79	22/11/2022	3.95	173	4.97	works of defense damages	◆

3.3 First proposal for alert threshold

On the basis of the data collected, elaborations and experience in other regions of Italy, it is therefore proposed, as a first
hypothesis, to use an alert system based on the following total water level thresholds, past which should be provided for appropriate containment or safety measures (Tab. 3).

Tab. 3 Proposed total water level thresholds, with color assignment.

Proposed thresholds	Color attribution
?	Yellow
>2 m	Orange
>3.5 m	Red

Graph of Fig. 5 shows the distribution of the coastal storms entered in the database for which there are all the information related to the total water level and the 12 storms for which the state of emergency has been declared by the Civil Protection.

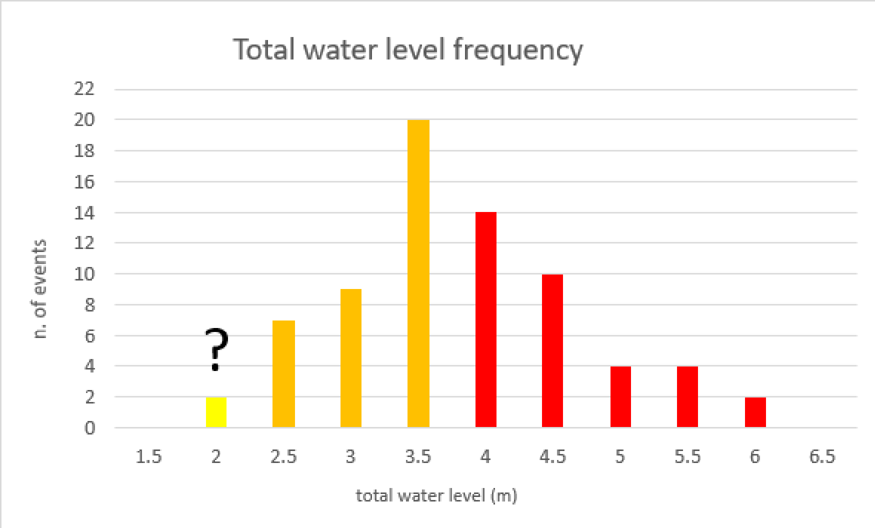

Fig. 5 Distribution of the 53 swells in the time interval between 1983 and 2022. The diamonds represent the storms from Decrees of Civil Protection illustrated above.

From the graph it can be seen that the events above the 3.5 m of total level have had rather heavy impacts on the coast, except for a single event (that of 16/05/2013) where is reported as the main damage the waste beached. Coastal erosion appears to occur above 2 m of the total water level, but there is not enough data to determine which is the lower threshold or the point of separation between the orange and yellow color.
As mentioned before, this is a first hypothesis of defining thresholds. The official definition will be responsibility of the Civil Protection of the Veneto Region.

3.4 Different coastal zones proposal

3.4.1 Hindcast data from model

The Veneto coast has very different orientations and for this reason a doubt was if it is necessary identify different alert thresholds for different coastal sectors. The Venetian coast was then divided into 7 homogeneous coastal sectors for orientation: Bibione-Brussa, Caorle-Eraclea, Jesolo-Cavallino, Lido-Pellestrina, Sottomarina-Isola Verde, Po Delta North, Po Delta South. For each section, a point has been identified offshore (about 10 km from the coast) where to extract the Hindcast data of each of the storms identified between 1994 and 2019 (period of action of the Hindcast dataset). The sea conditions data obtained in this way allowed to obtain more detailed information about the behaviour of a certain coastal storm on a certain stretch of coast.

The total water level data (including Hs and tidal level) of storms of each sector were correlated with the total water level data of the same storms extracted from the platform. The data were then distinguished according to the direction of origin of the waves. Also, these data are taken from the position of the platform. As an example, the Jesolo-Cavallino and Po Delta North sectors are shown in the Fig. 6: the represent the extremes of the indagated area:

Fig. 6 Jesolo-Cavallino and Po Delta North sectors, correlation between the total water level data extracted at the point off the two sectors compared to those extracted from the platform. In blue: directional sector Bora - Levante; in yellow: directional sector Scirocco.

