NAÇÃO: BRASIL
ESTADO FEDERAL: CEARÁ
Prefeitura de Caucaia
Localidade "Iparana-Icarai-Parazinho"

PARQUE EÓLICO OFFSHORE CAUCAIA
N. 59 AEROGERADORES

Anexo 1.1 para o Estudo de Impacto Ambiental (EIA)

ESTUDO MODELLO CINEMATICO-MOLHES

Empresa Proprietária

BI ENERGIA LTDA

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CEP 60170-002

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NOVEMBRO 2019

Restoration of the shore in Caucaia: numerical simulations

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Introduction

- The aim of this work is to investigate, through numerical modeling, the effects of the introduction of a set of breakwaters in the shelf region next to Caucaia (Brazil)

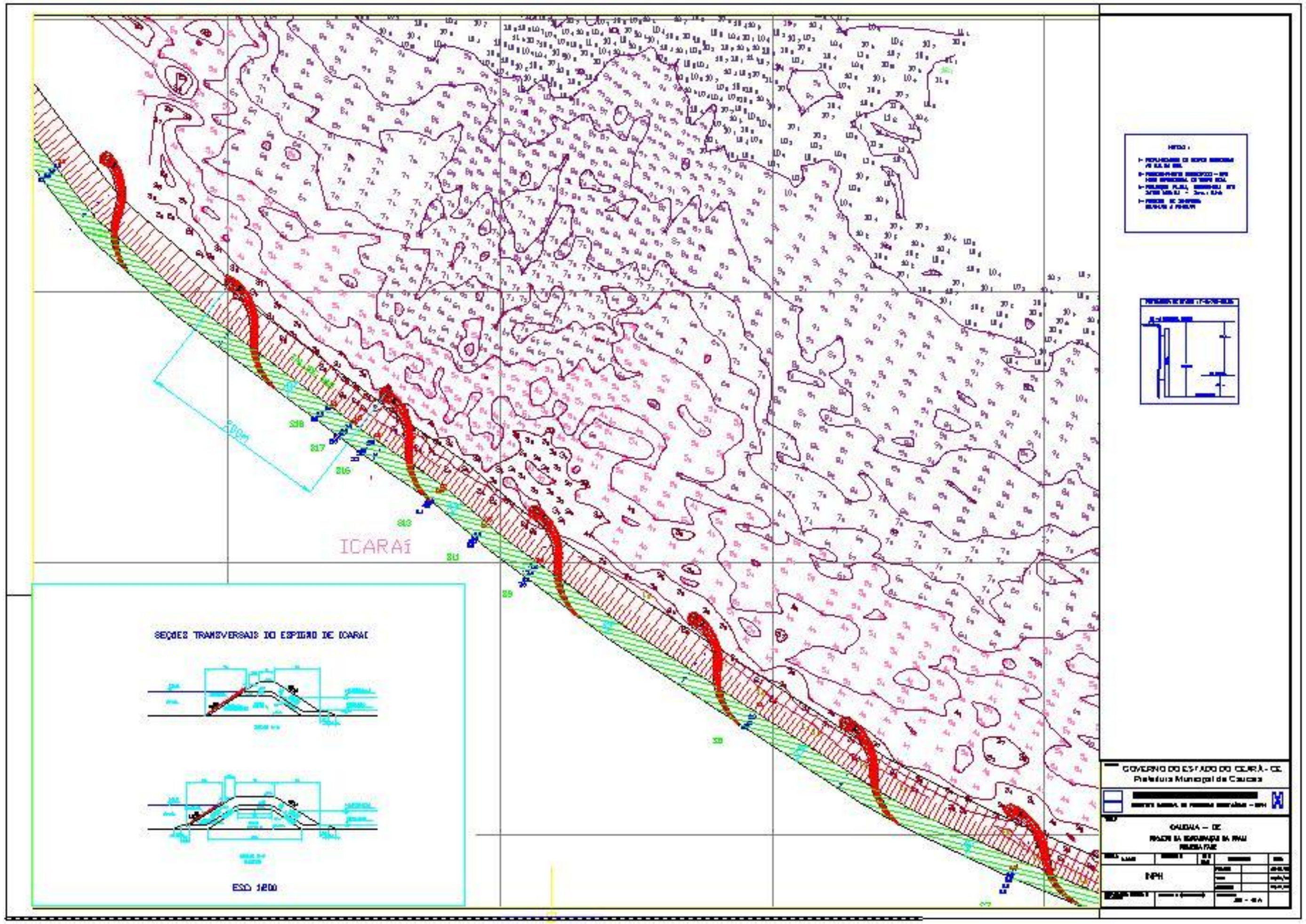
- In the last few years this region has been affected by a strong erosion probably due to the recent construction of the *Molhe do Titã* and of the *Espigão da Praia do Futuro* in Mucuripe, south of Caucaia

- The introduction of 11 breakwaters is proposed for the restoration of the shore next to Caucaia

- Here the Princeton Ocean Model (POM) has been implemented in two different nested domains. Several scenarios have been simulated with and without the breakwaters

- A preliminary analysis of the propagation of long gravity waves off the coast after the hypothetical implementation of the project has been carried out

