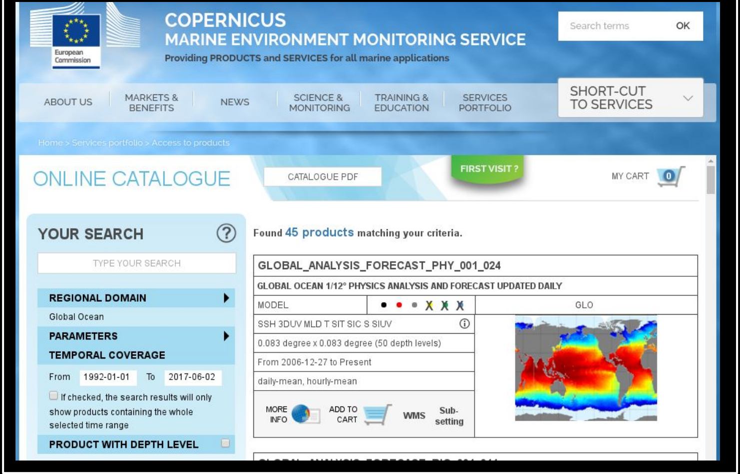
Prevention of river flooding in the French Roussillon Mediterranean Coast

SIROCCO academic research group, Laboratoire d'Aérologie, CNRS & Toulouse University, France

We are long-time and intensive users of COPERNICUS products

Coperninus physical fields (u,v,T,S,ssh,…) at global scale provide initial and boundary conditions of most of our regional/coastal applications



Principal applications:

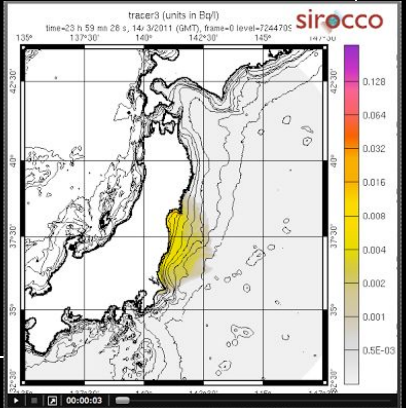
Physical modelling, Biogeochemical modelling at regional/coastal scales

SIROCCO develops tools for ocean modelling:

- SYMPHONIE (3D regional/coastal ocean model)
- FES, TUGO (2D global/regional tidal models)
- ECO3M-S (biogeochemical model)

An exceptional use case in 2011:

- The Fukushima accident
- Real-time forecast (in synergy with MERCATOR operational centre) of the radioactive plume in the sea



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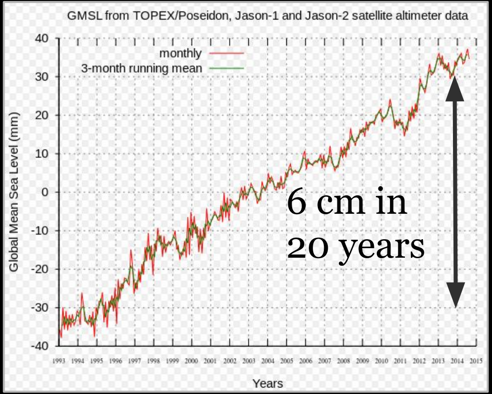


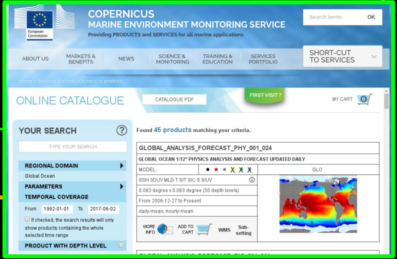
Extreme, fast, possibly hazardous, and localized events

Flooding due to precipitations
Runoff , Overflowing rivers

Flooding due to marine submersion
Wind, Waves, Tsunamis

Large scale background 'regular' conditions for marine submersion

At global/regional scales the sea surface level is also related to:
- Tides
- Atmospheric pressure
- The general thermohaline ocean circulation
- The slow rise of water due to climate change



With climate change, coastal areas are increasingly vulnerable to flooding. This is a major issue of coastal modelling.

A multi-scale problem:

Global scale: mean sea level, tides,…
Regional scale: atmospheric pressure variation, winds, tides on shelves,…
Local scale: river overflow, wave breaking,…

Timescales: from short extreme events to climatic change (6 cm since 1993)

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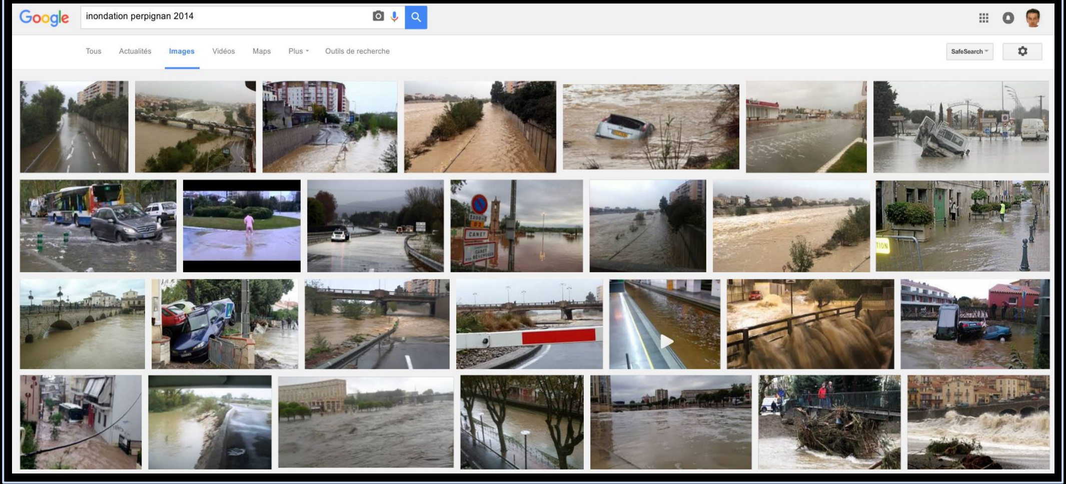
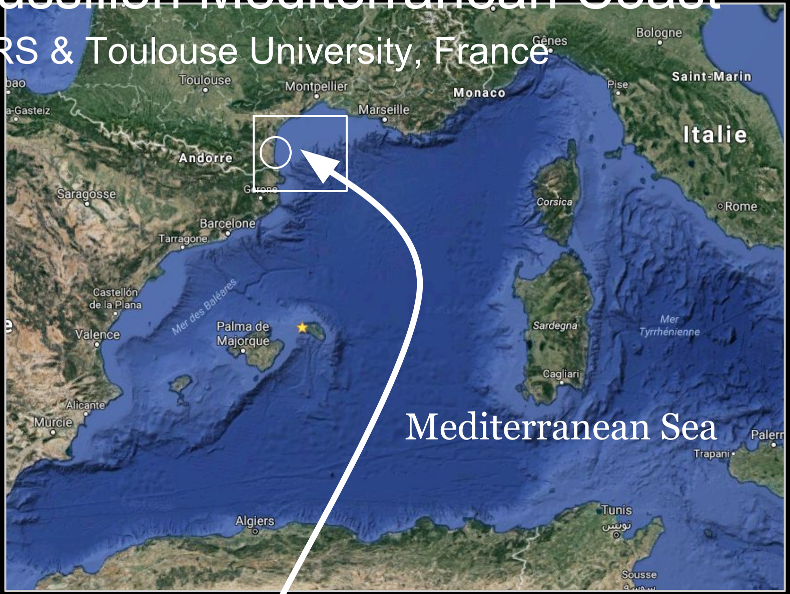
A typical downscaling problem and a challenge for coastal ocean modelers…

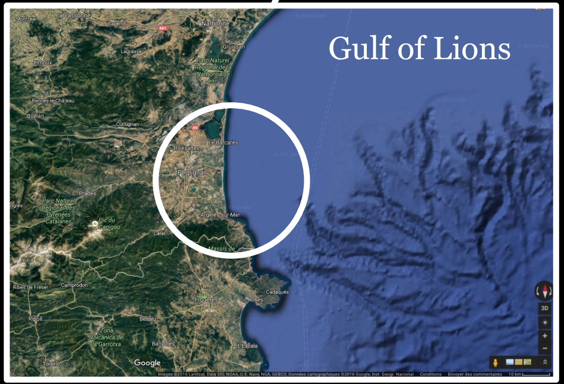
A case study: the flooding of the river Tet

(Perpignan, France)

The french "Roussillon" mediterranean coast is regularly exposed to flooding events







Prevention of river flooding in the French Roussillon Mediterranean Coast

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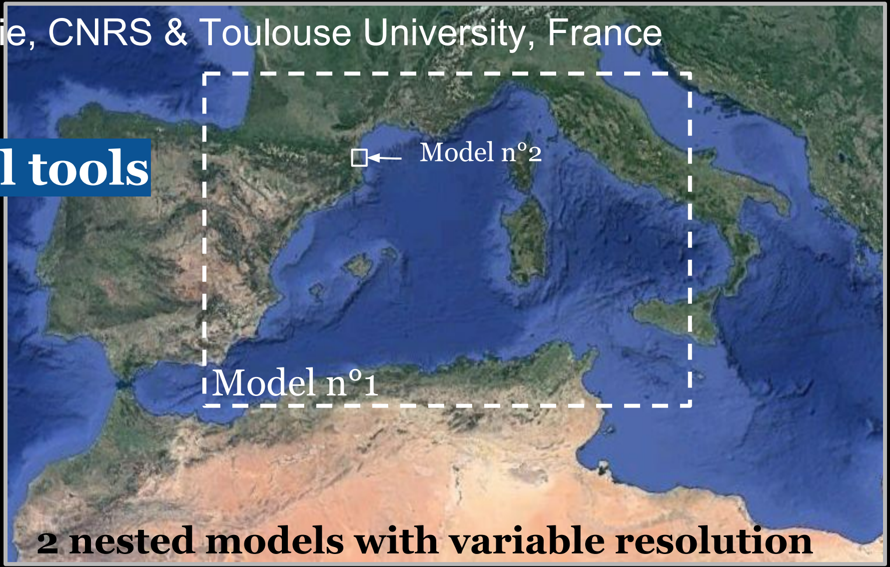
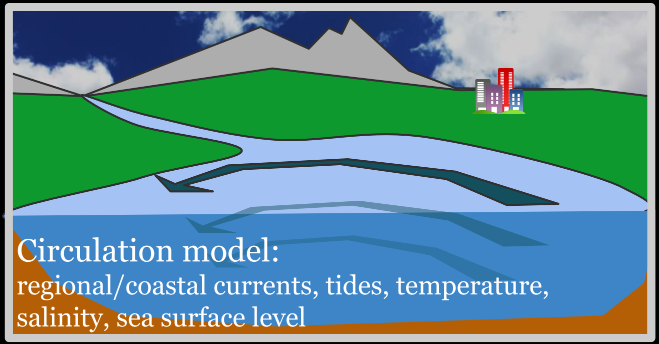
Choosing a grid strategy and numerical tools

