Smart Control of the Climate Resilience in European Coastal Cities

STORM SURGES AND SEA WATER LEVEL

FUTURE PROJECTIONS

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CNR-IAS, Oristano, Italy

Thursday, 18 January 2024
11:00 a.m.- 12:00 p.m. (CET)

CONSORZIO LaMMA

Ollscoil Teicneolaíochta an Atlantaigh
Atlantic Technological University

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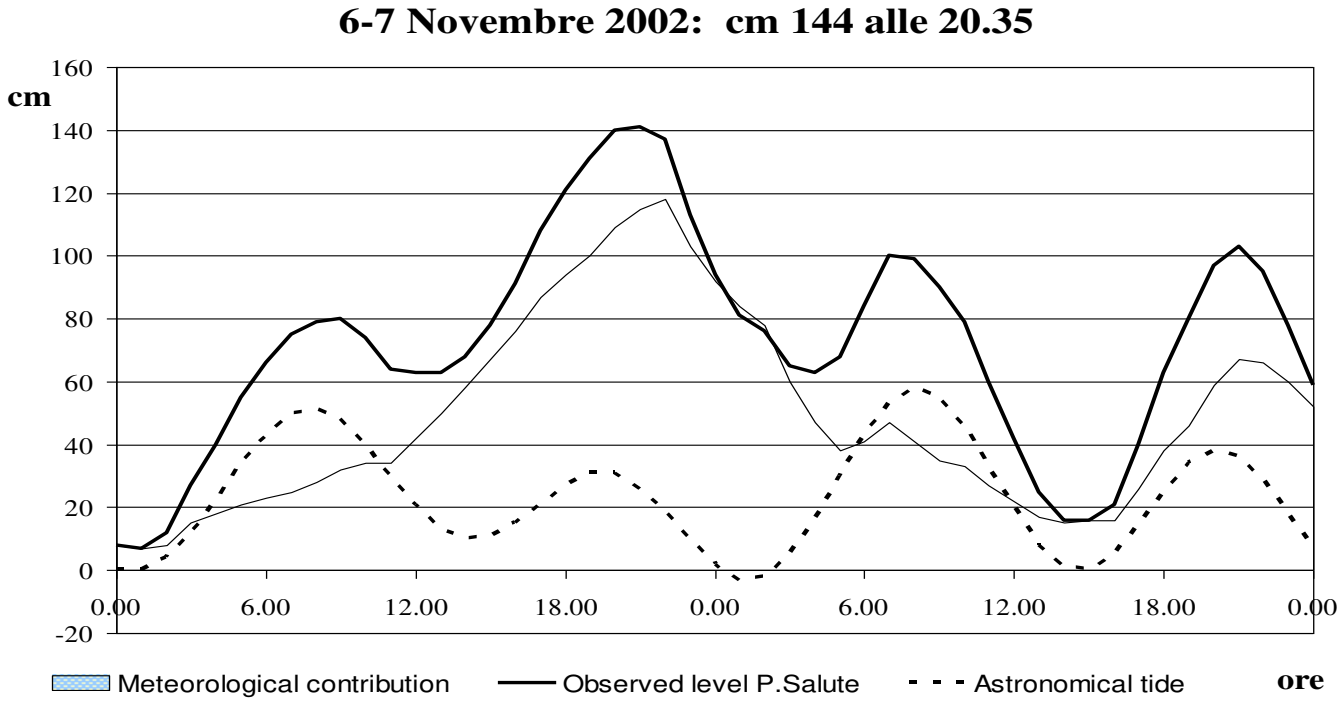
STORM SURGES & EXTREME EVENTS

(image from NASA, www.visibleearth.nasa.gov)

Storm surges, defined as masses of water that are pushed toward the shore by meteorologic forces (**wind and atmospheric pressure**), are a primary cause of the injuries, deaths, and structural damages associated with hurricanes, cyclones, northeasters, and other coastal storms. When the advancing surge of water coincides with high **tides**, the resulting rise in sea levels is further exacerbated.

THE "ACQUA ALTA" IN VENICE - NOV. 2002.

TWENTY YEARS AGO, 144 CM ABOVE THE MSL WAS CONSIDERED AS AN EXTREME EVENT



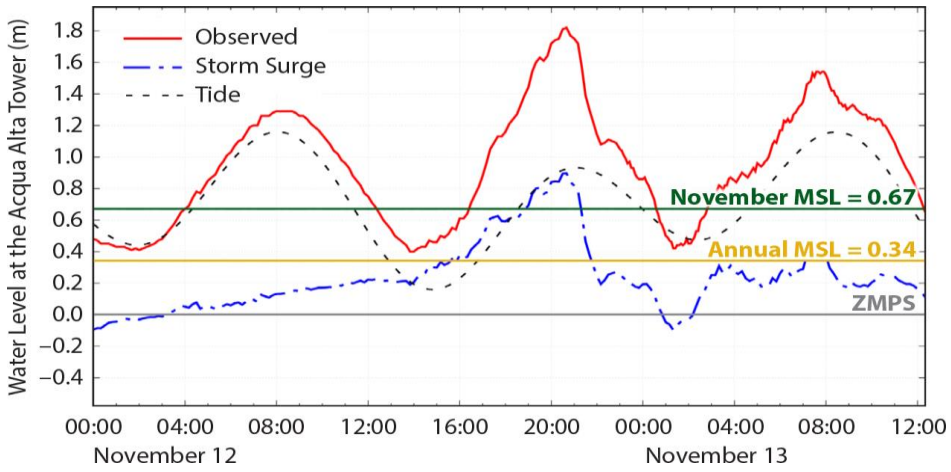
STORM SURGES & EXTREME EVENTS

…. AND NOWADAYS?