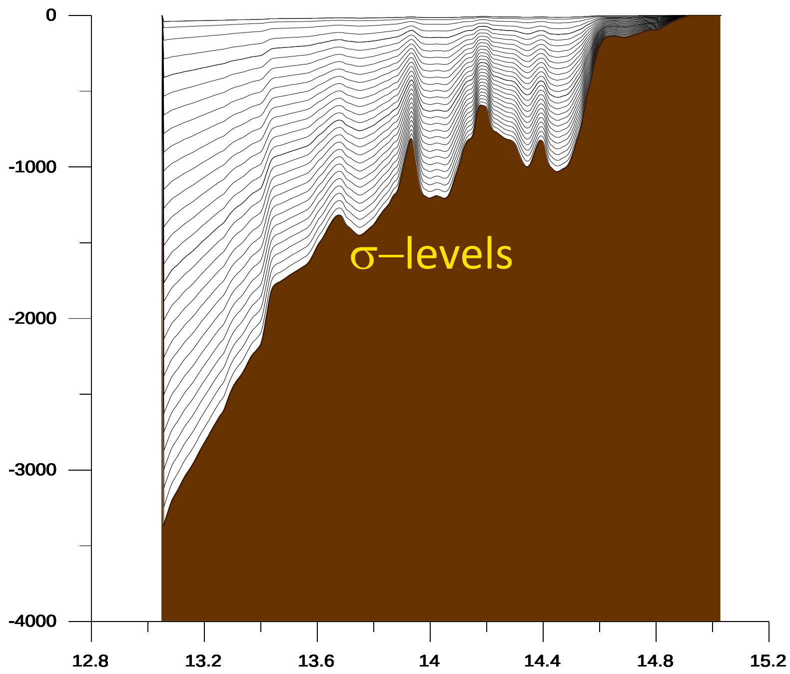
The project suggested



The model

- The model that we have adopted is the Princeton Ocean Model (POM), one of the most popular general circulation models in the physical oceanographic community

- POM is a 3D, primitive equation sigma-coordinate model originally developed for coastal circulation studies



Among the many interesting features of POM, its “terrain-following” sigma-coordinate vertical discretization allows one to simulate a realistic bottom boundary layer. This is important in coastal waters and in tidally driven estuaries

The equations

The barotropic version of the POM has been implemented for this study. The basic equations solved by the model are:

$$\frac{\partial UD}{\partial t} + \frac{\partial U^2 D}{\partial x} + \frac{\partial UVD}{\partial y} - fVD + gD\frac{\partial \eta}{\partial x} = \frac{\partial}{\partial x}\left[H2A_M \frac{\partial U}{\partial x}\right] + \frac{\partial}{\partial y}\left[HA_M\left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x}\right)\right] + (\tau_b - \tau_w)_x - \frac{gD}{\rho_0}\int_{-1}^{0}\int_{\sigma}^{0}\left[D\frac{\partial \rho'}{\partial x} - \frac{\partial D}{\partial x}\sigma'\frac{\partial \rho'}{\partial \sigma}\right] d\sigma' d\sigma$$

$$\frac{\partial VD}{\partial t} + \frac{\partial V^2 D}{\partial y} + \frac{\partial UVD}{\partial x} - fUD + gD\frac{\partial \eta}{\partial y} = \frac{\partial}{\partial y}\left[H2A_M \frac{\partial V}{\partial y}\right] + \frac{\partial}{\partial x}\left[HA_M\left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x}\right)\right] + (\tau_b - \tau_w)_y - \frac{gD}{\rho_0}\int_{-1}^{0}\int_{\sigma}^{0}\left[D\frac{\partial \rho'}{\partial y} - \frac{\partial D}{\partial y}\sigma'\frac{\partial \rho'}{\partial \sigma}\right] d\sigma' d\sigma$$

$$\frac{\partial DU}{\partial x} + \frac{\partial DV}{\partial y} + \frac{\partial \eta}{\partial t} = 0$$

where

$\sigma = \frac{z - \eta}{H + \eta}$ that ranges from 0 at z= and -1 at z=H

$D = H + \eta$ (total tickness of the sea)

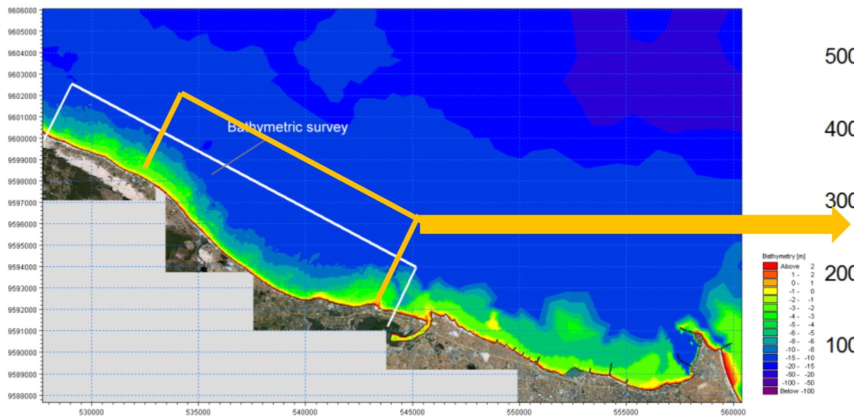
$U = \int_{-1}^{0} u \, d\sigma$ (integrated u velocity)

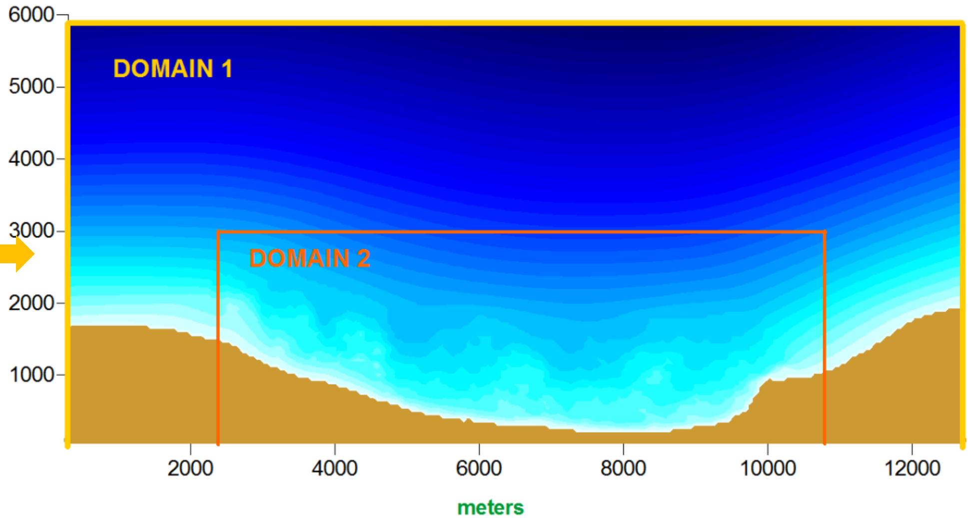
$V = \int_{-1}^{0} v \, d\sigma$ (integrated v velocity)