From the Fig. 6 it is noted that the sector Jesolo-Cavallino is invested with more force by events from the second quadrant (Scirocco), with a damping of only 9% compared to the height extracted at the position of the platform. The events from the first quadrant (Bora-Levante) come with a greater damping, equal to 22%. On the other hand, the Po Delta North sector, exposed to Northeast seas, even shows a slight amplification of the total level heights caused by storms from the first sector (Bora-Levante), while showing a 23% damping for the Scirocco seas. This sector is in fact placed perpendicular to the direction of the Bora (which here arrives with force having covered its maximum fetch) but is sheltered by the delta itself with respect to the direction of the Scirocco.

3.4.2 Recorded data

The analysis and the results obtained through the hindcast data extracted from the model are also supported by the analysis of the events that are part of our database: considering some hotspot zones for the most important events a similar role of the orientation towards the Hs reached by the events of the past is confirmed.
Only half of the 79 selected storm events reported information about the affected locality and not all of the Veneto coastline was covered by this information. It was then possible to group events for only 4 of the 7 sectors of coastline identified by orientation: Bibione-Brussa, Caorle-Eraclea, Jesolo-Cavallino e Sottomarina-Isola Verde. As an example, here are 2 sections, the northern one Bibione-Brussa (Fig. 7 A) and Sottomarina-Isola Verde with a different coastline orientations (Fig. 7 B). It is possible to note a different exposition to Bora-Levante or Scirocco sea (Fig. 7 A e B):

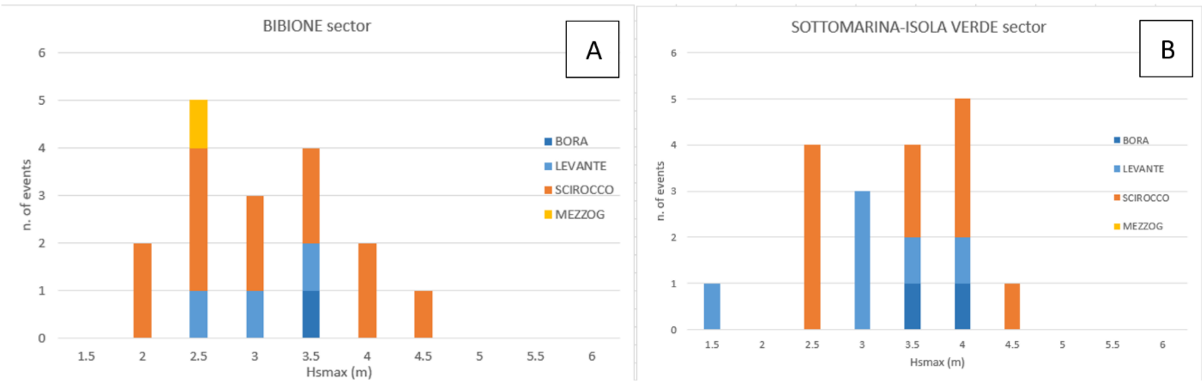

Fig. 7 Frequency of the Hsmax for the events that hit the coast of Bibione - Brussa (A) or that of Sottomarina - Isola Verde (B), distinguished by wind directions.

Fig. 7 A and B also pays attention to the fact that the northernmost coasts are more exposed to the winds of Scirocco (e.g. Bibione-Brussa), conversely those located further south are also affected by a fair number of events from Bora-Levante (e.g. Sottomarina-Isola Verde).

3.5 Conclusions

The data collected so far can give a lot of information about the wave climate in the North Adriatic, mainly off the Venetian coast. A first hypothesis of thresholds has been formulated on the basis of information from the data on the damage caused by the heaviest storms. They are few and an extension of this database would be necessary to the collection of further information to define a solid storm warning system.

CHAPTER 4

Early warning system: state of the art in Italy

4.1 Introduction

"*Alerting means all forecasting activities based on available knowledge, real-time monitoring and surveillance of events and the subsequent evolution of risk scenarios, in order to activate the civil protection system at different territorial levels.*" This is the definition of alert system by the Emilia Romagna Region, one of the Italian regions with the highest number of monitoring on phenomenology that can impact the territory. Each of the Italian Regions has been equipped with different monitoring and alert systems that provide continuous observation of the criticality of the phenomena and a dedicated alert system. The most frequent monitoring and warning systems are meteorological, hydro-geological and hydraulic, including storms, landslides and floods. Some regions are equipped with monitoring systems that also cover extreme temperatures (heat waves, cold) or heavy snowfalls and avalanches. Others assess the risk of volcanic, seismic and forest fires. However, in most Italian regions, despite 15 of them facing the sea, there is no system of alerting and monitoring coastal storms. It is only issued as a forecast weather report where the sea conditions are also reported (little rough, rough or very rough). The Veneto Region, despite being equipped with weather warning systems, avalanches, snow and a specific and very advanced warning system for high water for the city of Venice, is not equipped with a coastal warning system for storm events. Project Stream has among its objectives a first response to this need.