- ★ Downscaling
  - ○ A: Grid nesting
  - ○ B: a single grid with variable resolution
  - ○ C: a combination of A and B
- ★ Tools
  - ○ Ocean circulation model (SYMPHONIE, LA)
  - ○ Ocean waves (swell +sea state) model (WW3)



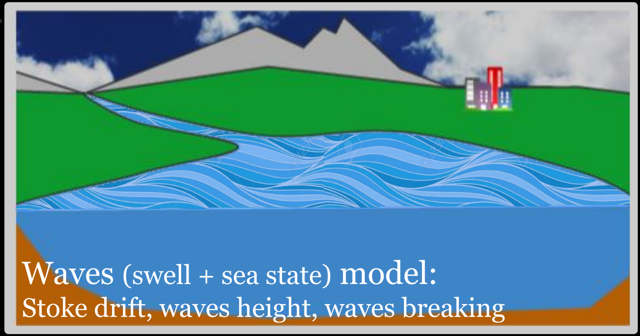
2 nested models with variable resolution



Surface current, sea level →

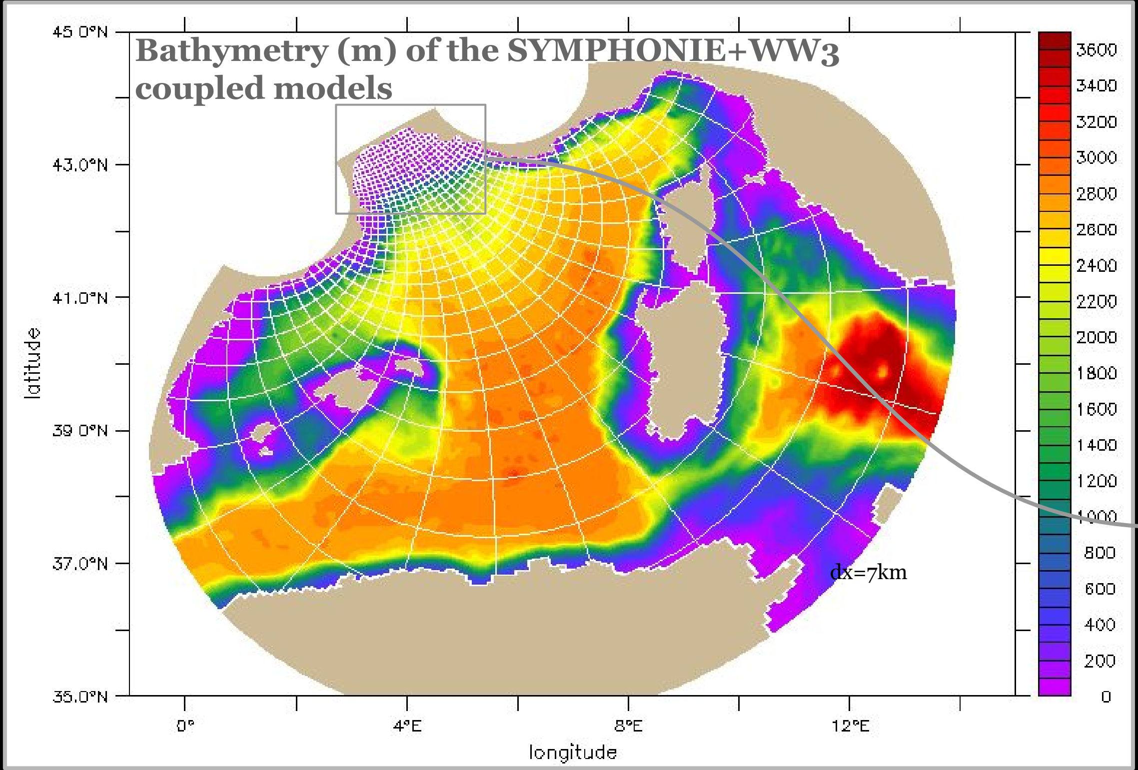
← Stoke drift, turbulence input

OASIS coupler (CERFACS, Toulouse)



Two nested grids with variable resolution

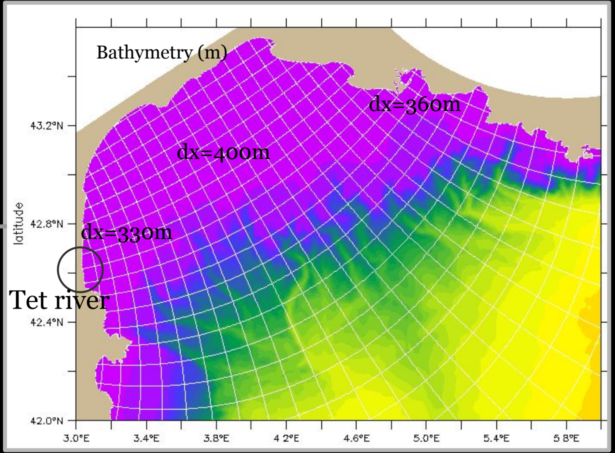
MODEL n°1: a single curvilinear bipolar grid (Bentsen et al, 1999) of the Western Mediterranean Sea with 1/12° resolution at the open borders and 400m on the shelf of the Gulf of Lions

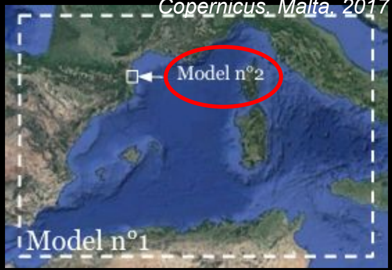


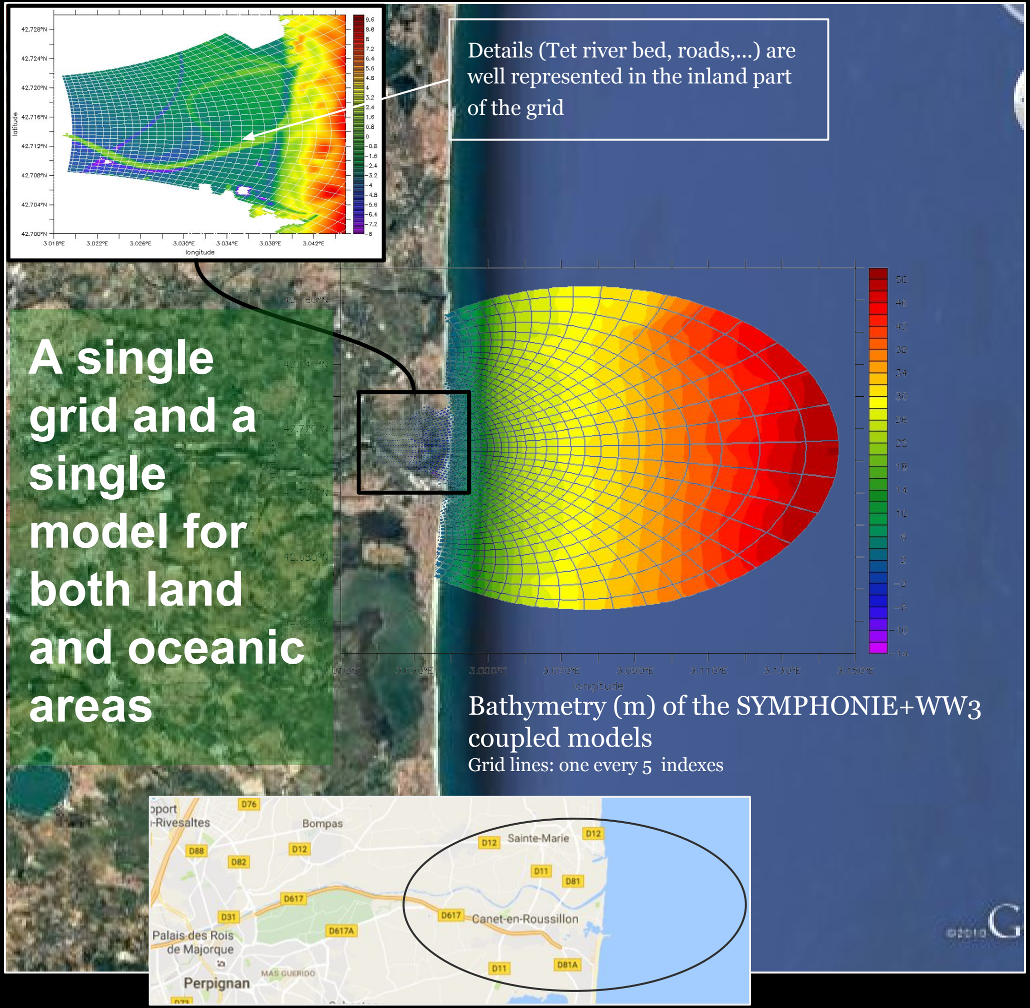
Bathymetry (m)

White lines: one every 20 grid indexes

Resolution quite homogeneous on the shelf break







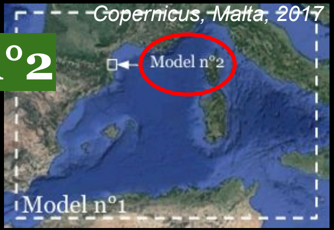
Model n°2 of the "Tet river mouth"

- Bipolar curvilinear grid with 200m resolution at the eastern open border and 10m resolution in inland part
- Nested in Model n°1