Topography and domains of integration

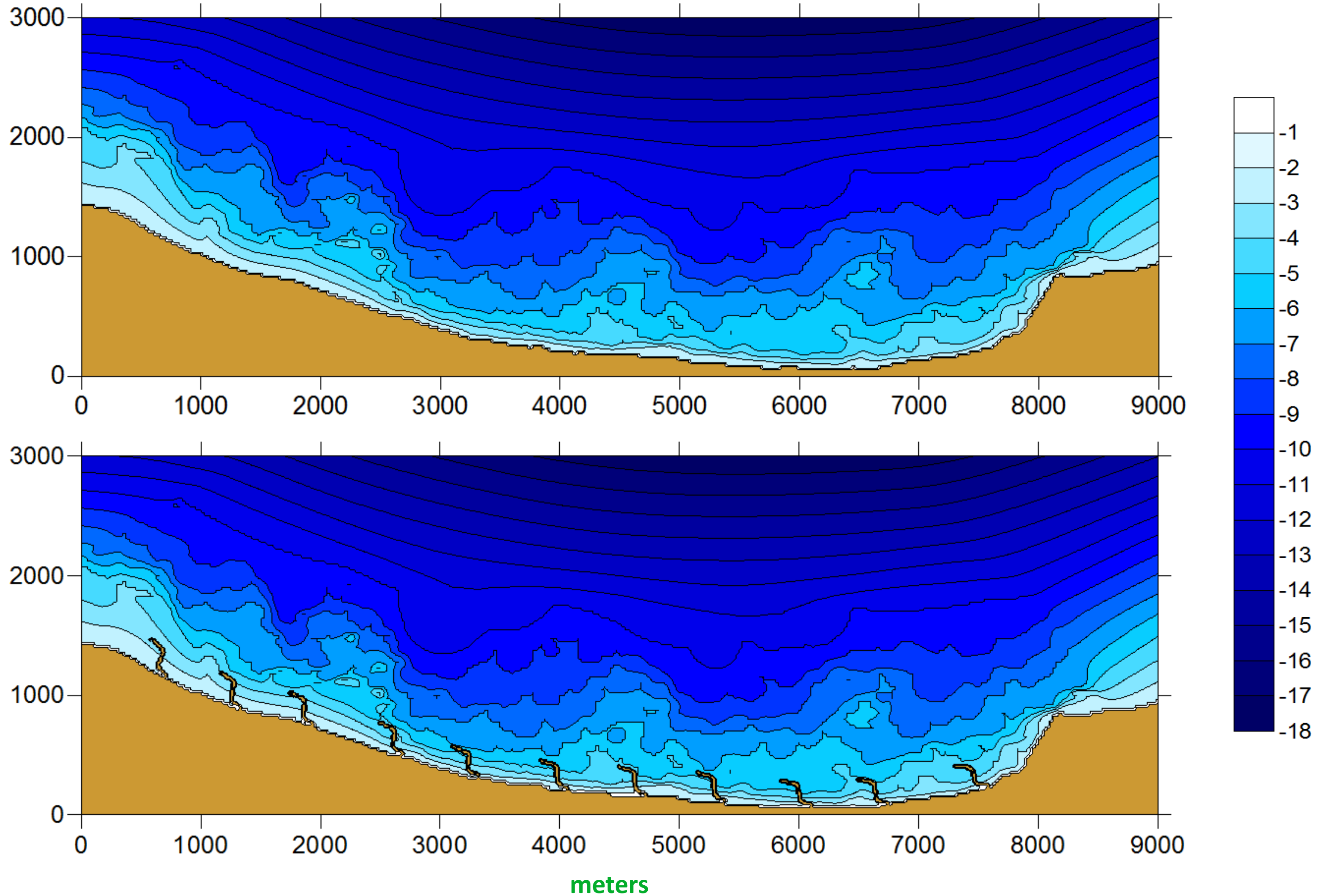
- Starting from the available data, the profile of the coast and the bathymetry have been recostructed for two different domains

- Domain 1 (13 km x 6 km with a horizontal spatial resolution of 50 m) has been used to obtain the boundary conditions to be imposed along the lateral boundaries of Domain 2 (9 km x 3 km with resolution of 12,5 m). Thus, Domain 2 is one-way nested to Domain 1