4.2 The warning systems in Italy

All the Italian regions have divided their territory into homogeneous territorial areas for danger, called *alert zones*. At regular intervals, the forecast parameters of meteorological, hydrogeological, hydraulic phenomena, etc. are analyzed and a risk statement is issued. At European level, a very intuitive methodology has been adopted to make people aware of the risks present in the territory at a certain time and in a certain place: a different color ranging from green (no risk) to red (situation of maximum risk), passing through intermediate colors, such as yellow (ordinary risk) and orange (moderate risk) as shown in Tab. 4:

Tab. 4 Meaning of the warning coloring (table from Technical Annex DGRT 536/2013 and 895/2013).

color	meaning
GREEN	there will be no intense and dangerous phenomena
YELLOW	intense phenomena, **locally dangerous** or dangerous for the performance of particular activities.
ORANGE	predicted phenomena more intense than normal, **dangerous** for things and people.
RED	predicted extreme phenomena, **very dangerous** for things and people.

Color is assigned based on both the probability of occurrence of the event and possible impacts. Each color involves a different activation of the civil protection system and suggests behavior of self-protection by citizens.
As already mentioned, few Italian Regions are also equipped with a storm warning system. These include the Tuscany Region and the Emilia Romagna Region.

4.2.1 Tuscany Region

The Tuscan territory is divided into 26 alert zones and on each, once a day at 13:00, the Functional Center analyzes and summarizes the predictions for the next 36 hours on criticalities evaluated relative to each risk. Information is issued via Bulletin and displayed on maps, with risks highlighted with different colors (Fig. 8).

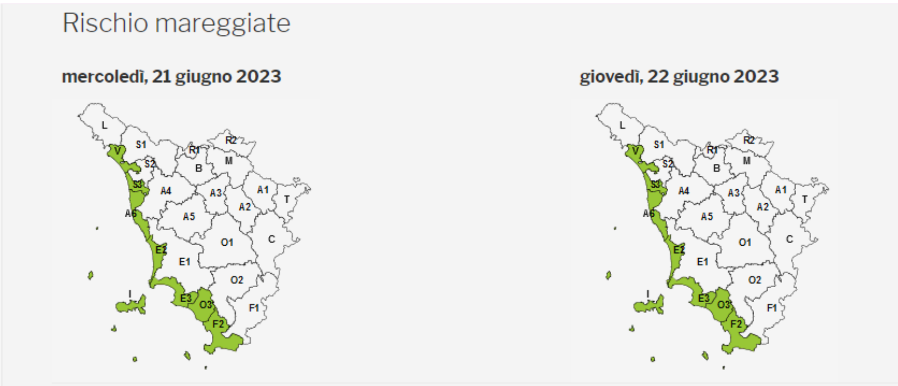

Fig. 8 Example of coastal storms warning for alert zones on the Tuscan coast (tratto da: https://www.regione.toscana.it/allertameteo)

The criticality related to coastal storms is evaluated based on the significant height of the wave offshore. The risk is reported when the phenomenon is expected to last at least 6 hours. The alert also assesses the possible damage along the coast.
The table below, published on the site of the Functional Center of the Tuscany Region, summarizes the principal possible expected effects and the recommended rules of self-behavior for each type of criticality (Tab. 5):

Tab. 5 Summary of possible expected effects and suggested behavioural norms during the issuance of an alert (taken from: https://www.regione.toscana.it/-/rischio-mareggiate).