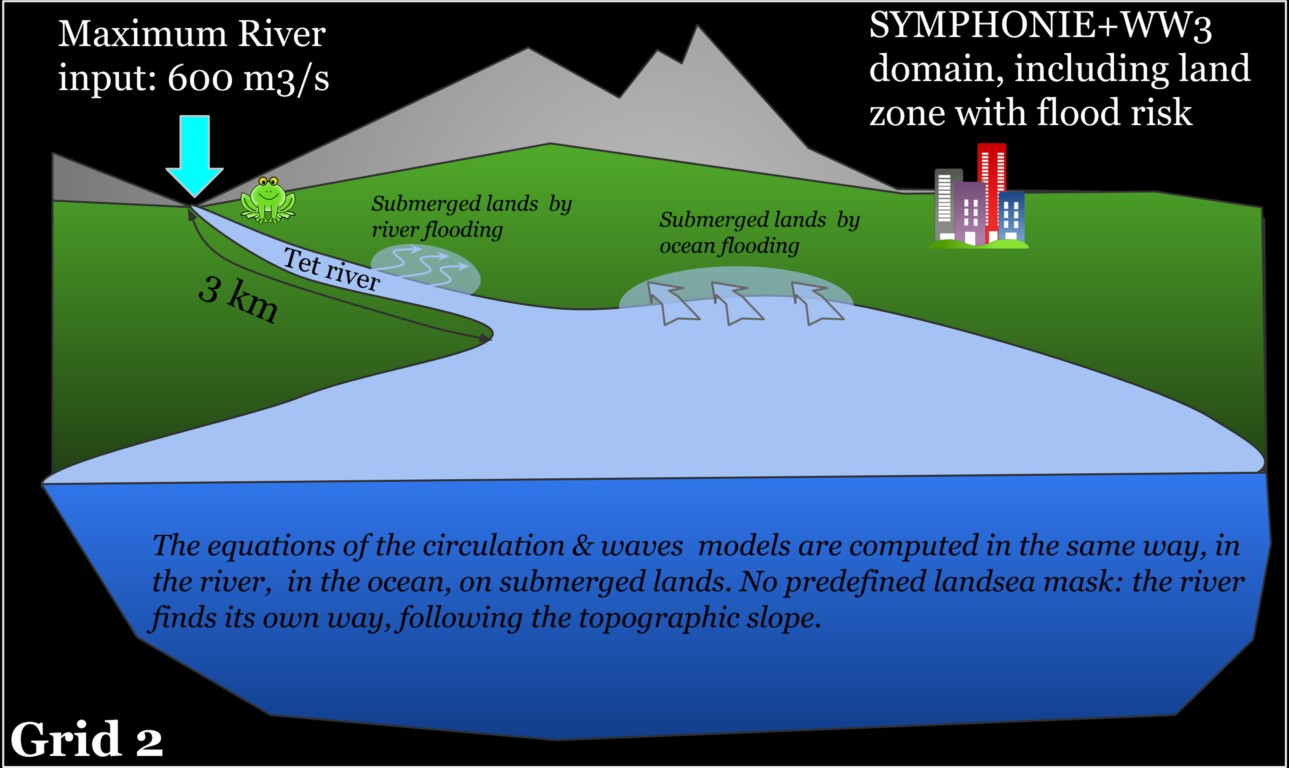
An accurate and "continuous" bathymetry database is necessary on land and in the sea:

- IGN RGE 1m resolution
- LIDAR DREAL 2009 5m resolution
- SHOM HOMONIM 100m resolution
- GEBCO, EMODNET (open sea)

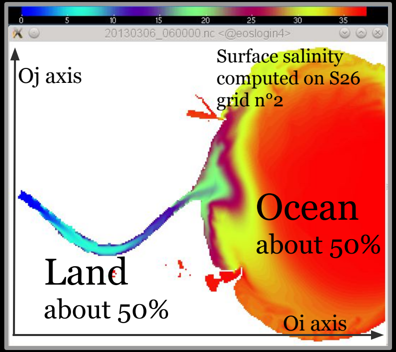
Flooding of the Tet river zone with very high resolution Model n°2



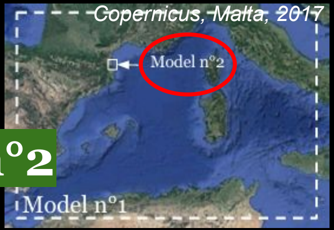
A single model for the ocean, the Tet river and submerged lands



Grid mapping in indexes space

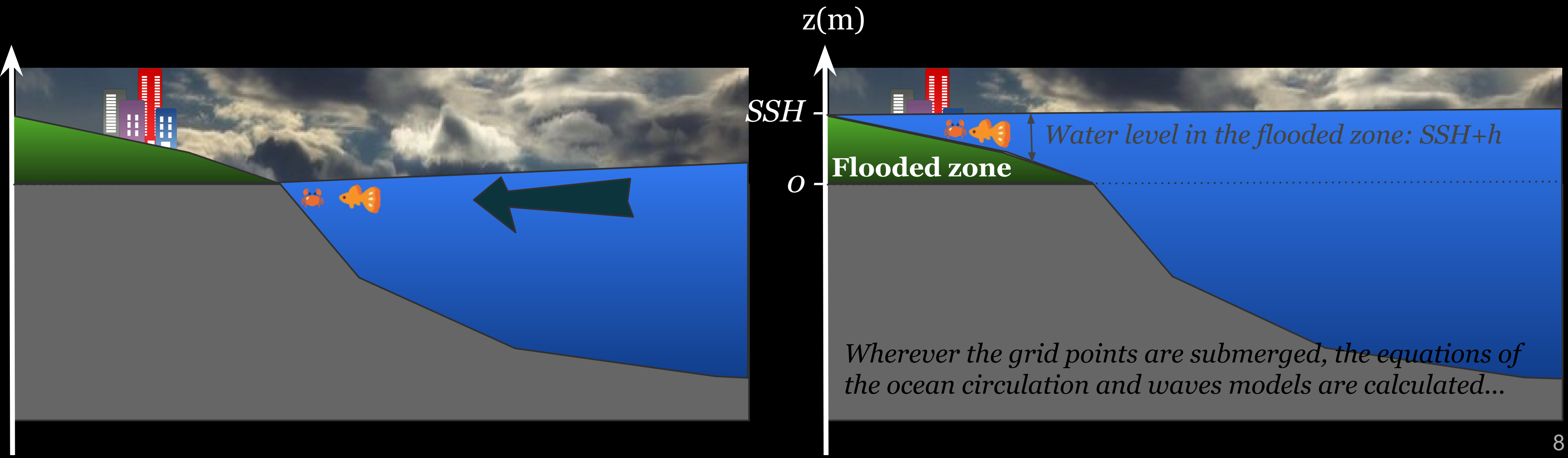


- All the grid points are active
- Half of the domain covers land
- About 6 points in the cross-river direction

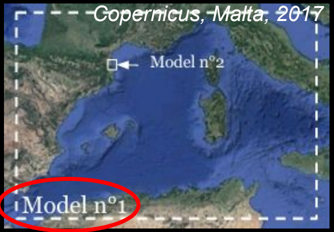


Flooding of the Tet river zone with very high resolution Model n°2

- **Inland progression of seawater is computed by the ocean circulation model using a "wetting/drying" algorithm**



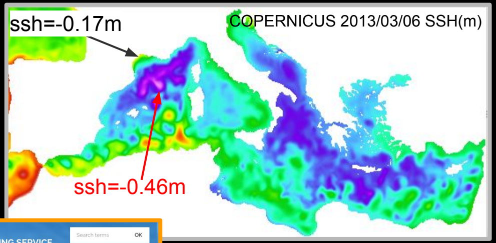
Large-scale analysis fields

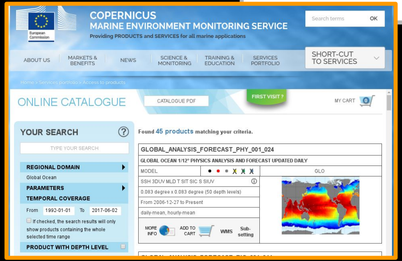


Model n°1 is initialized and forced by:

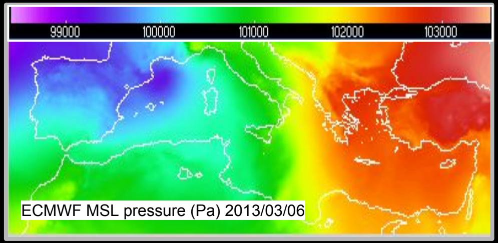
- **COPERNICUS general circulation** 1/12° daily outputs (SSH, u,v,T,S)
- **FES tides** harmonic components (M2,N2,S2,K2,K1,O1,P1,Q1,M4)
- **ECMWF atmospheric forcing** 1/8° hourly outputs (wind, T,q, pressure,...)
- **WW3 sea state** implemented by SIROCCO team on COPERNICUS grid 1/12°
- **River daily fluxes** from "Banque Hydro" database

COPERNICUS

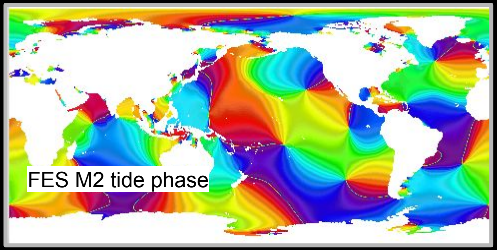




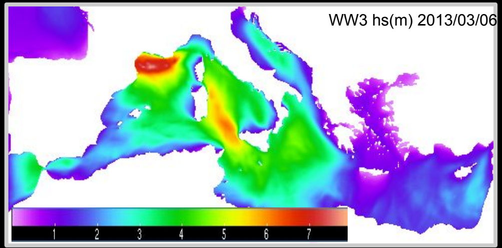
ECMWF



FES (LEGOS, F. Lyard)



WW3

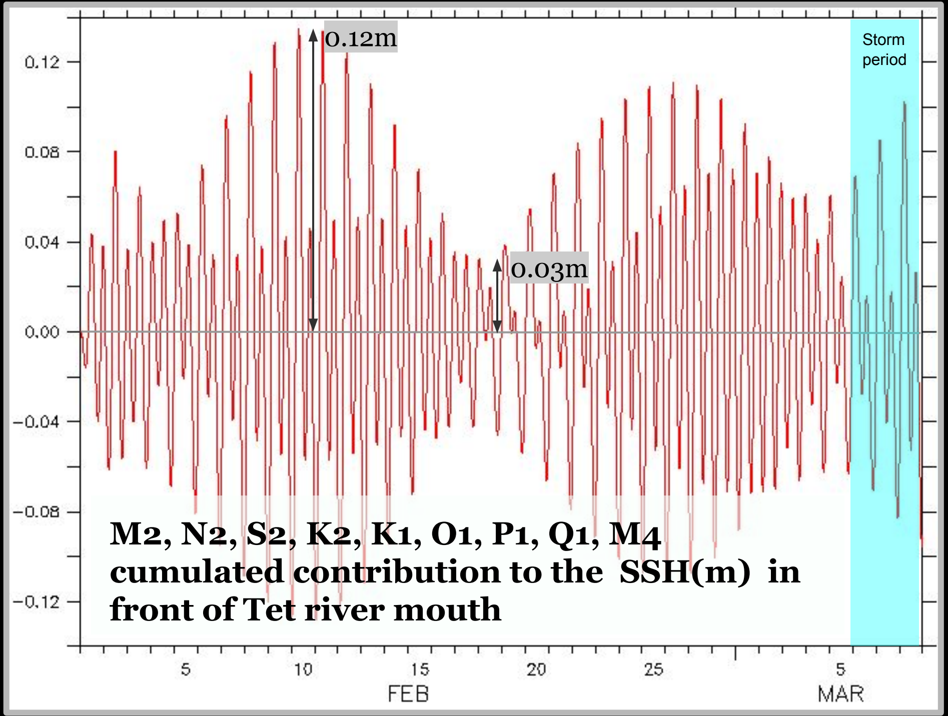


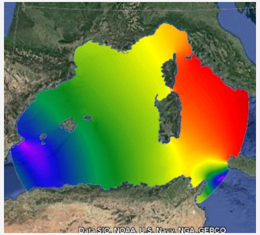
What are their respective contributions to the modelling of sea level in our coastal region of interest?