IN NOV. 2019, THE SSH PICKEAD UP TO 187 cm ABOVE THE MSL …

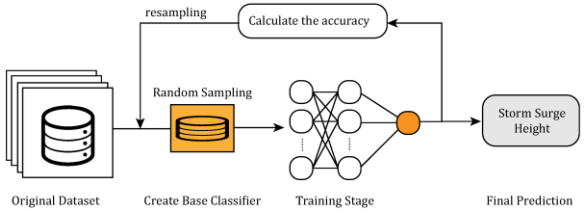
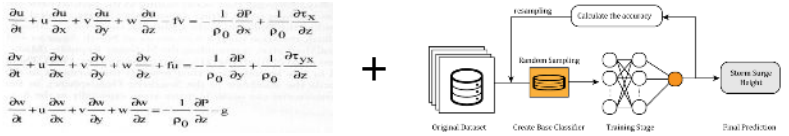
IN THE PREVIOUS YEAR, THE 2018, ANOTHER RECORD, 156 cm !! WITH 140 cm DUE TO SURGE ONLY !!

IN 2018 THE TIDE WAS AT MINIMUM …. IT COULD REACH 210 cm !!



…. AND IN THE FUTURE? IN THE NEXT 100 YEARS?

HOW DO WE PREDICT STORM SURGE EVENTS?

	SHORT-TERM PREDICTION METEOROLOGICAL TIME SCALE HOURS TO WEEKS	LONG-TERM PREDICTION CLIMATOLOGICAL TIME SCALE MONTHS TO CENTURIES
DATA DRIVEN MODEL		
COMBINED PROBABILISTIC – DETERMINISTIC		
DETERMINISTIC MODEL	$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho_0}\frac{\partial P}{\partial x}+\frac{1}{\rho_0}\frac{\partial \tau_x}{\partial z}$$ $$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-\frac{1}{\rho_0}\frac{\partial P}{\partial y}+\frac{1}{\rho_0}\frac{\partial \tau_{yx}}{\partial z}$$ $$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho_0}\frac{\partial P}{\partial z}-g$$	$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho_0}\frac{\partial P}{\partial x}+\frac{1}{\rho_0}\frac{\partial \tau_x}{\partial z}$$ $$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-\frac{1}{\rho_0}\frac{\partial P}{\partial y}+\frac{1}{\rho_0}\frac{\partial \tau_{yx}}{\partial z}$$ $$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho_0}\frac{\partial P}{\partial z}-g$$

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HOW DO WE PREDICT? DETERMINISTIC APPROACH

SHYFEM SYSTEM OF HYDRODYNAMIC FINITE ELEMENTS MODULES

[1] 3D HYDRODYNAMIC MODEL
FE model solving the 3D hydrostatic / non-hydrostatic primitive equations sys. based on the Boussinesq approximation.

[2] WIND WAVE MODEL – WWM / WWIII
Phase averaged wind wave model based on FE method

[3] TURBULENCE CLOSURE MODEL– GOTM

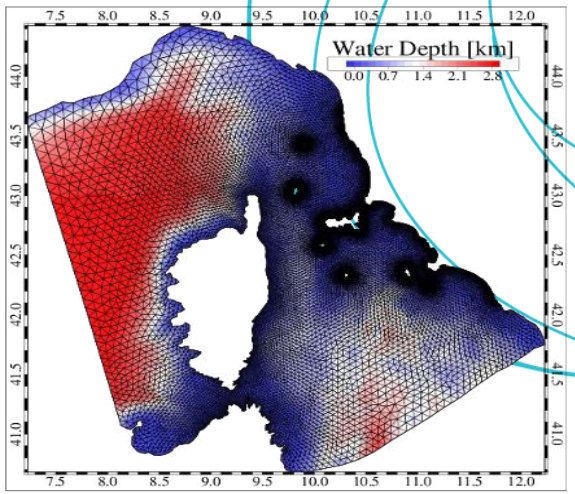
[4] 3D EULERIAN TRANSPORT & DIFFUSION MODEL

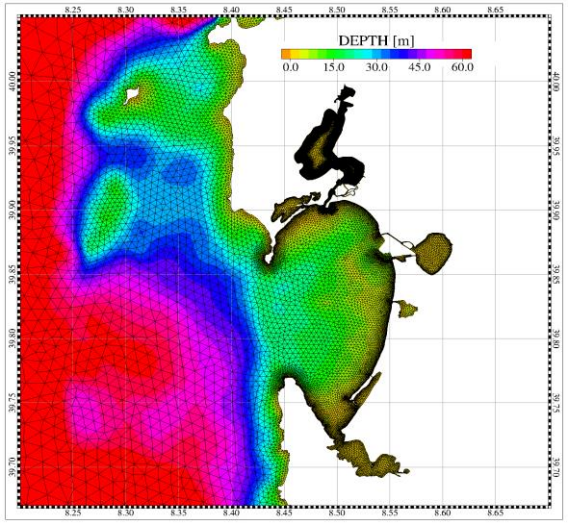
[5] 3D LAGRANGIAN TRANSPORT & DIFFUSION MODEL
Inline / offline lagrangian transport + biological / chemical reactor

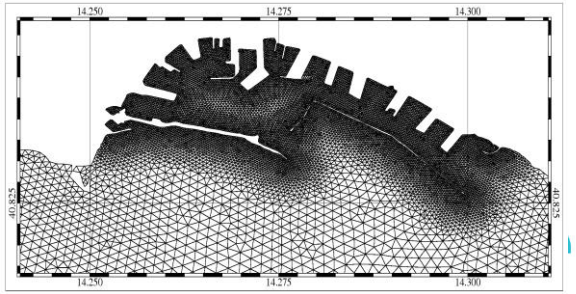
[6] 3D SEDIMENT TRANSPORT MODEL – SEDTRANS05
Cohesive and non-coesive sediment transport and deposition