Alert code	What is forecasting	How to behave
GREEN	***Sea from calm to very rough***	Prepare a list of useful numbers in case of emergency in general, especially at sea.
YELLOW	***Rough offshore sea, locally also very rough, waves wide up to 4m high.*** Bathing establishment problems	Keep up to date on the evolution of weather conditions Avoid recreational sports, swimming and nautical activities at sea.
ORANGE	***Very rough offshore sea, locally also big, waves wide up to 6m of height*** Bathing establishment damages Coastal erosion Warning navigation	Avoid, if possible, passing in the road sections close to the coast or shore
RED	***Large offshore sea, waves over 6m high*** Extreme danger	Secure recreational craft and any many movable property that can be reached by abnormal waves before the storm

4.2.2 Emilia – Romagna Region

Emilia Romagna is one of the regions with the highest number of monitoring and alert systems in place. They cover river floods, landslides, thunderstorms, wind, snow, avalanches and more (Fig. 9). In addition, it has developed an articulated coastal storm warning system that involves the use of different operators and passages before defining a level of alert.
The region has come to this point after many studies and many years of research, at first it began with finding information on the storms that in the past had affected the coast of Emilia - Romagna. The system Early warning of Emilia-Romagna is started in experimental mode since December 2012. Today it is operating and provides daily prediction of the potential impacts of a storm on the coast with an advance of about 72 hours.
One of its main objectives is the ability to predict with sufficient warning and accuracy both the extent of dune erosion, the location, timing and extent of marine floods along this coast. To this end, a chain of atmospheric, hydrodynamic and morphodynamic models are performed daily to obtain a 3-day prediction of coastal risk in various strategic locations along the coast.

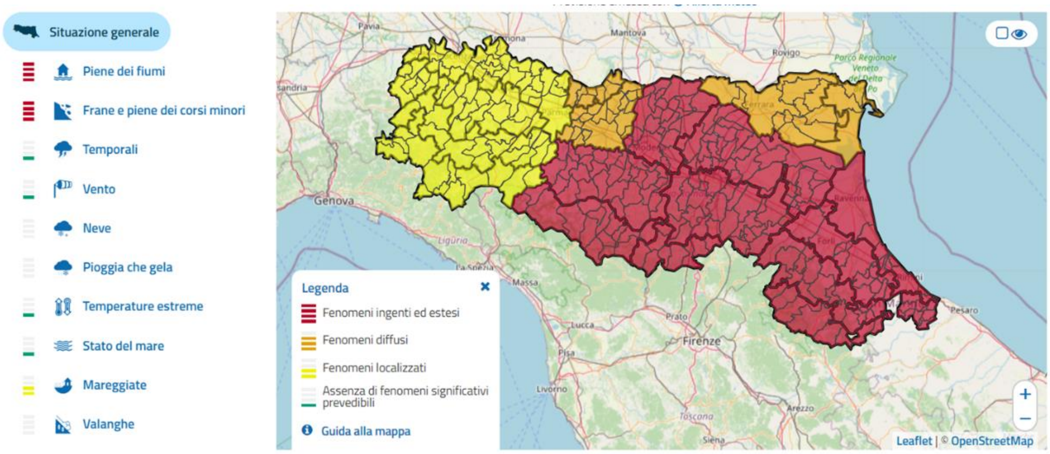

Fig. 9 Map of Emilia Romagna Region that identifies the flooding during the disastrous flood of May 2023 (Taken from: https://allertameteo.regione.emilia-romagna.it/).

The main steps are:

1. 3-day wave and water-level forecasts are undertaken daily by ARPA-SIMC through its meteomarine operational forecasting system (Russo et al., 2013), based on model SWAN, COSMO-I7 e ROMS (Regional Ocean Modeling System).

2. Based on the wave climate forecast in the open sea, the expected behaviour of the beach morphology is monitored on a series of 22 transverse profiles corresponding to 8 coastal sites (Fig. 10). Here runs the Xbeach model (two-dimensional medium depth model that solves cross-shore and alongshore coupled equation for wave propagation, flow, sediment transport and bottom level variations (Roelvink et al., 2009).

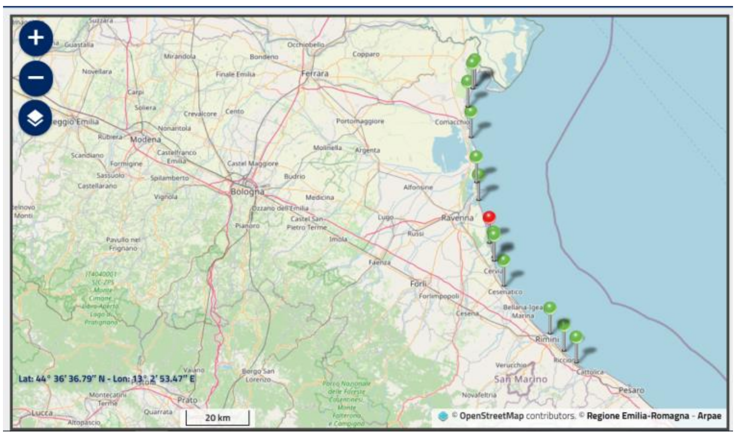

Fig. 10 Some of the transverse profiles located along the coast of Emilia - Romagna. Only after a complex forecasting and decision-making process, the alert is issued (Taken from: https://geo.regione.emilia-romagna.it/schede/ews/).