Downscaling of tides

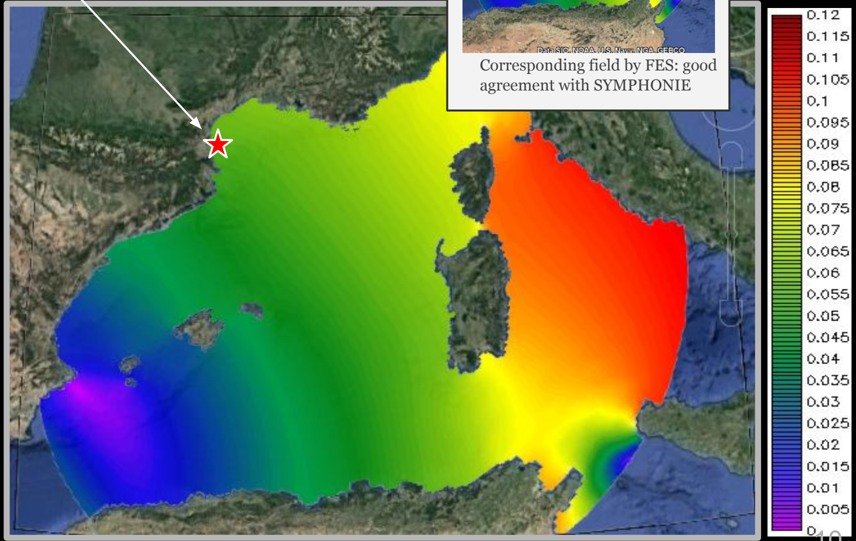
Model n°1 : FES tidal forcing at open borders of SYMPHONIE

According to the phasing of tidal components sea surface height (SSH) may exceed 0.1m in front of Tet river mouth





Corresponding field by FES: good agreement with SYMPHONIE



M2 amplitude (m) computed by SYMPHONIE on "Grid 1" with FES forcing at open borders. Astronomical forcing as in Pairaud et al (2008)

Atmospheric Pressure

Copernicus, Malta, 2017

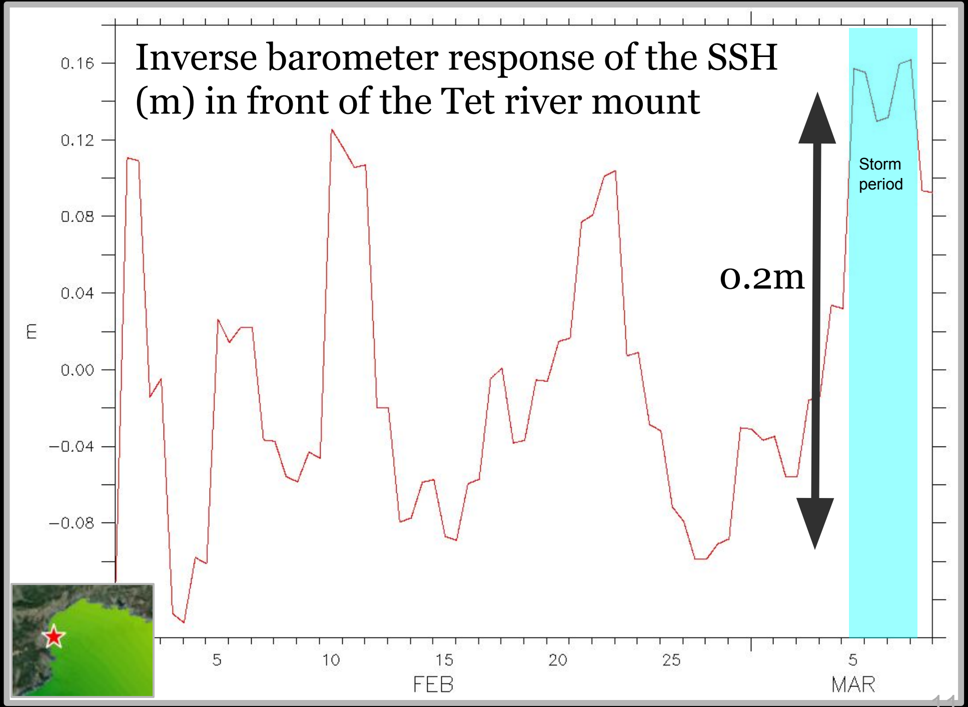
Sea level response according to the “inverse barometer” rule:
a decrease of 1000 Pascals leads to a raise of 0.1m

$$\Delta\eta = -\frac{\Delta P_{surf}^{air}}{g\,\rho_w}$$

- Expected sea level increase during extreme events: > 0.2m (same order of magnitude than tides)

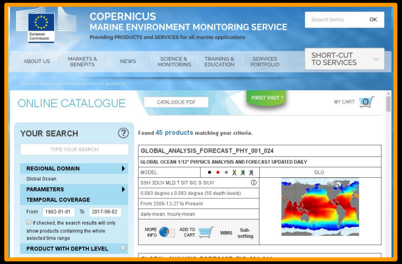
- The “inverse barometer” rule (*) is applied as a sea surface height (SSH) boundary condition for Model n°1

- Atmospheric pressure is taken into account in SYMPHONIE momentum equations

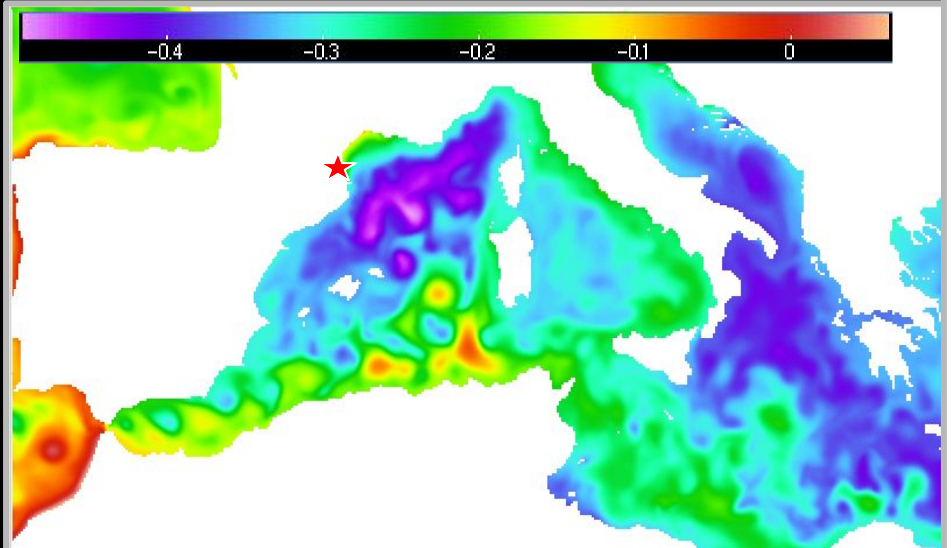


(*): a somehow questionable hypothesis since the expected phase lag related to surface wave propagation is neglected

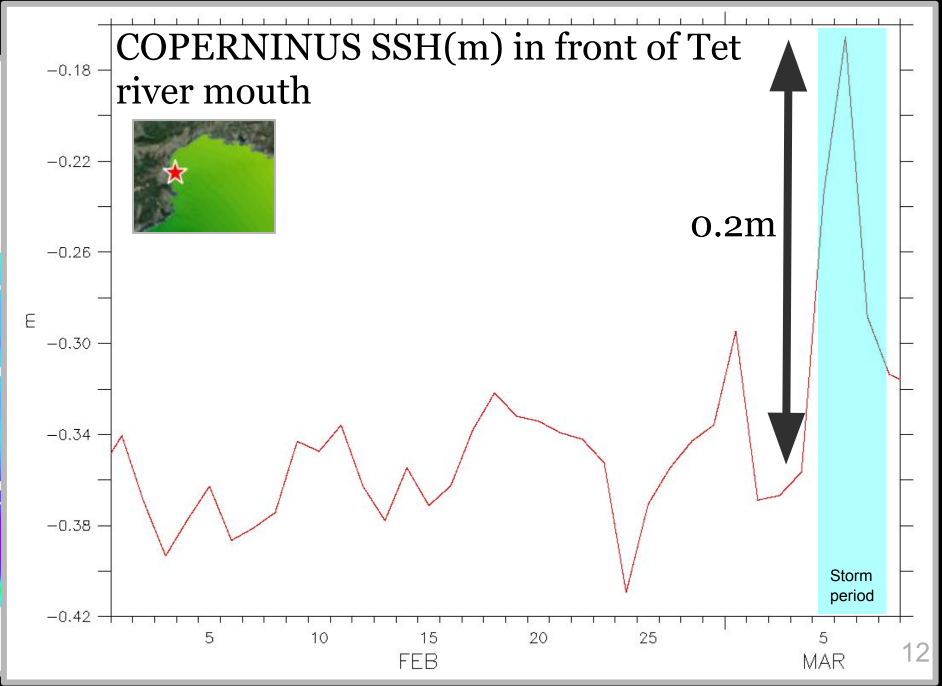
SSH related to ocean circulation in COPERNINUS daily fields



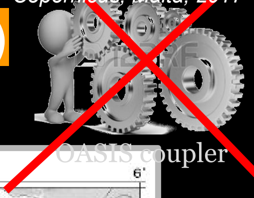
- COPERNICUS SSH fields do not contain tide and atmospheric pressure effects
- SSH (sea surf. height) gradients are mainly a response to T,S gradients and wind
- At regional scale spatial variations of SSH can reach 0.5m
- In front of Tet river, during the storm event, SSH variation > 0.2m