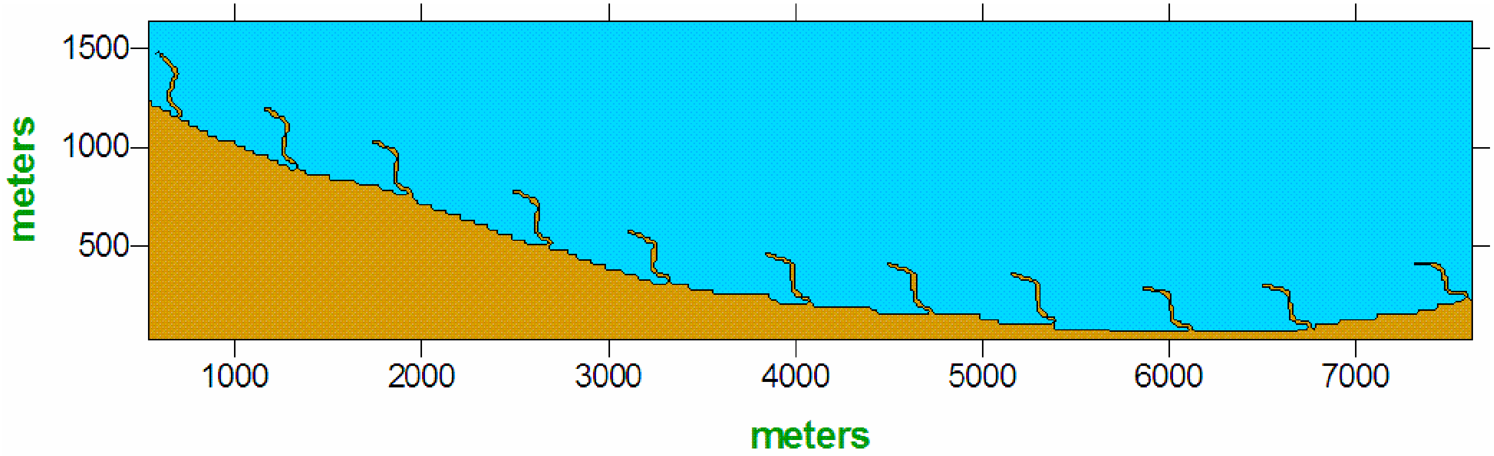


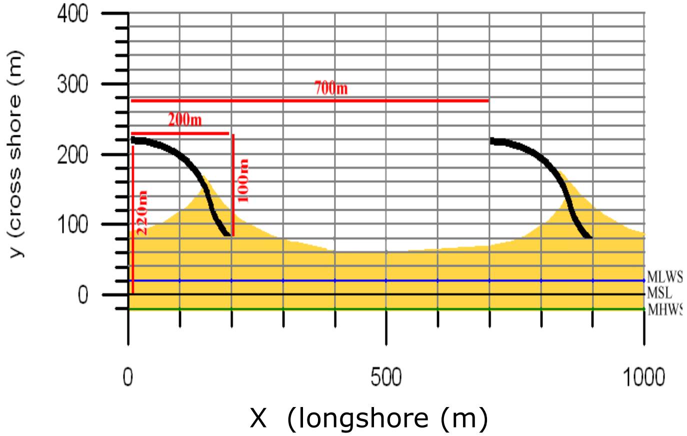


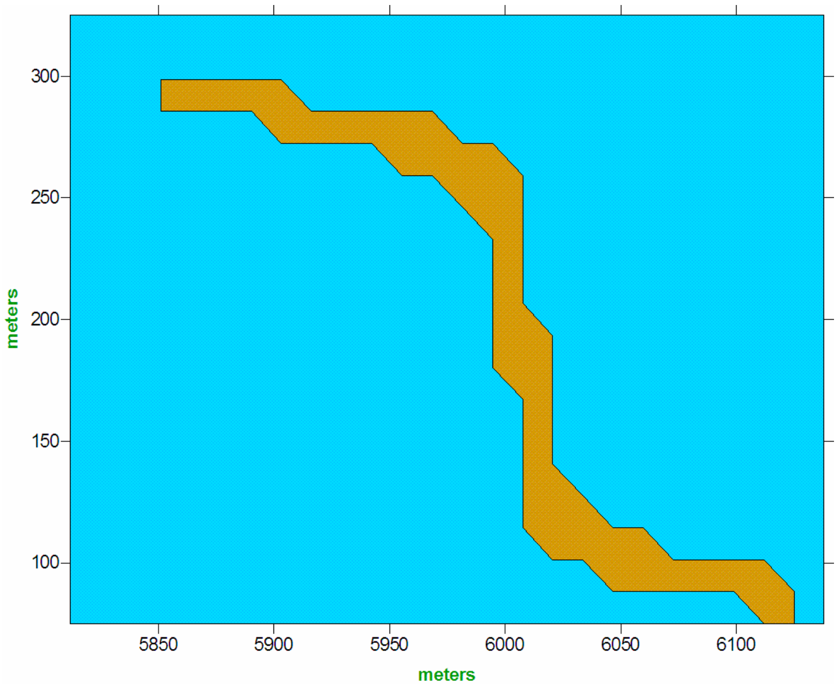
Domain 2 and introduction of breakwaters