3. Two different indicators are used to translate XBeach's predictions into storm hazard indicators, depending on whether the coastline is urbanised or in its natural state (Fig. 11).

If the respective thresholds are exceeded, it activates the expert staff who has the last decision word and the alert is issued.

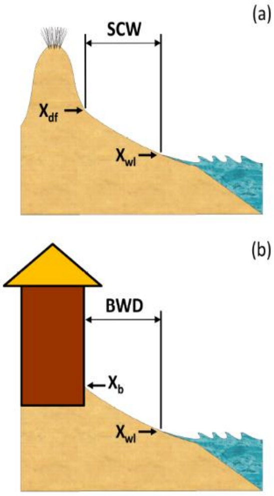

Fig. 11 The two indicators of storm impact; SCW: Safe Corridor Width BWD: Building waterline distance (taken from: Harley et al., 2015).

SCW: Safe Corridor Width, measure the amount of dry beach available between the foot of the dune and the water level for safe passage of beach users.
BWD: Building Waterline Distance, measures the amount of dry beach available between the sea edge of a building and the water level for safe passage of beach users.

The Fig. 12 A and B show the forecast of the width of the stretch of dry coastline for a site profile in a natural area (Fig. 12 A) and for one in the urbanized area (Fig. 12 B).

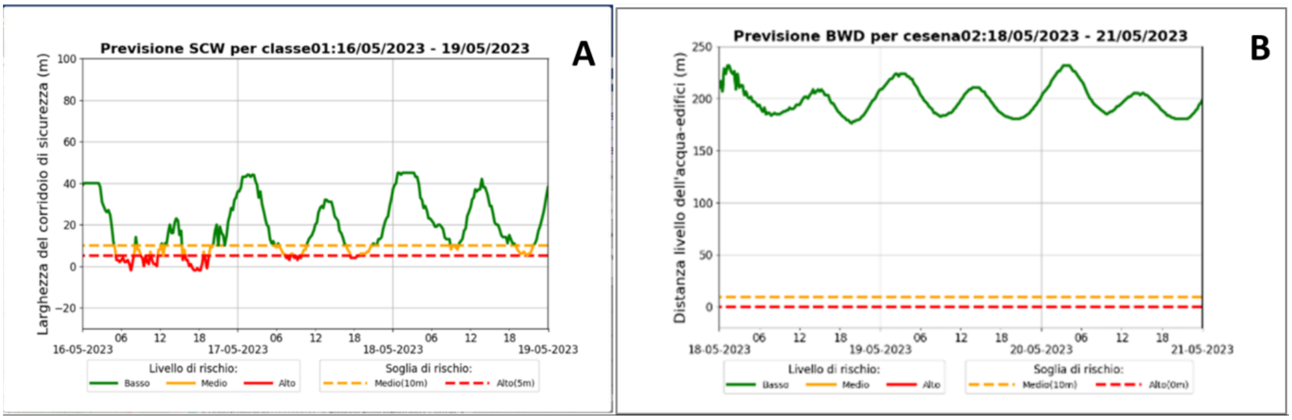

Fig. 12 Example of forecasts for a natural (A) and an urbanized (B) section.

In sectors of natural coastline (Fig. 12 A) the threshold of 10 m is used to separate low risk (green) from medium risk (orange) conditions. The 5 m threshold is used to separate the medium risk (orange) and high risk (red) condition.
In urbanized coastal sectors, the threshold of 10 m is used to separate low risk (green) from medium risk (orange) conditions and the threshold of 0 m to separate the medium risk (orange) and high risk (red) conditions. 0 m means FLOOD (Fig. 12 B).
The alerts are published on the portal "Allerta Meteo Emilia-Romagna", operating 24 hours a day and 365 days a year, managed by the Agency for Territorial Security and Civil Protection of Emilia-Romagna and Arpae Emilia-Romagna (https://allertameteo.regione.emilia-romagna.it/il-progetto-allerte-emilia-romagna).