COPERNICUS SSH (m) 2013/03/06

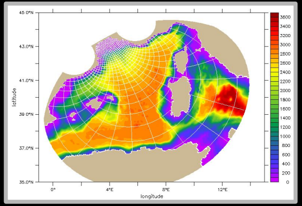


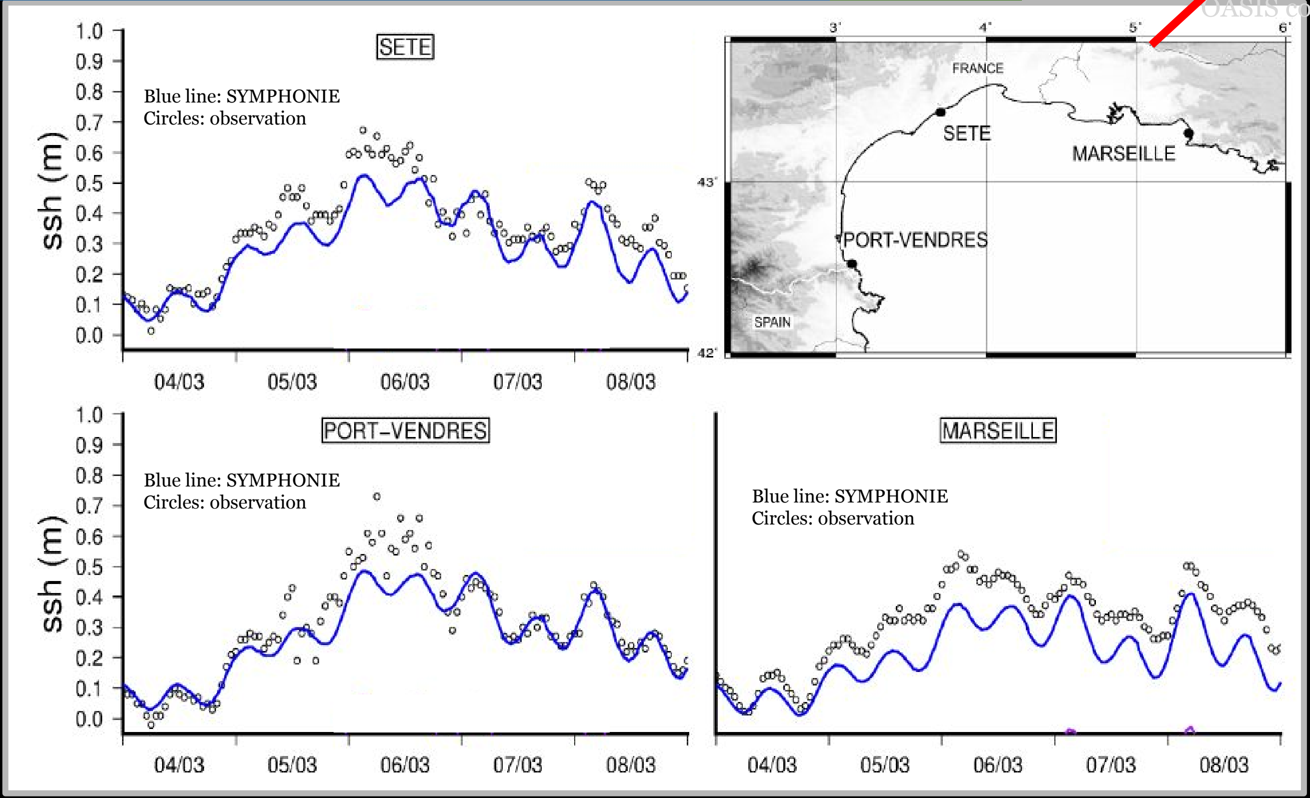
A first experiment based on the circulation model only (no waves effect)



Combine tides, meteorological forcing and COPERNICUS fields using Model n°1

Model n°1 versus Observations



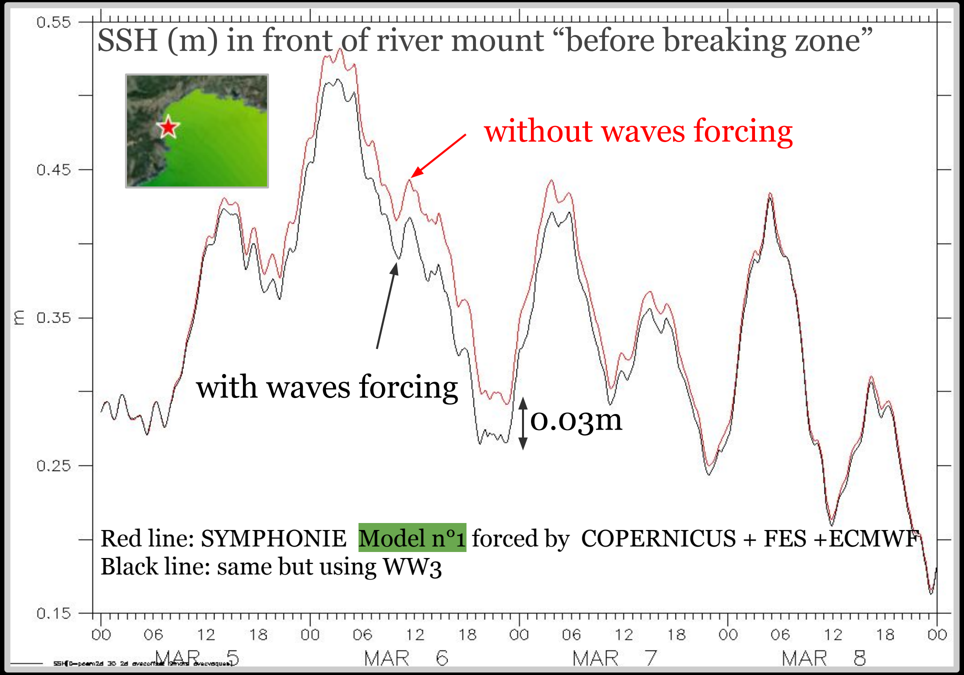


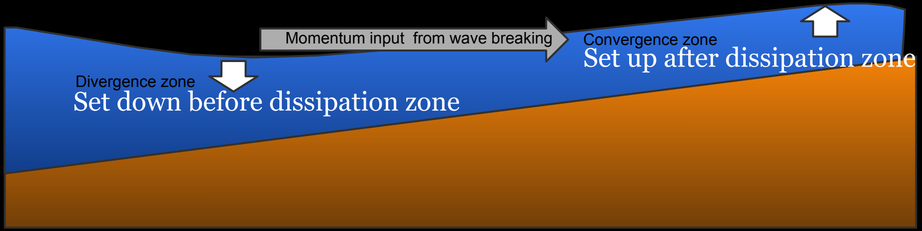
SSH (sea surf. height) > 0.5m observed at several stations, generally underestimated by the model

Added value of the WW3 waves model in the numerical system?

Effect of waves in Model n°1

- The circulation model is forced by the waves using *Ardhuin et al 2008* parametrisation
- Stokes transport and momentum input related to breaking and dissipation of waves have a significant effect on the computation of the sea level elevation.





A set down of 3cm (only?) due to wave forcing.

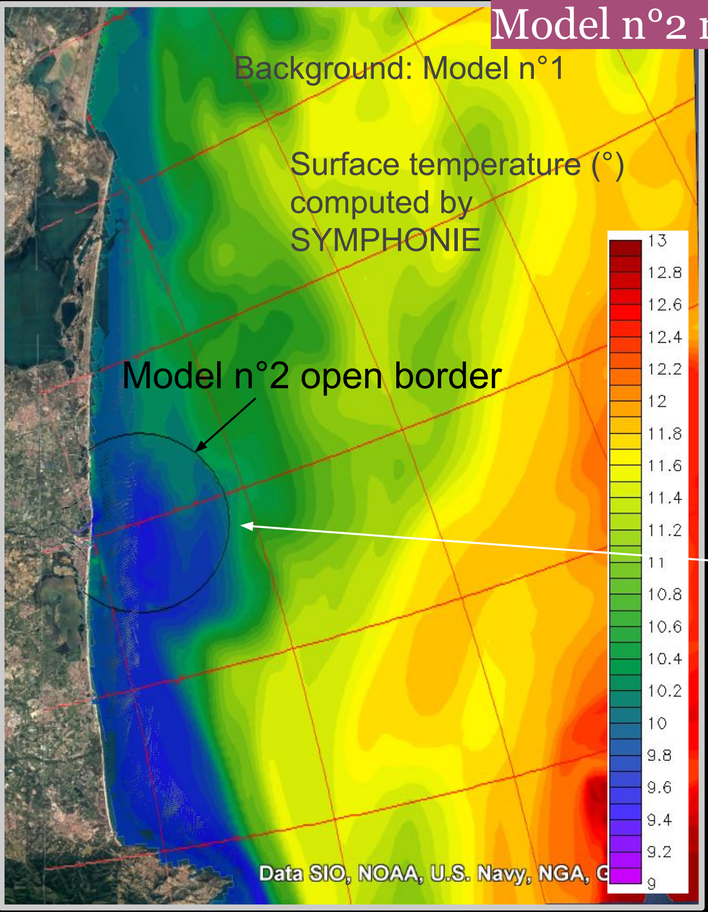
Waves effect on SSH "seems" smaller than tides, atmospheric pressure and ocean circulation?