[7] 3D WATER QUALITY MODEL – BFM

OCEAN MODELLING ACROSS SCALES – FROM OPEN OCEAN TO COASTAL AREAS







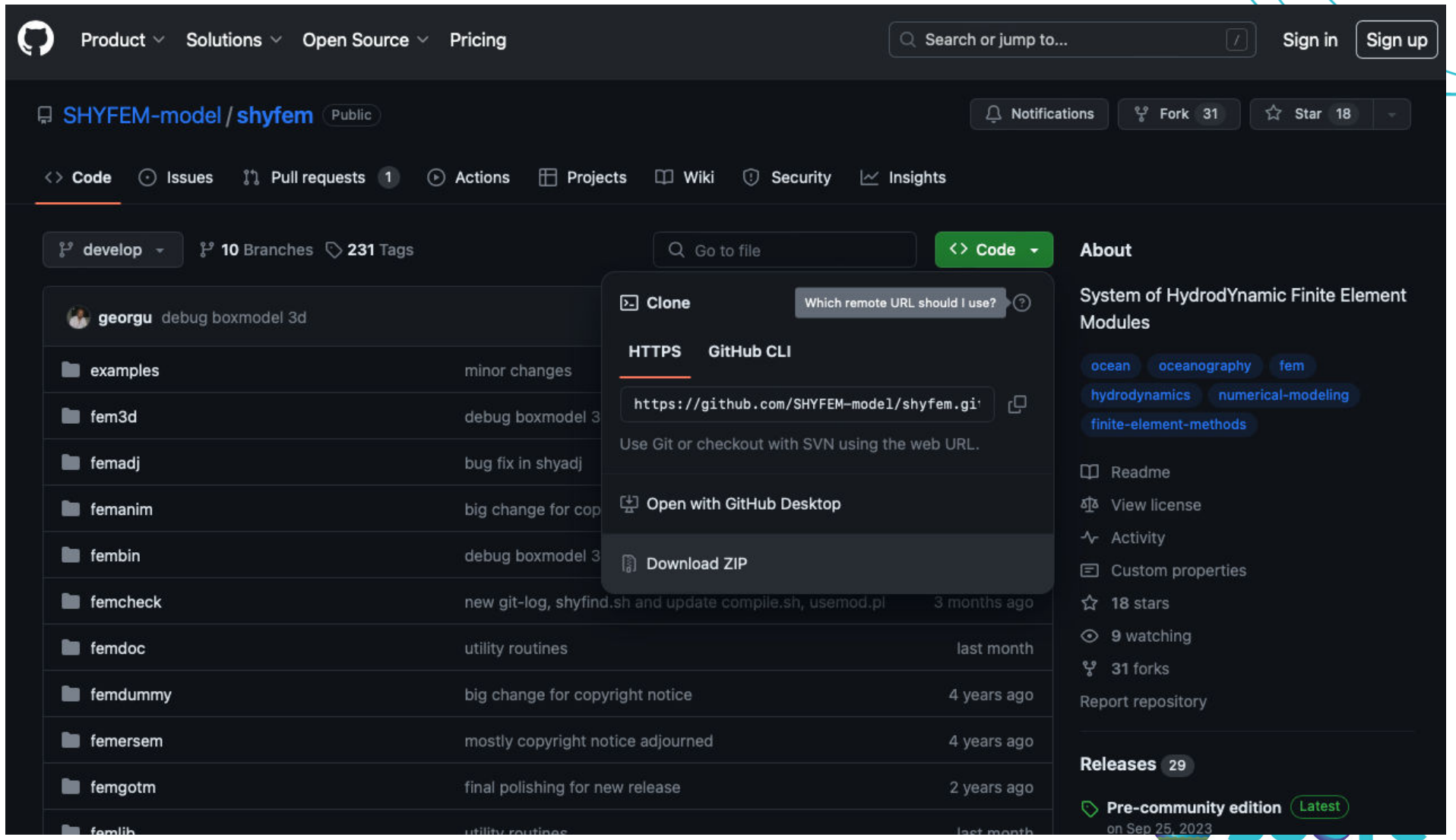
DOWNLOADING

Code freely downloadable at **https://github.com/SHYFEM-model/shyfem**

Based prerequisites:
LINUX
FORTRAN
C++

Download via SVN-GIT
or
Download zip file

unzip shyfem-develop.zip



COMPILING