4.3 Conclusions

Today, the Emilia-Romagna protocol is the most reliable example from which Veneto might draw inspiration when designing a storm warning system. The two regions really border each other and share numerous similarities. Together with the findings obtained throughout the course of the current project, the Emilia-Romagna methodology can serve as a beginning point for the creation of a methodology that can face future challenges.

CHAPTER 5

Proposed operational protocol for ordinary and post-event coastal morphological monitoring

With regard to the Horizon 2020 ECFAS project, this activity involved gathering knowledge from literature on pre/post storm event monitoring techniques and methods.

5.1 General structure

Effective planning is necessary for the management of emergency situations, and this planning can be organised within a cycle model that is often defined in five key phases (UN-SPIDER, UNEP 2012):

1. Early warning: early prediction and recognition of imminent risks, to alert people and enable them to get to safety.
2. Early impact (Response-Rapid Mapping): provision of emergency services and public assistance during or immediately after a disaster. The products normally provided are maps and geo-spatial data, with accuracy varying according to delivery times and needs.

3. Recovery: reconstruction and improvement, if necessary, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce the risk factors of the disaster itself.
4. Mitigation: reduction of negative impacts and related disasters.
5. Preparedness: knowledge and capabilities developed by authorities, recovery organisations, communities and individuals to effectively anticipate impact, respond to it and subsequently recover from probable, imminent or ongoing hazard events.

In order to provide early impact-early response-rapid mapping data and make it available to the required authorities, many projects have been established and put into practise by several international bodies, according to Toschi and Remondino (2016).

5.1.1 EU Horizon 2020 ECFAS Project and the Early Warning System

The European Flood Awareness System (EFAS, 2016; in activity since 2012) and the Global Flood Awareness System (GloFAS, 2017; in activity since 2017) are systems that aim to provide timely flood information to national authorities to support national capabilities, in particular with early and probabilistic information. EFAS also provides information to the Emergency Response Coordination Centre (ERCC) of the European Commision to support flood disaster response (Poljanšek et al., 2017).

Specifically, to the coastal area, the EU launched in 2021 the project "A Proof-Of-Concept for the Implementation of a European Copernicus Coastal Flood Awareness System (or simply ECFAS). The ECFAS project contributed to the evolution of the Copernicus Emergency Management Service (CEMS). It has also contributed to the integrated risk monitoring service through the implementation of an awareness-raising system specifically targeted at coastal areas (preparation phase) and impact assessment (response phase) following a flood event. A representative scheme of the whole system is seen from the Fig. 13.