Wave dissipation occurs near the coast and requires better resolution than Model n°1

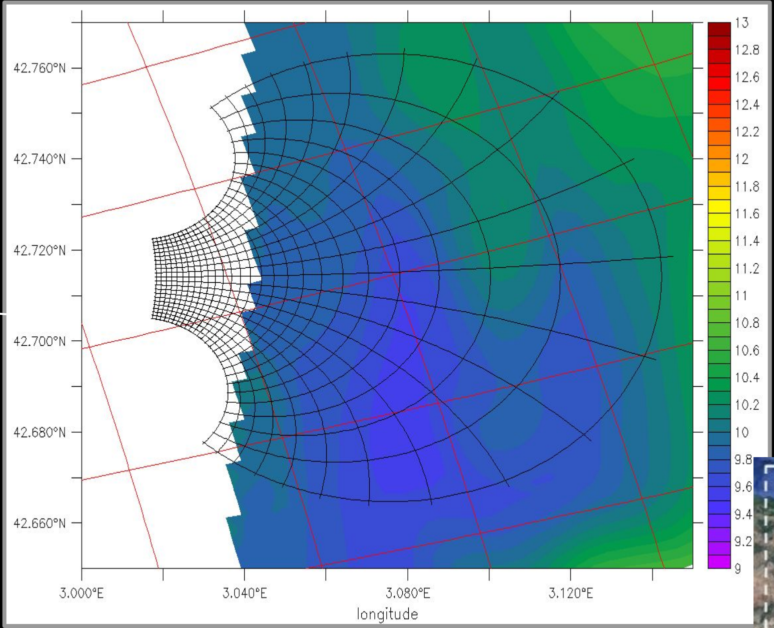
Flooding of the Tet river zone with very high resolution Model n°2

Copernicus, Malta, 2017

Model n°2 nested into Model n°1



Model n°1 resolution around Model n°2: about 300m
Model n°2 resolution at open border: twice that of Model n°1
Model n°2 resolution inland: about 10m



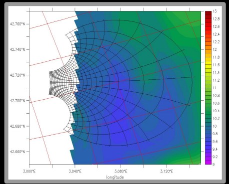
Red lines: Model n°1 grid indexes (1/10 in each direction)
Black lines: Model n°2 grid indexes (1/10 in each direction)

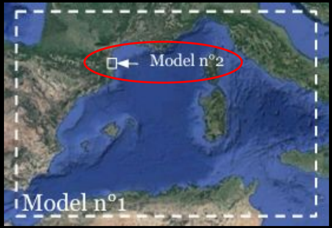
A variable resolution grid for a single model from the river (including the surrounding flood zone, up to 2km inland) to the sea (10km offshore)

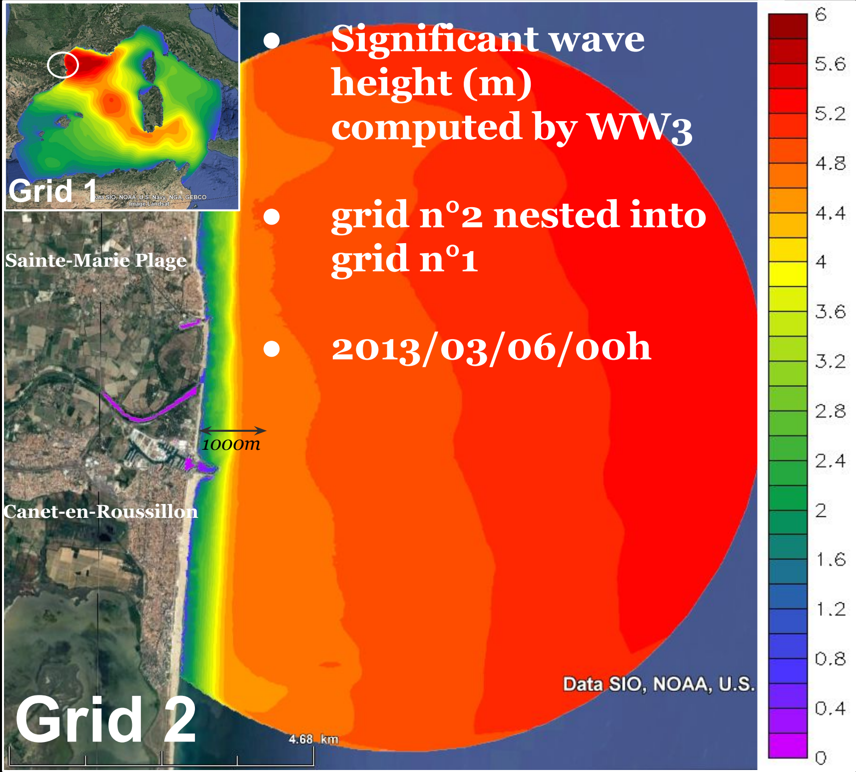
Flooding of the Tet river zone with very high resolution Model n°2

Waves downscaling using WW3 on grids n°1 & n°2

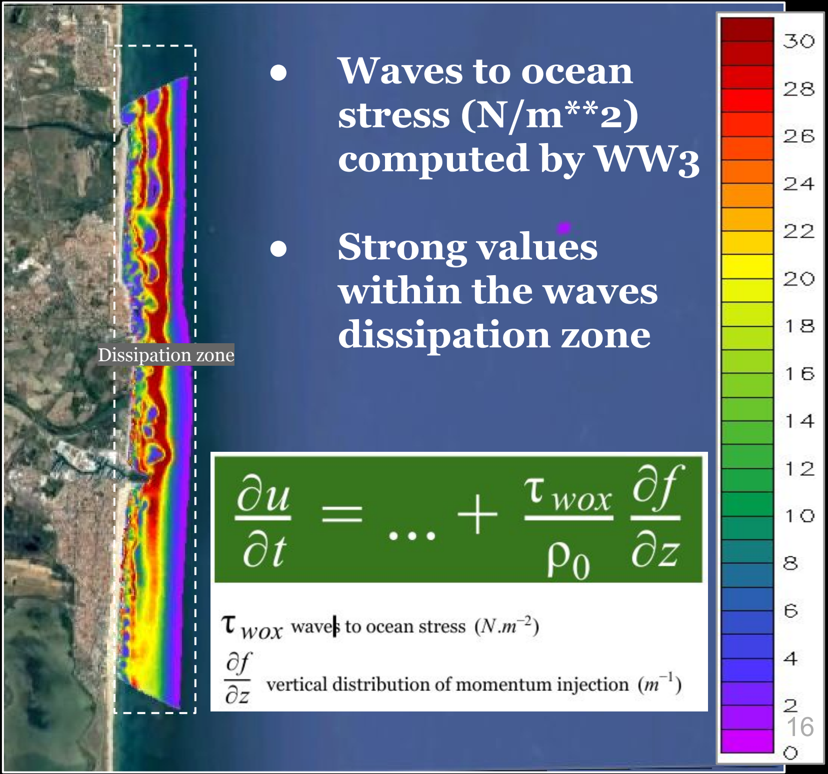
Momentum lost by waves (swell + sea state) is transferred to surface layer currents...







- **Significant wave height (m) computed by WW3**
- **grid n°2 nested into grid n°1**
- **2013/03/06/00h**



- **Waves to ocean stress (N/m**2) computed by WW3**
- **Strong values within the waves dissipation zone**

$$\frac{\partial u}{\partial t} = \ldots + \frac{\tau_{wox}}{\rho_0}\frac{\partial f}{\partial z}$$

τ_{wox} waves to ocean stress $(N.m^{-2})$

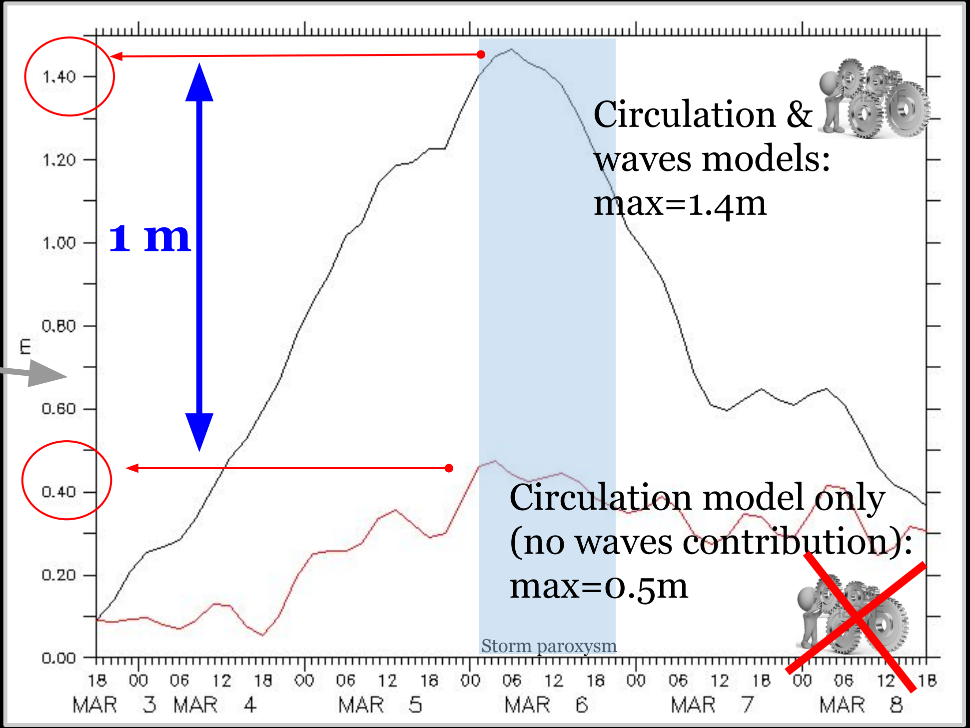
$\frac{\partial f}{\partial z}$ vertical distribution of momentum injection (m^{-1})

Flooding of the Tet river zone with very high resolution Model n°2

Effect of waves in ocean circulation Model n°2

More realistic sea level set up with waves forcing!

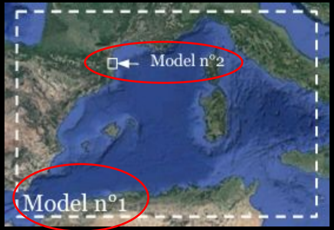
Two simulations, with and without waves forcing



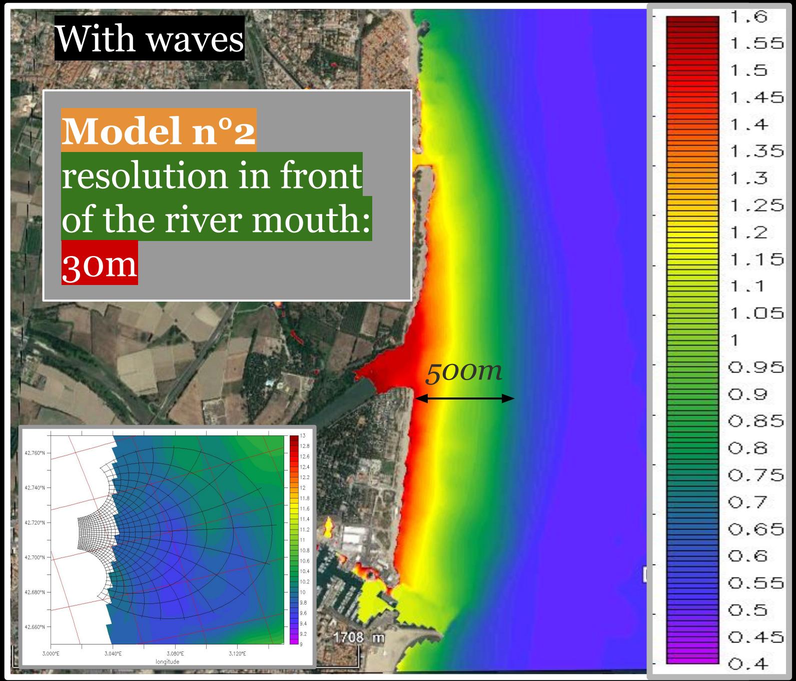
Sea surface height in front of the Tet river mouth computed by SYMPHONIE circulation model