Structure of the breakwaters

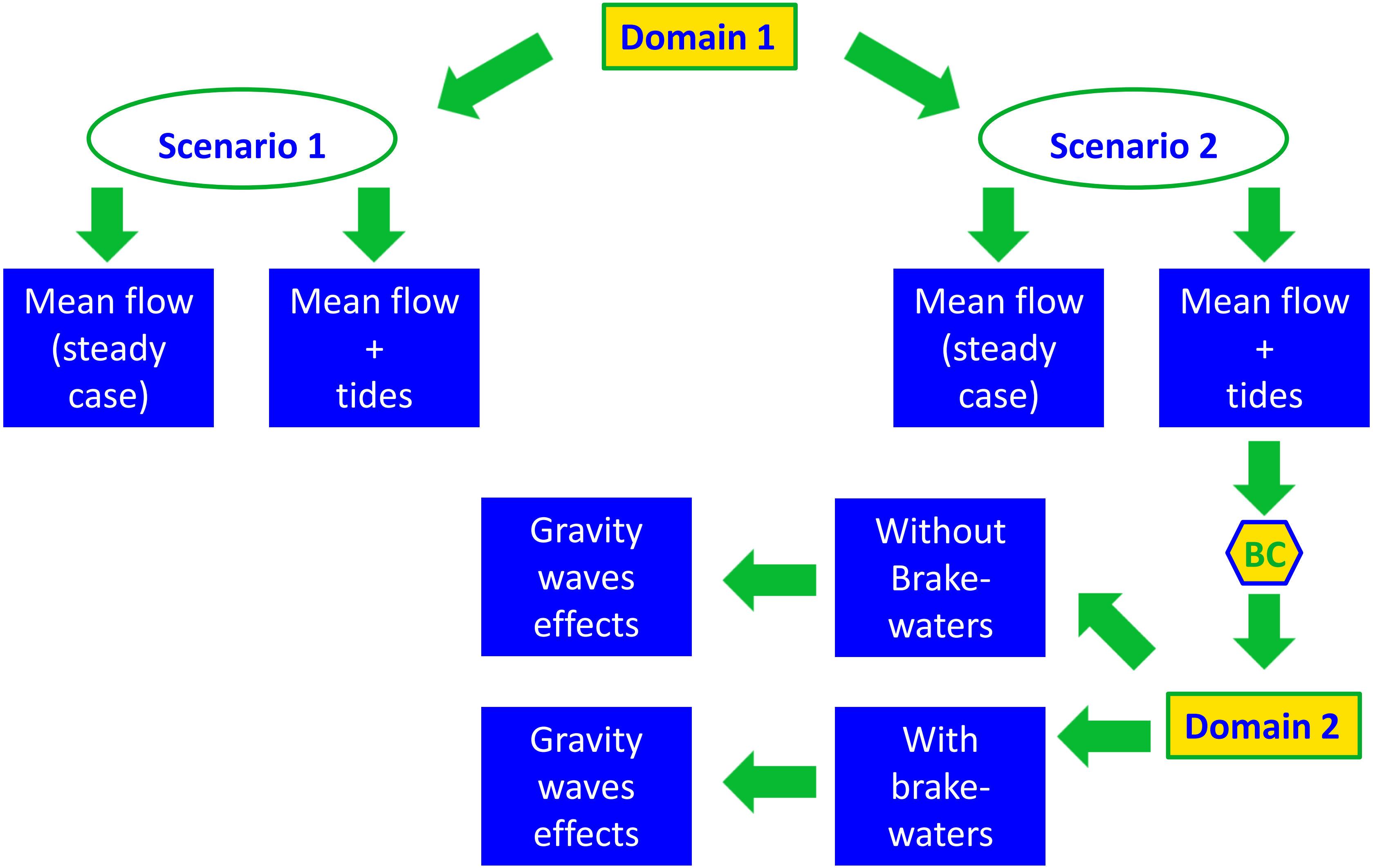






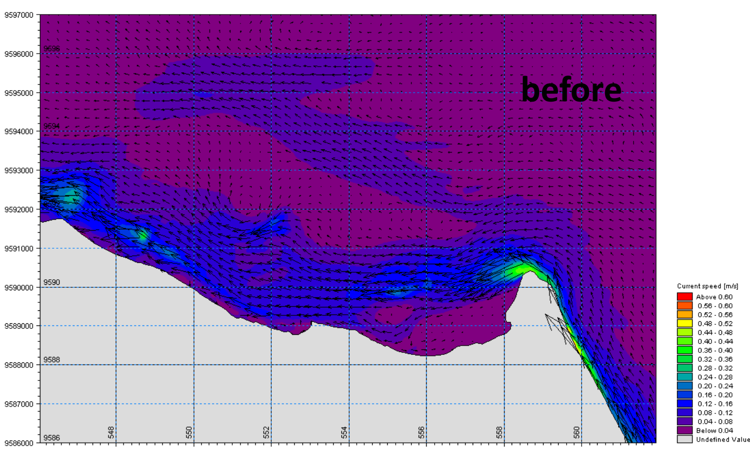
Each brakewater has been introduced following the indications of the project

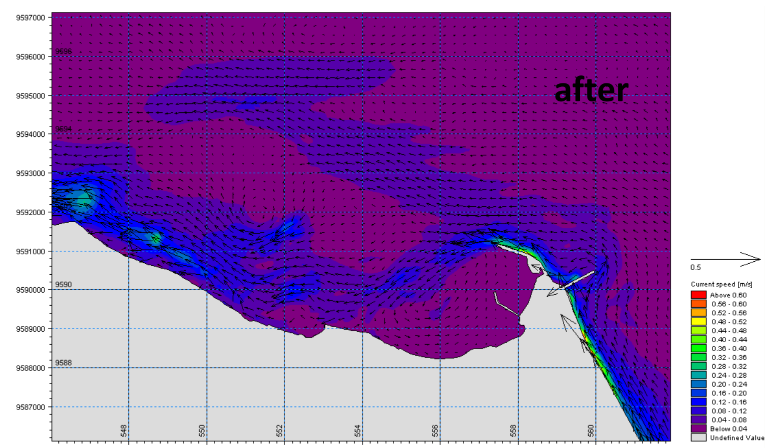
Hyerarchy of the experiments



Simulation in Domain 1

- The simulations in Domain 1 constitute the necessary step for the implementation of the model in the area of interest (Domain 2). They are essentially useful for:
  1. simulating the mean flow due to the prevailing winds in the Caucaia region
  2. simulating the effect of tides
  3. obtaining the boundary conditions to be imposed on Domain 2
- After the construction of the port in Mucuripe the characteristic circulation in this area is changed:



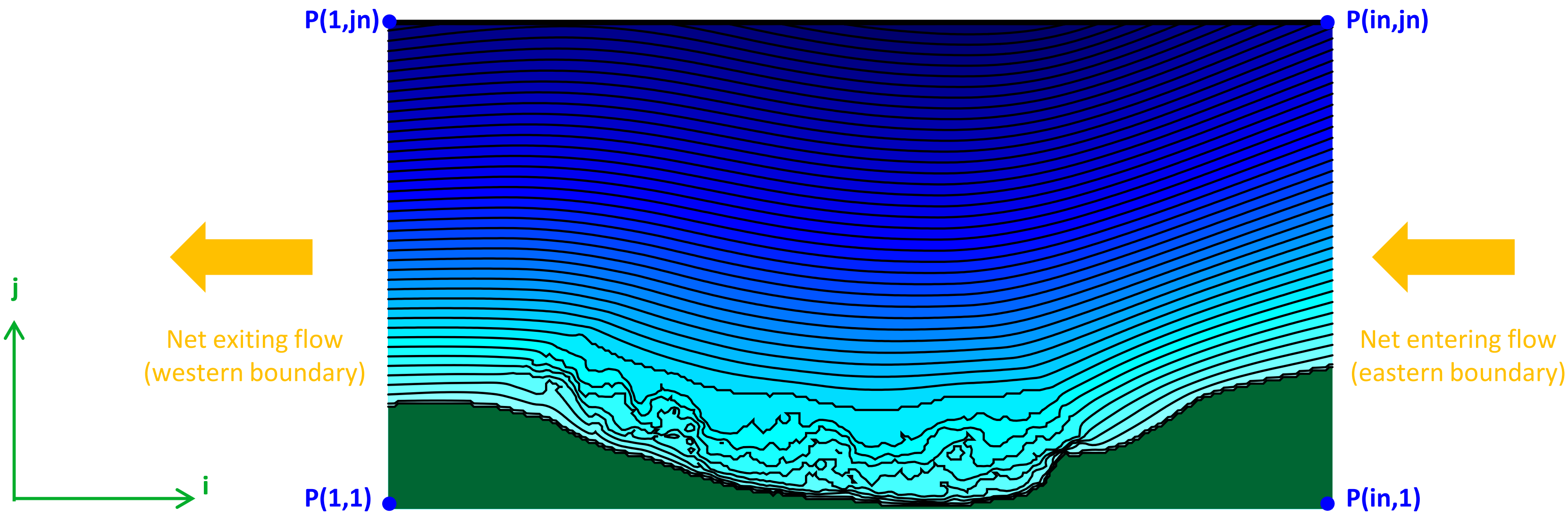


- Through the imposition of appropriate boundary conditions, we have reproduced these two scenarios

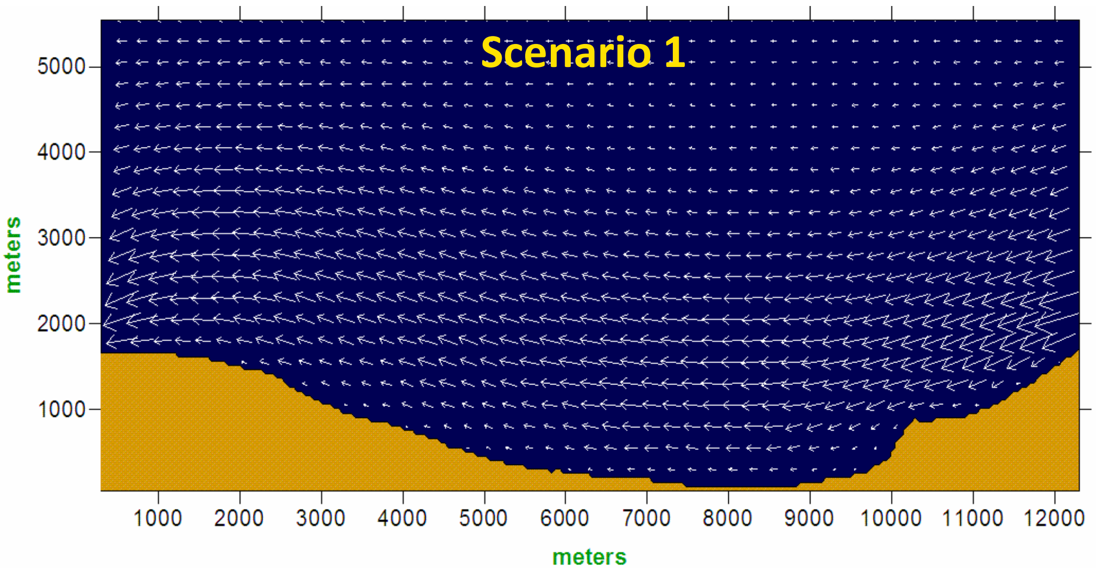
The two scenarios

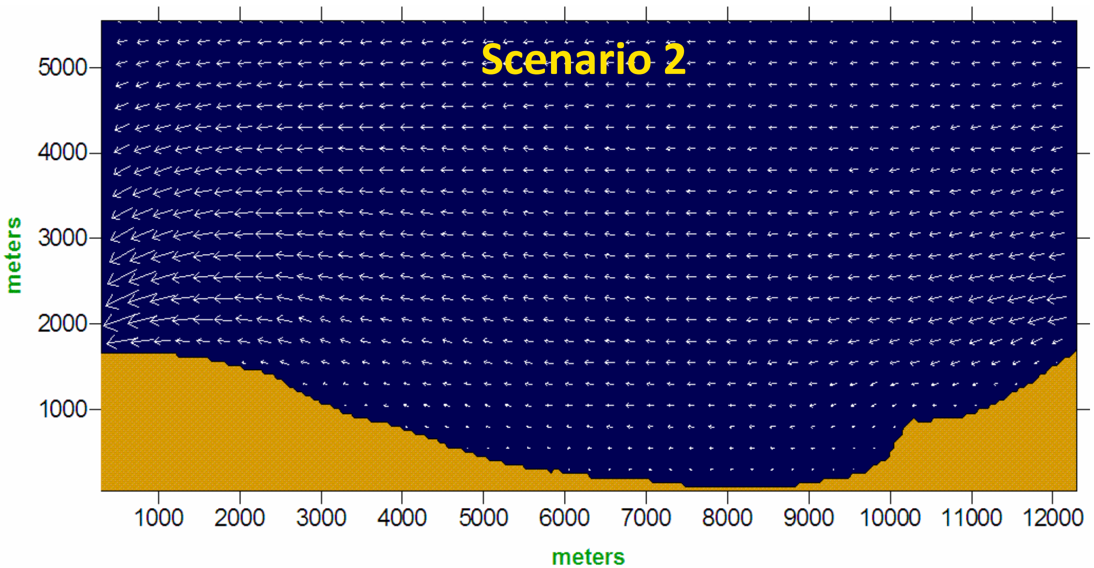
- The starting point is the simulation of the mean flow in domain 1 due to prevalent wind stress in the region (south-east winds) as it was after (scenario 2) and before (scenario1) the building of the Molhe do Titã and of the Espigão da Praia do Futuro in Mucuripe
- We forced the system simply imposing the east-west boundary current (***u***) in a way such as to have the net entering flow on the east side of the same amount of the net exiting flow from the west side