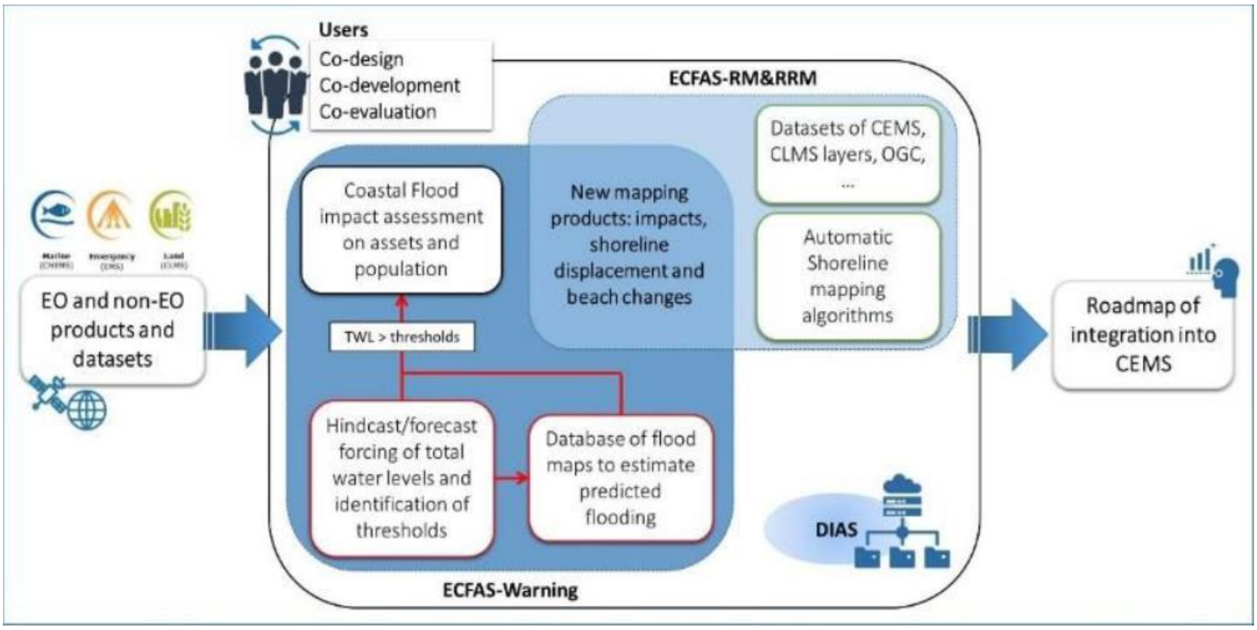

Fig. 13 ECFAS model (https://cordis.europa.eu/project/id/101004211/results/it).

More information on the procedures and results of the project can be consulted by the ECFAS derivables present at this Internet address https://cordis.europa.eu/project/id/101004211/results/it.

An alert system is therefore essential in this context. Early warning (EW) is defined as "the forecast of timely and effective information, through identified institutions, which will enable persons exposed to a hazard to take measures to avoid or reduce risk and prepare for an effective response". The early warning system (EWS) instead defines a technological infrastructure that can help to carry out these tasks.

The early warning therefore concerns not only the ability to accurately predict a storm event in a timely manner, but also the behaviour of the people in response to such an alert (Pescaroli and Magni, 2015). To implement effective alert systems, it is necessary to understand what is danger and where the vulnerable areas are located (Perini et al., 2016; Lapidez et al., 2015). Such information requires a high-resolution monitoring to produce quality maps for end users and identify the regional vulnerability. Furthermore, continuous monitoring makes it possible to assess the ability to deal with more extreme and less frequent events when they occur (Perini et al., 2016). This highlights the need to catalog storm levels at the time they occur (as done by Wadey et al., 2015), which also provides a base for establishing any prior conditions that contribute to increasing coastal vulnerability (see also Dissanayake et al., 2015).

Lack of standardized monitoring to enable the uniformly popularization of the instrument is one obstacle to moving such instruments from local to national scale (Knight et al., 2015).

5.1.2 Monitoring the effects on the coast of extreme events

Post-storm assessments require capturing the morphological marking of the event using rapid, quantitative mapping as soon as safety conditions permit, after the event, but before recovery processes (i.e., natural or human-led) begin. This data can be difficult to obtain, as traditional post-storm investigation techniques are costly or time-consuming on a large scale.

To correctly quantify impacts, a quantitative mapping of the area is necessary before a storm and its damages occur (pre-event measurements). In recent years, methodologies for coastal mapping and impact assessment of extreme events have been proposed and tested in order to improve traditional, costly and time-consuming mapping approaches, both as regards the beach emerged both as regards the beach of submarine.

As concern the beach emerged, below are the main methodologies for monitoring:

- Real-Time Kinematic Geographical Positions Systems (RTK GPS), for ground surveys, are the traditional method for topographical data, requiring highly accurate (sub-decimetric) positioning measurements. These systems are used in coastal environments for temporal and spatial monitoring of many morphological characteristics through periodic monitoring and post-event surveys. However, since the density of the sampling points of the GPS RTK survey affects the accuracy of the representation of the morphology of the beach (e.g. digital models of the terrain), insufficient resolutions (for example data acquisition through profiles spaced over 100 m) can lead to inaccurate or misleading morphological interpretations of storm impacts;
- Terrestrial laser scanners improve point density, but require time and physical efforts similar to GPS RTK, particularly when large areas are detecting;
- Aircraft lasers (lidar) and recent satellite images are significantly improved in terms of resolution, but the high costs of operations and the low frequency of measurements make these options impractical for local scales and for rapid or frequently repeated measurements ;
- Uncrewed aerial vehicles (UAVs), informally known as "drones", attempt to solve the problems of local time and space sampling due to the speed of use, the economic feasibility and accuracy of high-resolution topographical data in monitoring changes in the coastal zone in the pre- and post-event period;
- Interviewing the local population in the immediacy of an extreme coastal event provides important information on the local evolution of the storm, on the effectiveness of emergency preparedness and on the response phases.