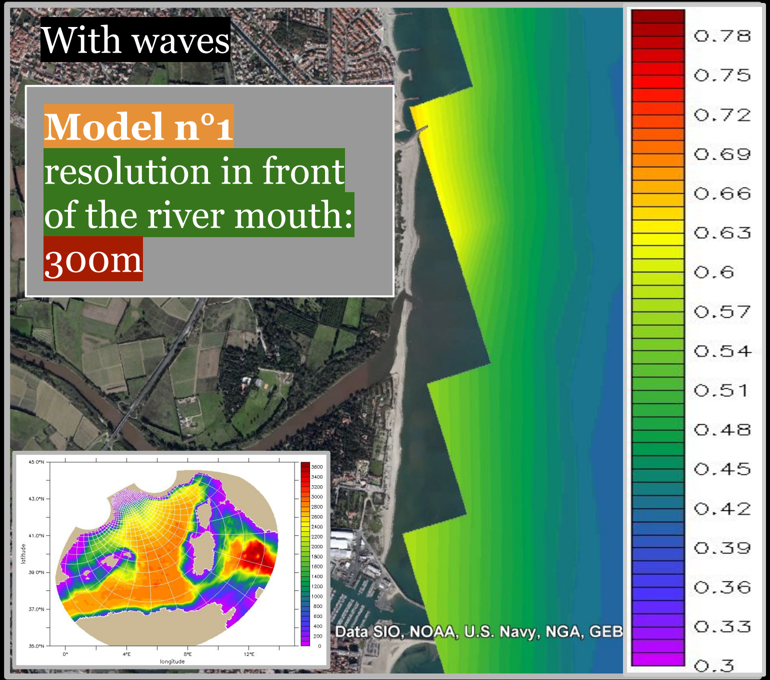
Flooding of the Tet river zone with very high resolution Model n°2

Effect of waves in Model n°2 versus Model n°1



Evidencing lack of resolution of Model n°1…

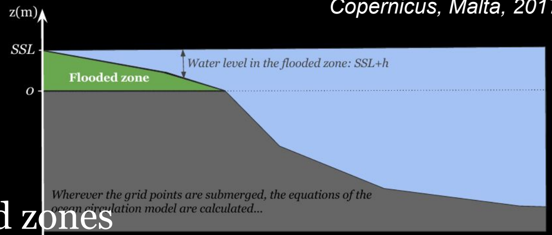




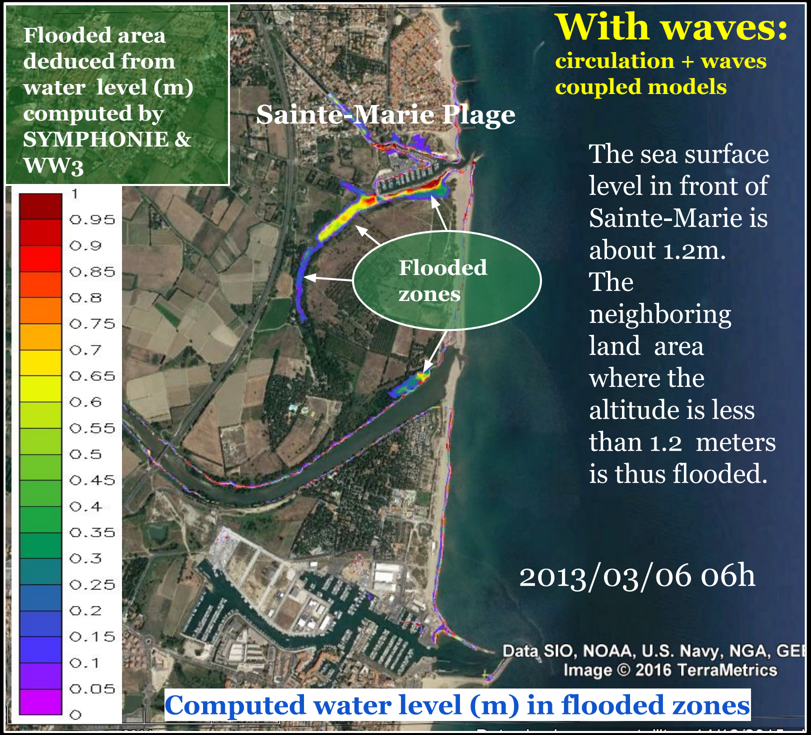
Sea surface height (m) computed by SYMPHONIE + WW3, 2013/03/06 12h

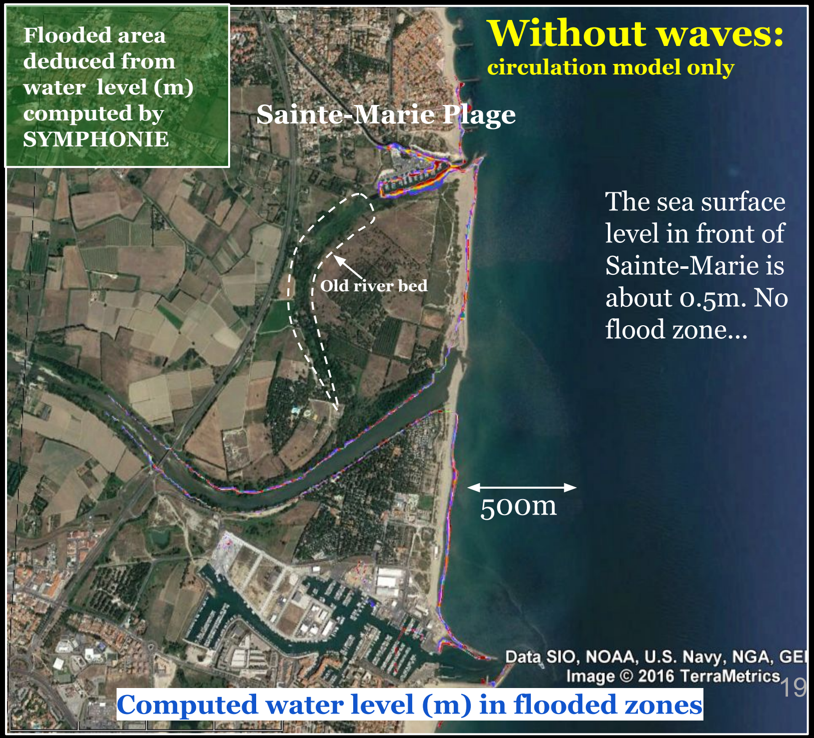
Flooding of the Tet river zone with very high resolution Model n°2

Effect of waves in Model n°2



- SYMPHONIE "Wetting Drying" 3D algorithm enables to create flooded zones
- The wave-induced SSH increase leads to the flooding in the northern part

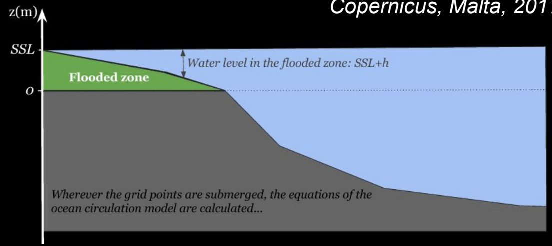


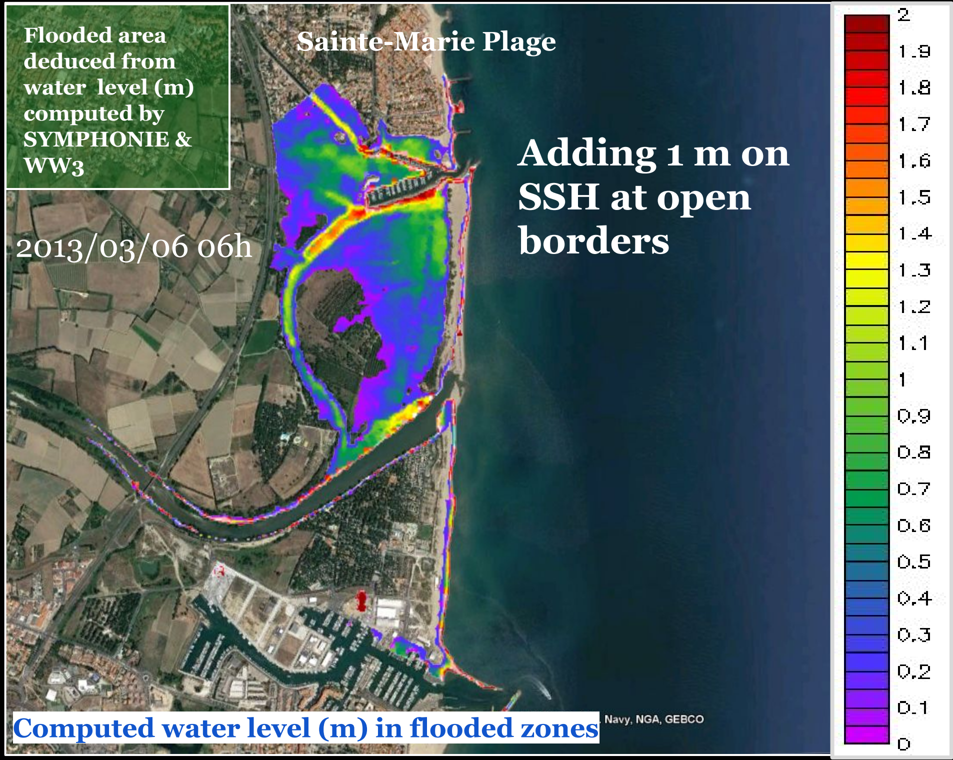


Flooding of the Tet river zone with very high resolution Model n°2

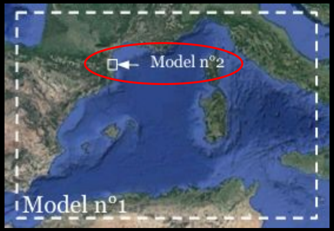
Effect of waves in Model n°2

Climate-related assumptions on mean sea level





Flooding of the Tet river zone with very high resolution Model n°2



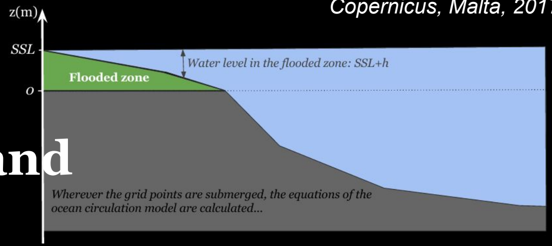
Impact of a strong river discharge and sensitivity to sand accumulation at the river mouth