$$\bar{u}(i,j) : \sum_{j=1}^{j=\text{jn}} \bar{u}(1,j) = \sum_{j=1}^{j=\text{jn}} \bar{u}(\text{in},j)$$



The mean flow





- These two simulations are only a preliminary approach to test the right implementation of the model.
- The results are however the starting point for a right implementation of the effects of the tides

→
0.4 m/s

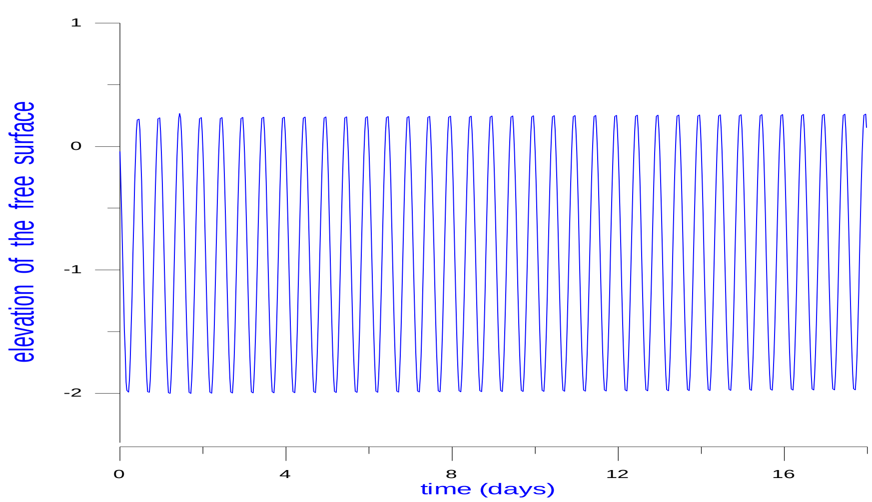
The effect of tidal flow

- The area next to Caucaia is strongly influenced by a semidiurnal tide as shown from measured data
- The effect of M_2 tidal currents has been introduced adding a variable part (***var***) to the steady boundary condition for the mean flow (***mean***)
- The variable part has to have the same period (***T***) and the same amplitude (***A***) both for east and west boundary condition but a different phase (φ)

$$BC_{east} \rightarrow u = mean + var_{east}$$
$$var_{east} = A * \cos\left(\frac{2\pi}{T} + \varphi_{east}\right)$$

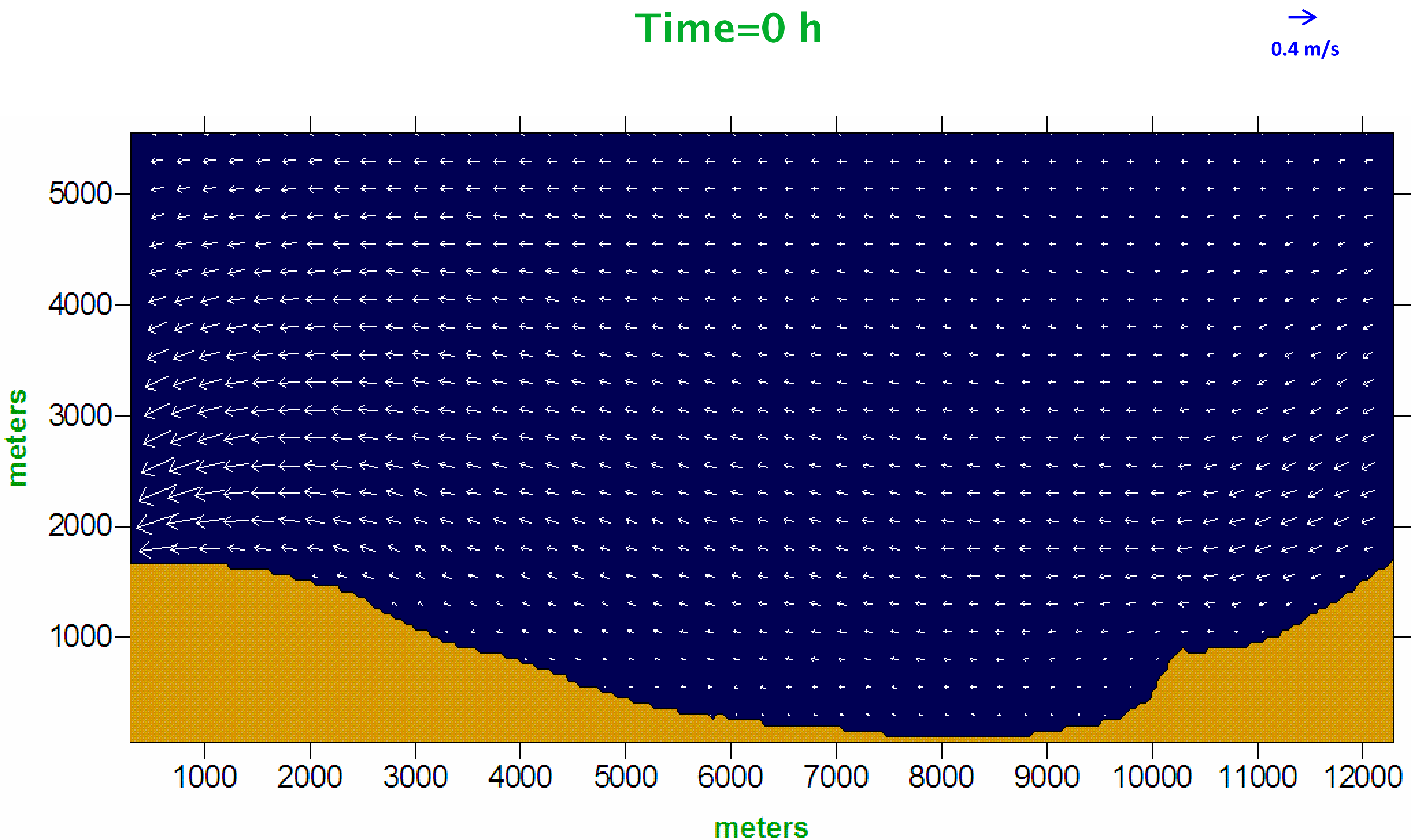
$$BC_{west} \rightarrow u = mean + var_{west}$$
$$var_{west} = A * \cos\left(\frac{2\pi}{T} + \varphi_{west}\right)$$