To detect morphological changes, a "base state" of pre-storm conditions is necessary. Typically, the pre-event survey, which consists of a topo-bathymetric survey, should be performed whenever it is possible to acquire data, with sufficient time and resources. However, it is particularly necessary to do so especially (i) at sites where major morphological changes occur in a short time and/or (ii) when no other baseline data are available. In all other cases, it can be assumed that the baseline is the most recent topo-bathymetric data set available. As concern the post-event data collection, ideally, it must be activated and completed as soon as possible, before the start of the processes of restoration of beaches (natural or anthropic).

In the literature there are examples of post-event monitoring ranging from detailed topographic survey to satellite data analysis. However, in our opinion the most complete system is the one indicated in the publication of Duo et al. (2018) in which is reported an example of rapid monitoring protocol applied in the coast of Lido degli Estensi following a storm event occurred between 5 and 7 February 2015.

The publication developed a local approach for post-storm field investigations, hereinafter referred to as the quick-response protocol (or quick-response protocol, QRP), implemented by a team of detectors, called quick-team response (QRT), and developed by integrating Emilia-Romagna Early Warning System inputs, RTK GPS and APR detection techniques, interviews with local stakeholders and damage observation.

5.2 Proposed protocol

A prospective pre- and post-event monitoring procedure for the Veneto is proposed below, based on the basic concepts gathered from the international literature on storm effects and post-storm reconstruction, as well as the first protocol conducted in the Emilia Romagna and published by Duo et al (2018).

STEP 1: PREPARE AND PLANNING

The first pre-event phases are summarized here.

1. collect earlier coastline information (orthophotos, DSM and DTM of the sandy shore, bathymetry, topographic beach sections, sedimentological data, etc...) to have a "state of the art" or "time zero" with which to make comparisons;
2. if there is no current data or no topo-bathymetric data for the area, it is critical to move quickly and organise a survey campaign. This technique must be implemented before the start of the autumn season, when the first and often most significant sea storms occur statistically;
3. identify at least one "type" profile representing the unit and at least one profile showing the area's greatest criticality for each physiographic unit. In this manner, it is possible to perform comparisons by section in the aftermath of a storm, as well as to allow for calibration in calculating the modification of the beach profile following a storm event forecast (see X-

Beach). It is preferable for the profile assessment to encompass the shoreface as well as the subaerial portion;

4. to identify areas with historical erosion hotspots of particular interest to the Region for recurrent monitoring, as well as areas with complete beach-dune systems where the reaction of these environments to intense events can be observed.
5. it is useful to install fixed webcams along the shoreline in the pre-autumn period; these installations will allow, during the autumn-winter-spring period, to acquire additional data that will lead, through the analysis of storm event frames with special machine learning algorithms, to be able to parameterise wave, surge, and tide data, as well as monitor beach conditions (e.g. shoreline position) and be of assistance in the preparation of surveys.

<u>STEP 2: EARLY WARNING</u>

The establishment of an EWS as indicated by CHAPTER 1 also includes the activation of the procedures foreseen in the next step and the identification of areas subject to impact.

<u>STEP 3: POST-EVENT SURVEYS</u>

Here are the essential procedures to better monitor in the post-event the beach areas decided in the FIRST STEP:

1. assessing satellite images (e.g., Copernicus Sentinel) and webcams deployed on the littoral to confirm the likely formation of massive sedimentary overflows (e.g., washover) and planning a survey campaign;
2. to confirm that the surveys' safety conditions are assured;
3. in the case of concession beaches, ensure that there is no sand movement, removal of beached waste, or placement of potential seasonal barriers until the surveys are completed;
4. take note of any evident damage to coastal defences, buildings, or infrastructure;
5. photographing and mapping by RTK GPS the water penetration limit in the shoreline (evidenced by the presence of objects and debris moved inland during the storm) and the vertical flood levels (i.e. the water level at a specific point, clearly visible on structures and dunes);
6. conduct an aerophotogrammetric or Lidar beach survey using UAV flights and RTK GPS for profiles
7. conduct bathymetric surveys to detect morphological changes and estimate potential changes in the sediment budget;
8. interviews with citizens, restaurateurs, and other area stakeholders to get information on their reactions to the occurrence and to determine the effectiveness of the warning system;
9. in the event of storm surges or 'high water,' it is preferable that local Civil Defence volunteer teams carry out (where possible and avoiding all dynamically dangerous areas) measurements of the water head within built-up areas (a graduated rod is sufficient),

marking the time and noting the location. Any additional annotation in the course of occurrence is critical, especially to highlight points of flooding.

All of these measurements and observations are critical for tracking coastal flooding models and determining the point of countermeasure.

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