Code freely downloadable at **https://github.com/SHYFEM-model/shyfem**

Based prerequisites:
LINUX
FORTRAN
C++

make first_time

make check_software

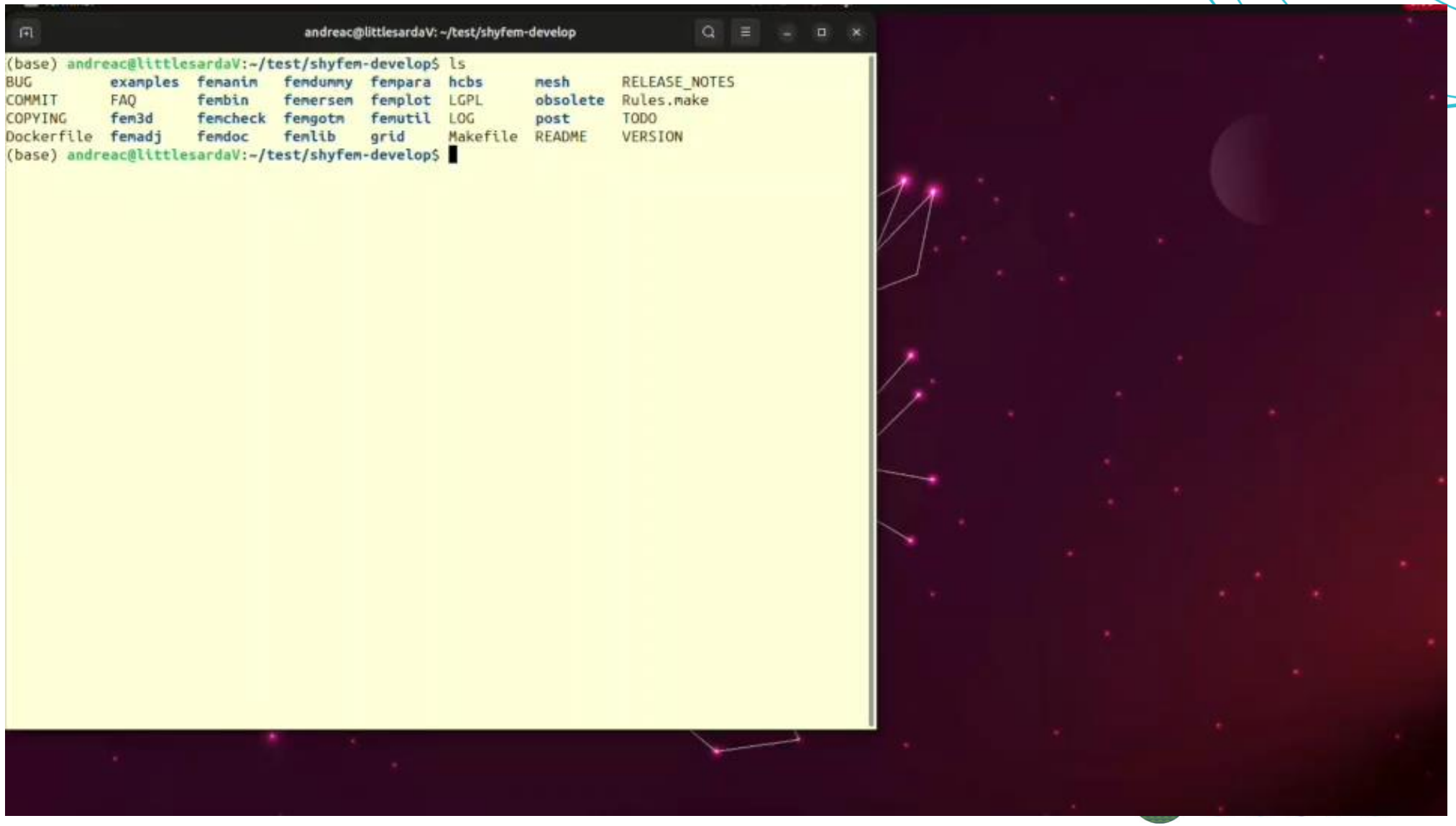
make configure

make install

make fem

cd fem3d

./shyfem



BUILDING THE MESH

GMSH software freely downloadable at **https://gmsh.info**

Based pre-requisites:

Coastline in *.geo (GMSH input)