Maximum river discharge: 600 m3/s

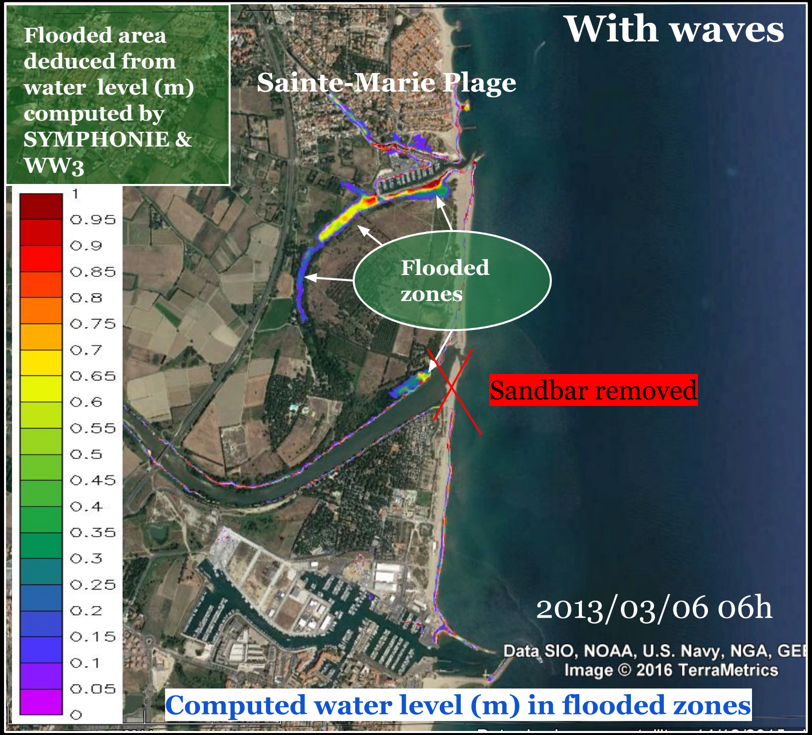
The river mouth is partly closed by a sandbar… possibly deletable by strong currents…

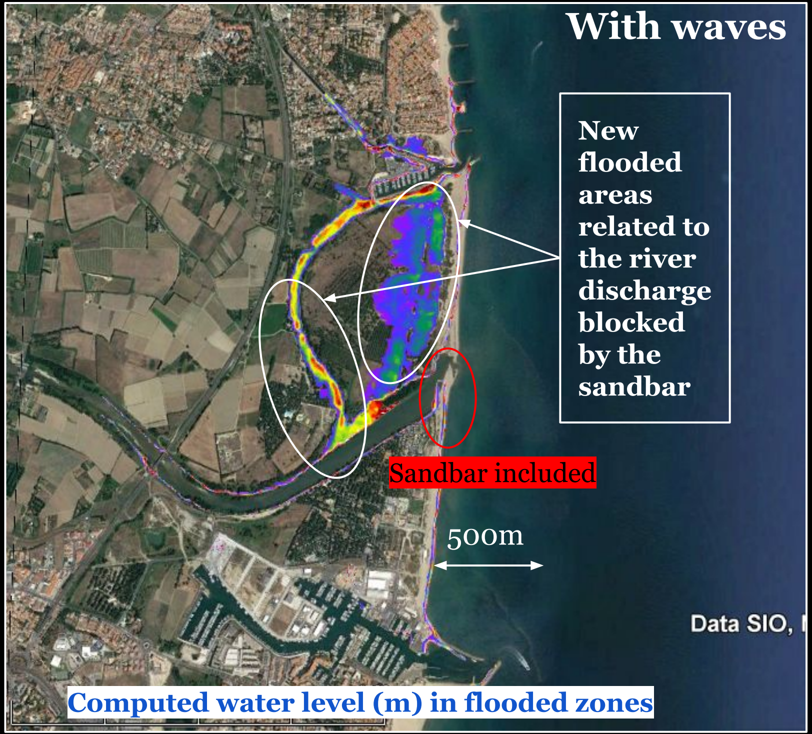
With or without sandbar: a numerical issue for flooding spatial extension

Flooding of the Tet river zone with very high resolution Model n°2



Impact of a strong river discharge and sensitivity to sand accumulation at the river mouth

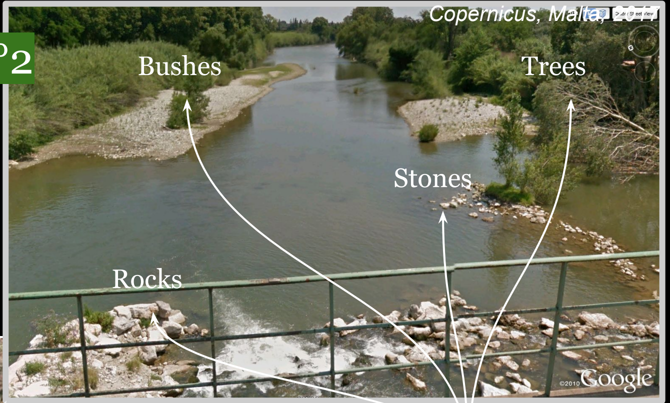


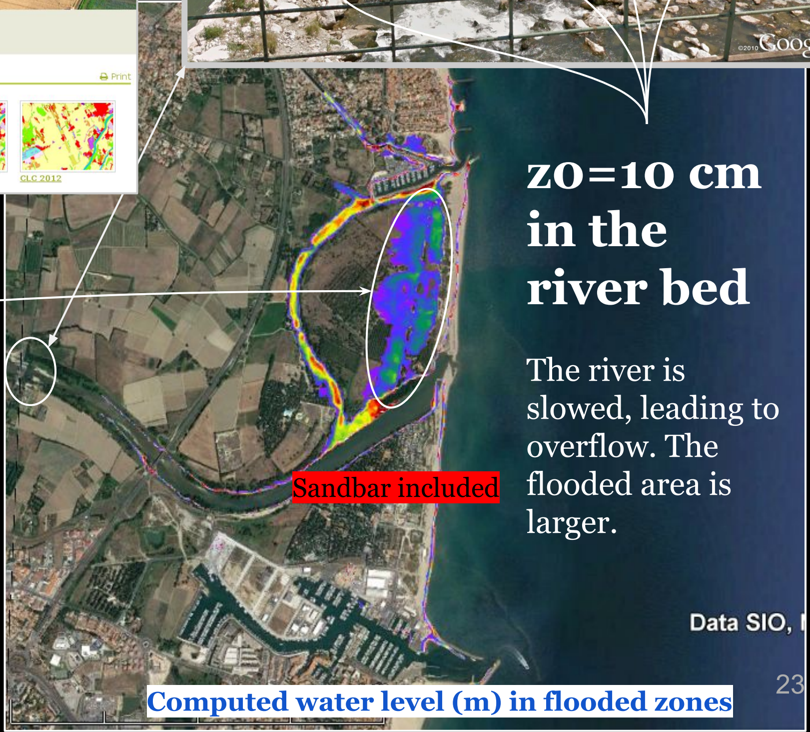


Flooding of the Tet river zone with very high resolution Model n°2

Impact of the setting of some model parameters

- The bottom roughness (possibly estimated from Copernicus Land Monitoring Service)





Prevention of river flooding in the French Roussillon Mediterranean Coast

SIROCCO academic research group, Laboratoire d'Aérologie, CNRS & Toulouse University, France

Conclusions:

- **Coastal flooding**: a growing problem in many parts of the world
- **COPERNICUS fields** provide the essential background conditions
- **Fine scales, extreme & local issues** supplied by expert teams in coastal flooding

Specific conclusions

- Effect of waves on coastal SSH is bigger than other processes in storm conditions
- Required resolution regarding wave breaking effect: better than 100m
- River flooding sensitive to morphodynamics (sandbar) and to model settings (bottom roughness…)

Perspectives:

- **Tides in NEMO model** (and some day in COPERNICUS products)

Sirocco group perspectives:

- **Sand and sediment online transport**
- **Coupling with regional atmospheric modelling**

Acknowledgments: Florent Lyard, LEGOS (FES tides, terrain model,…), MERCATOR team , IFREMER & SHOM (WW3 expertise)

Model n°1:

Initial time: 2013/02/01 (one month spinup)
Grid nodes: 670 x 508 x 40
mpi: 140 subdomains
cpu time / physical time = 8 mn / 1 days

Model n°2:

Initial time: 2013/03/05
Grid nodes: 262 x 211 x 10
mpi: 80 subdomains
cpu time / physical time = 45 mn / 1 day

WW3 simulations:

Basin scale simulations

MERCATOR-OCEAN PSY2V4R4 1/12° grid
Forcings: ECMWF wind + PSY2V4R4 surface current
Hourly outputs

North Western scale simulations

Model n°1 grid
Forcings: ECMWF wind
Open boundary conditions: "basin scale simulations"
Hourly outputs
Used in circulation model: one-way forcing (via netcdf files)

Short term perspectives (in test)

Two-way forcing using OASIS coupler (including grid n°2)

Acknowledgments: WW3 R&D team (IFREMER, Brest) and SHOM (Toulouse)

SYMPHONIE “S26” release:

Time stepping: hybrid “forward-backward” (gravity waves) and “Leap-Frog”
Fast surface mode: time-splitting, continuous, explicit, free surface
Turbulence: k-epsilon
Waves effect: Ardhuin et al (2008)
Meteorological forcing: bulk formulae
Grid: horizontal curvilinear C grid & generalised sigma
Scalar horizontal advection/diffusion: hybrid UP3/UP2
Scalar vertical advection: hybrid C2/UP2
Momentum horizontal advection/diffusion: hybrid C4+biharmonic (Griffies Hallberg 2000)/UP2
Momentum vertical advection: hybrid C2/UP2
Wetting-Drying: 3D scheme
Tides: Astronomical potential forcing as in Pairaud et al (2008)

Distributed by SIROCCO group, LA/LEGOS, CNRS & Toulouse University
References: Marsaleix et al, Ocean Modelling, (2008,2009,2011,2012)