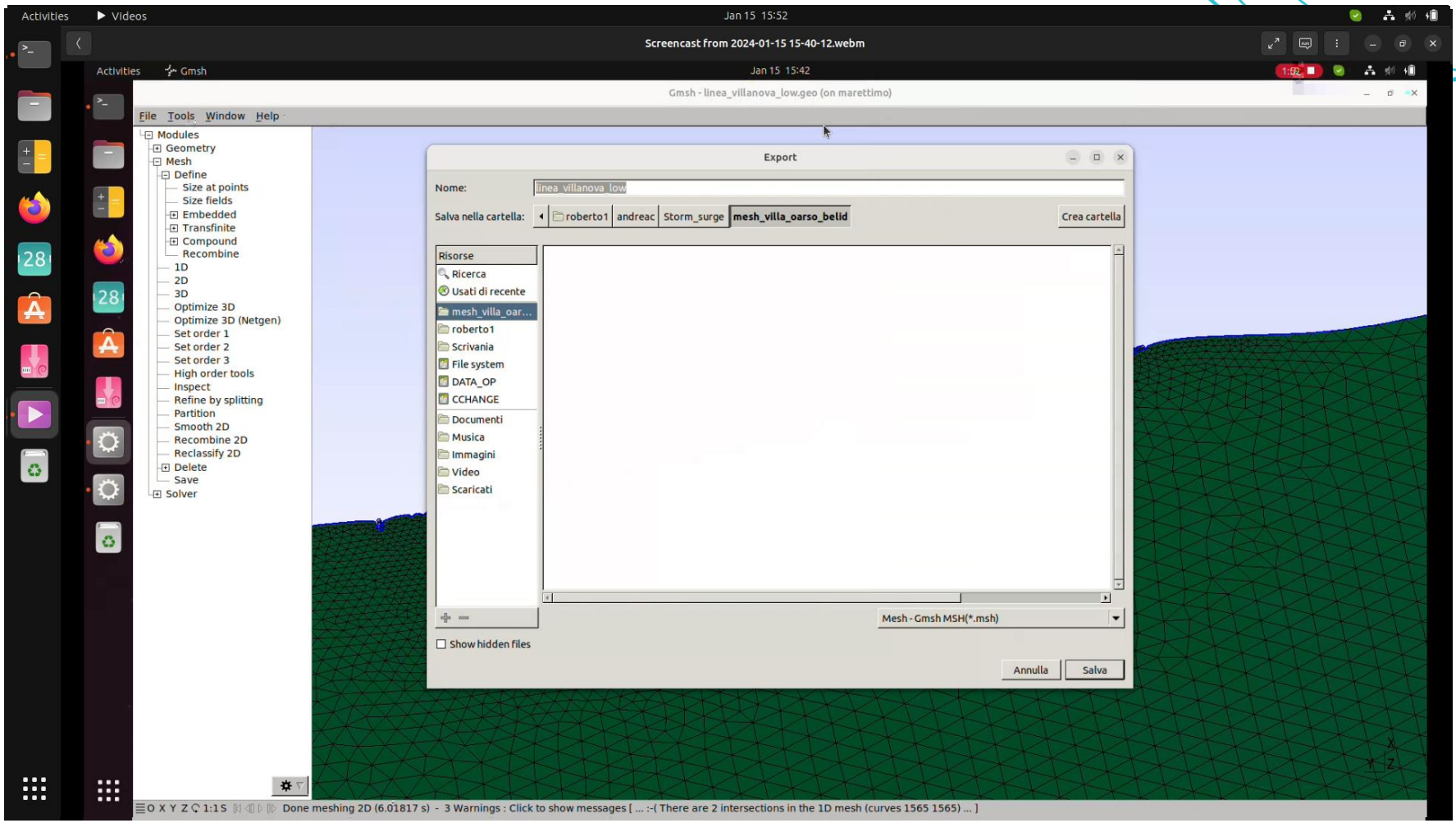
**.msh* to **.grd*

NODES GEOMETRY

```
1 249080 0 32.153976 35.449951
1 249081 0 2.857388 40.133186
1 249082 0 4.526668 40.960705
1 249083 0 30.167084 35.834484
1 249084 0 1.667464 41.192707
1 249085 0 0.739596 40.422077
1 249086 0 1.719222 39.500973
1 249087 0 2.302405 41.223495
1 249088 0 3.628218 41.427502
1 249089 0 0.432180 40.347748
1 249090 0 1.751905 41.125736
1 249091 0 24.567602 40.712246
1 249092 0 1.285289 40.623882
1 249093 0 2.377265 41.266407
1 249094 0 2.373151 37.975811
1 249095 0 1.611469 41.116096
1 249096 0 2.314944 41.232590
1 249097 0 3.739461 41.897522
1 249098 0 1.693860 38.801205
```

ELEMENTS

```
2 1 1 3 204508 204507 204506
2 2 1 3 202774 202776 202773
2 3 1 3 205493 205499 205494
2 4 1 3 204835 245549 204836
2 5 1 3 204378 204377 229719
2 6 1 3 204712 204711 204713
2 7 1 3 204532 204511 204510
2 8 1 3 203997 203996 248313
2 9 1 3 231119 244778 203918
```



SIMULATION SETUP & RUN

./shyfem structure_file.str ……. TO RUN IT

```
$title
        Meteo run for the Atlantic domain_20km
        0.005_0.0075_2021
        Atlantic_domain_nd.bas
$end

$para
        date =20210101  time=000000

        itanf = 0 itend = 31514300 idt=100

        itmout =0 idtout = 3600

        hmin = 2

        ireib  = 5     czdef  = 0.0075

        ilin   = 1      itlin  = 0

        itsplt = 2      coumax = 0.8  idtsyn = 3600
        idtmin = 0.1

        ampar  = 0.60   azpar  = 0.60  aapar = 1

        icor   = 1      isphe   = 1

        ilytyp = 3

        iwtype = 1      itdrag = 0      dragco = 0.005

        rtide  = 0    ltidec = 1e-6

        rlin = 1

$end

$extra
202491
$end

$name
        wind='INPUT_WIND/2021_00061218_windreg.fem'
$end
```

OUTPUT FILES NAME

MESH FILE NAME

REFERENCE DATE & TIME

STARTING, ENDING & TIME STEP

OUTPUT STARTING TIME AND FREQUENCY

BOTTOM FRICTION TYPE & COEF. VALUE

WIND DRAG TYPE & COEF. VALUE

ATMOSPHERIC FORCING INPUT FILE NAME

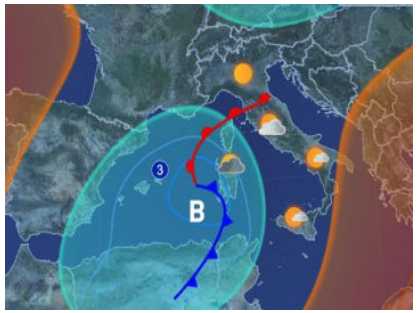
score

THE SCORE STRATEGY FOR STORM SURGE MODELING

Different approaches depending on the environmental features of the investigated CCLLs

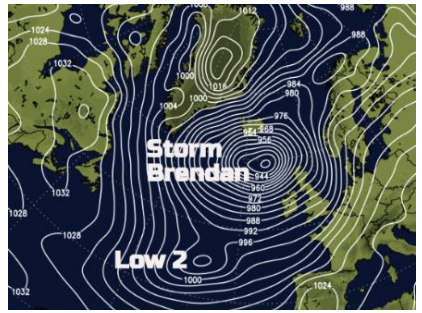
1. THE WIND FECTH LENGTH
2. THE AMPLITUDE OF THE TIDES
3. THE CONTRIBUTION OF THE ATMOSPHERIC PRESSURE GRADIENT ON THE TOTAL WATER LEVEL

WEST MEDITERRANEAN CCLLs



1. MODERATE LENGTH (FROM 500 TO 700 km)
2. BOTH DIRECT AND INVERSE BAROMETRIC EFFECT
3. VERY LOW TIDES

ATLANTIC CCLLs



1. LONG EXTENTION (MORE THAN 1000 km)
2. MAINLY DIRECT BAROMETRIC EFFECT
3. HIGH TIDAL AMPLITUDE

TESTING THE ROLE OF NON-LINEAR INTERACTION (N.L.I.) BETWEEN TIDES & STORM SURGES

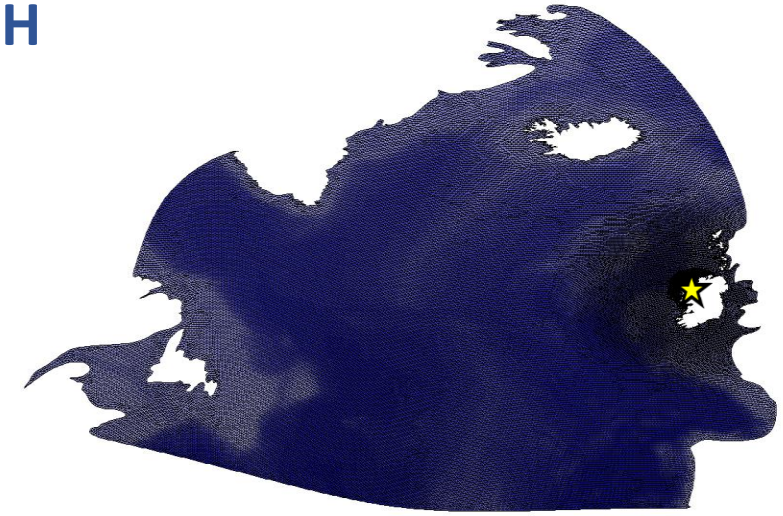
score

TESTING N.L.I. FOR ATLANTIC CCLL – SLIGO (IRL)

Basin Scale Model (BSM)-APPROACH

- ATM. FORCING OVER THE WHOLE BASIN
- COMPUTATION OF THE STORM SURGE
- NO TIDES

TOTAL WATER LEVEL = SS+TIDE IN POST-PROC



ACCURACY ESTIMATION MODELED VS OBSERVED SSH

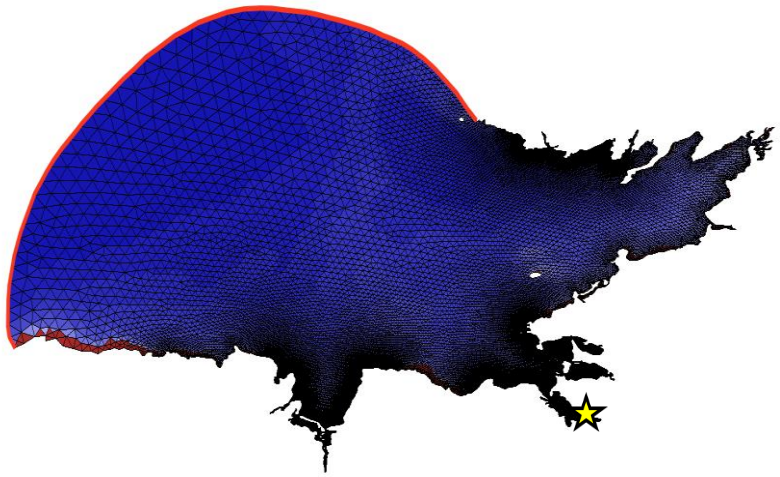
BSM		
ID	Corr	RMSE
SIM 6	0.827224	0.105659

BSM VS LAM
RMSE DIFF. ≅ 3 cm

Limited Area Model (LAM)-APPROACH

- ATM. FORCING ON A LIMITED DOMAIN
- SSH IMPOSED AT OB
- YES TIDE

COMPUTED TOTAL WATER LEVEL

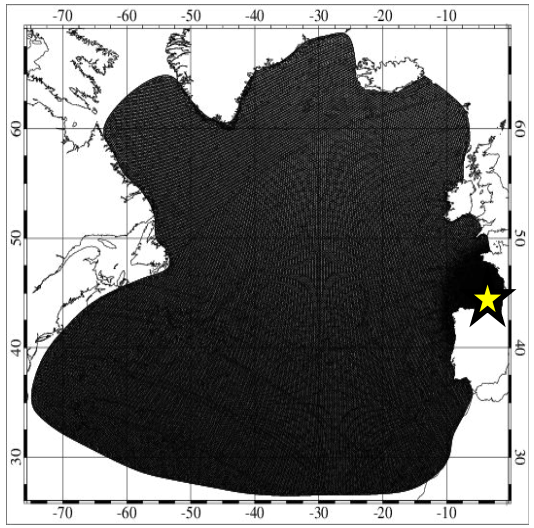


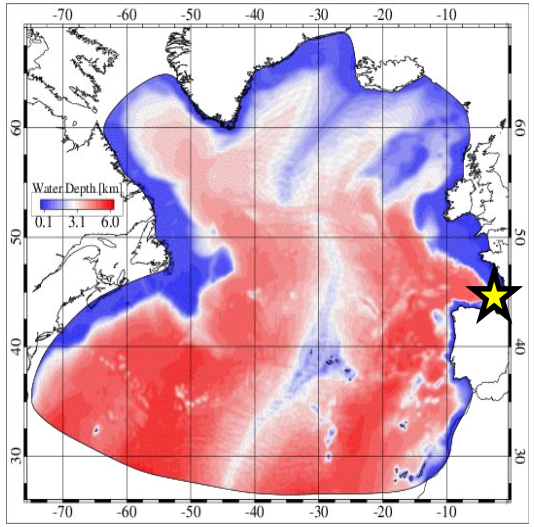
LAM		
ID	Corr	RMSE
SIM18	0.909076	0.076874

BSM APPROACH WORKS FINE !!

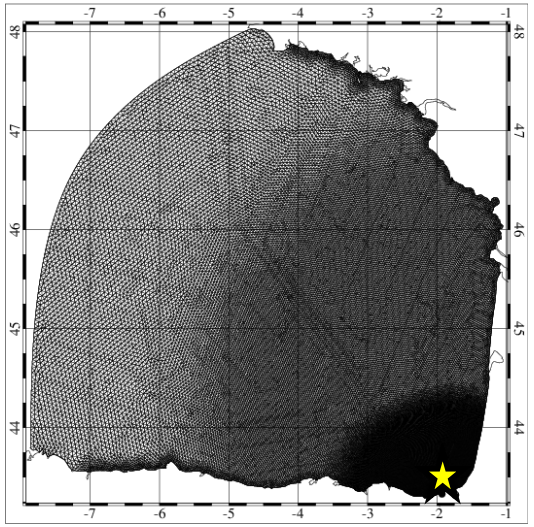
OTHER ATLANTIC CCLL – OARSOALDEA (SPAIN)

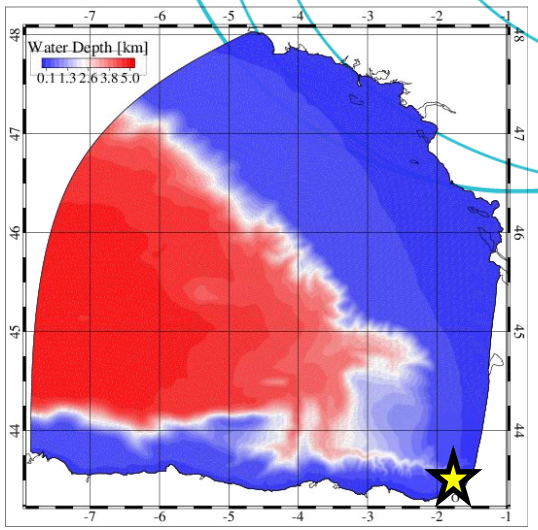
Basin Scale Model (BSM)-APPROACH





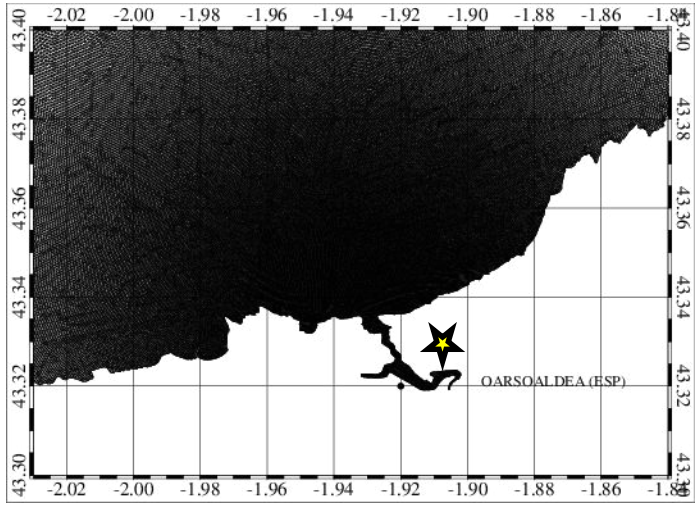
Limited Area Model (LAM)-APPROACH

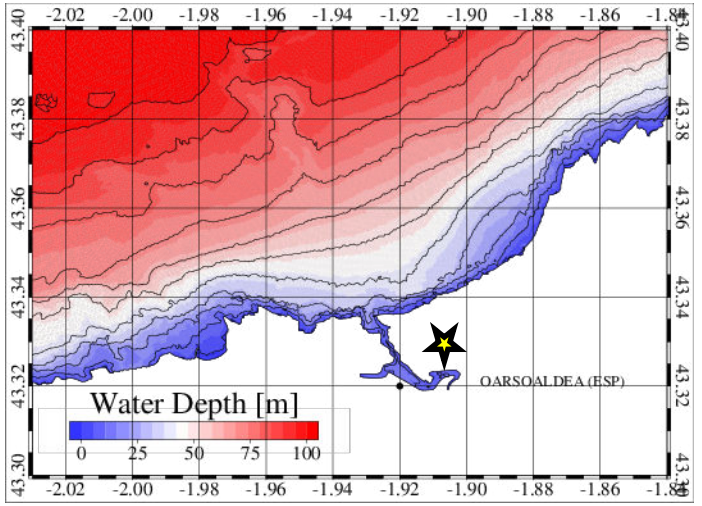




OARSOALDEA COASTAL SITE

**BSM has been extended to cover the entirety of the North Atlantic Basin.
No open boundaries are foreseen**





LAM has been extended to the whole Biscay Bay. Open boundary at the off-shore border of the mesh

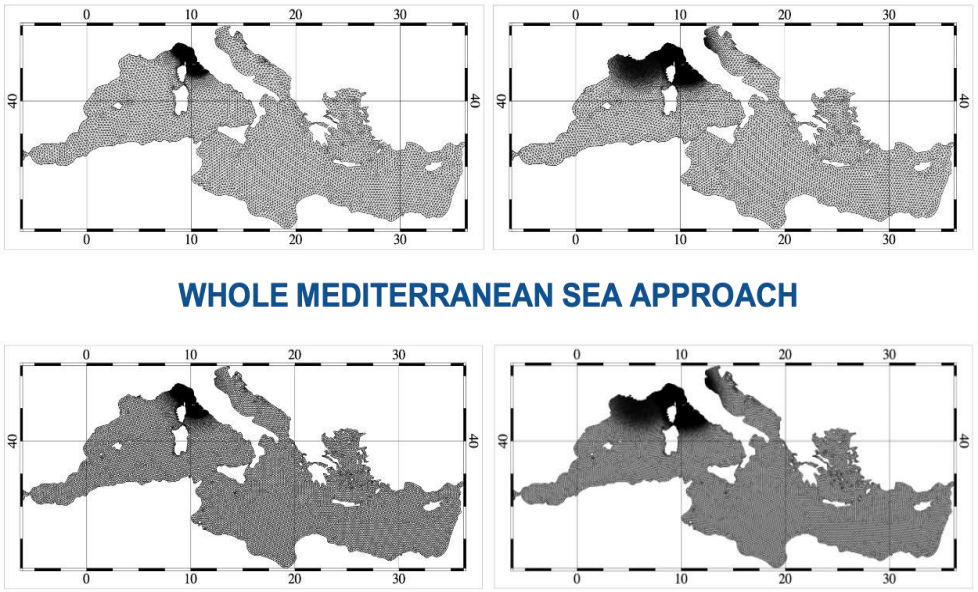
BSM APPROACH - MEDITERRANEAN CCLLS – VERY LOW TIDE
MASSA CCLL

MODEL MESH CONFIGURATION

Testing the mesh resolution with respect to computational time and prediction accuracy

Increasing the resolution along the main wind-fetch

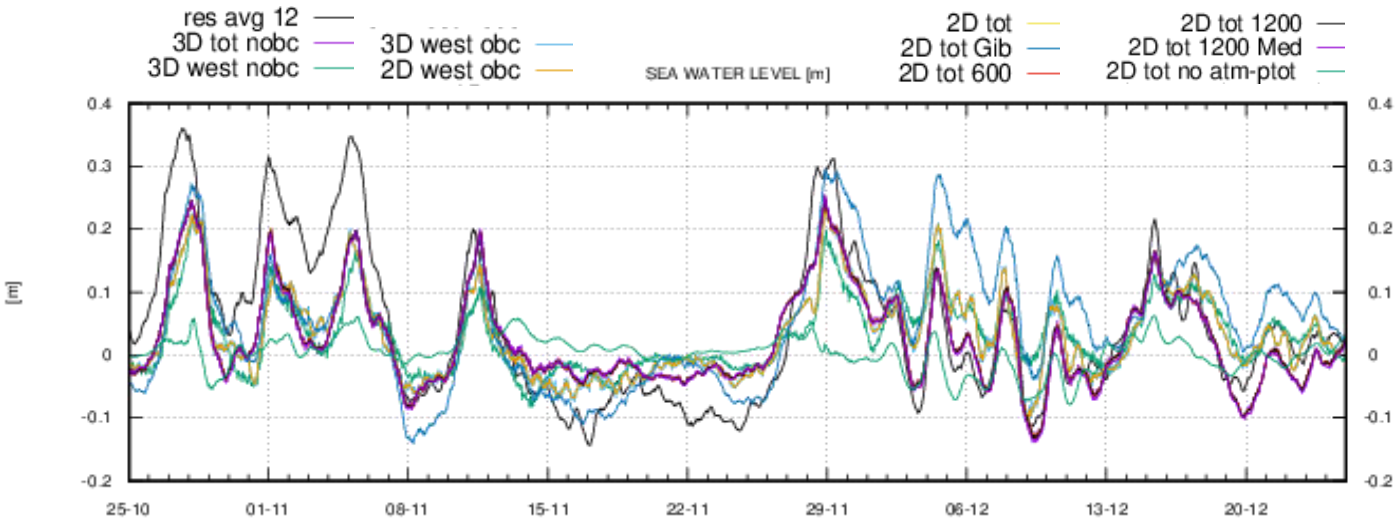
Increasing the overall mesh resolution



WHOLE MEDITERRANEAN SEA APPROACH

CALIBRATION & VALIDATION PROCEDURE

Simulating past storm surge events in the period 2012-2014. Modifying the model parameters values to increase the model accuracy in reproducing the observed residual SSH.



RUNNING SCENARIOS SIMULATION MEDITERRANEAN CCLLs

FORCING

WIND SPEED - ATMOSPHERIC PRESSURE

- **EUROCORDEX evaluation scenario (1950-2005) - historical dataset**
- **EUROCORDEX CC scenarios (2006-2100) RCP45 - RCP85 projection datasets**

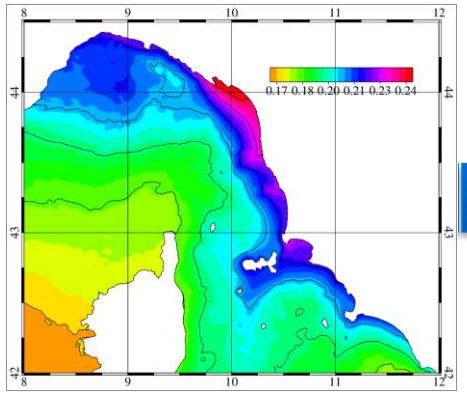
SCENARIO SIMULATIONS

Multiple parallel run - decadal simulations

Initial condition - steady state no motion

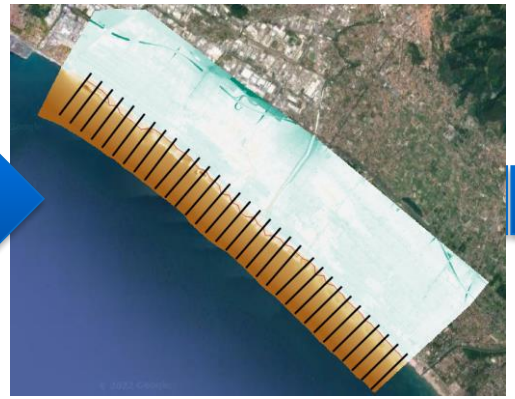
CC increasing water levels - post processing

STORM SURGE MOD.

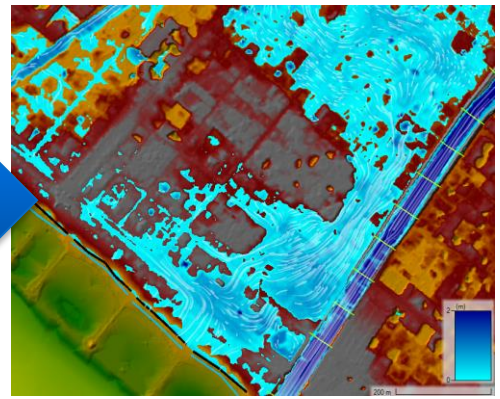


+ WAVE MOD…
+ ASTRONOMIC TIDE ...

NEAR-SHORE MOD.



URBAN SCALE MOD.



MED.SEA CCLLs

MASSA: URBAN SCALE SIMS
VILANOVA: NEARSHORE SIMS
BELIDORN: STORM SURGE SIMS