$$\sum_{j=1}^{j=jn} \sum_{t=t0}^{t=T} u(1, j, t) = -\sum_{j=1}^{j=jn} \sum_{t=t0}^{t=T} u(in, j, t)$$



The sampling of the results of the elevation of the free surface in a generic internal point of the domain during the simulation has shown that the M_2 tide is well reproducted

Time=0 h


0.4 m/s
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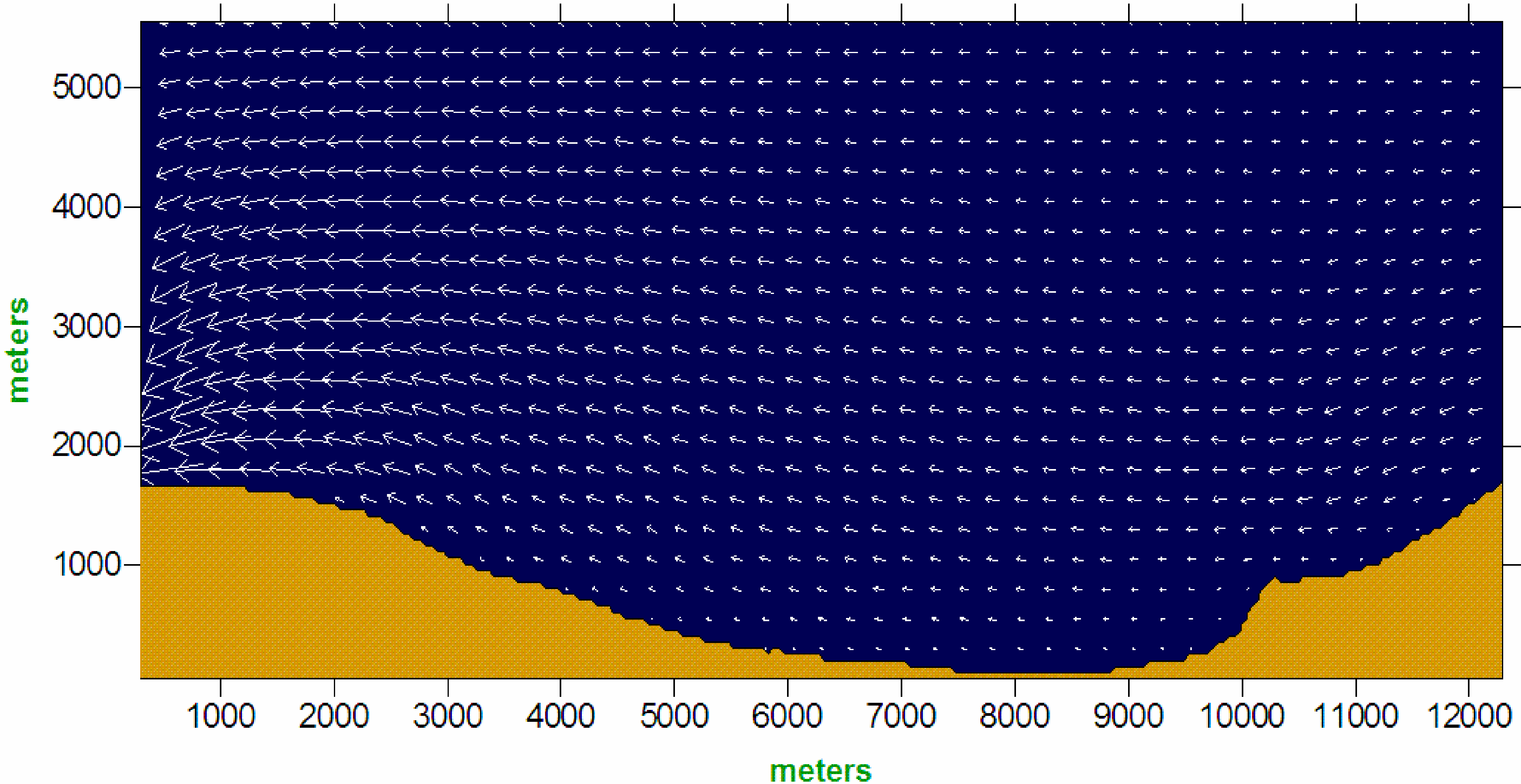
Time=2 h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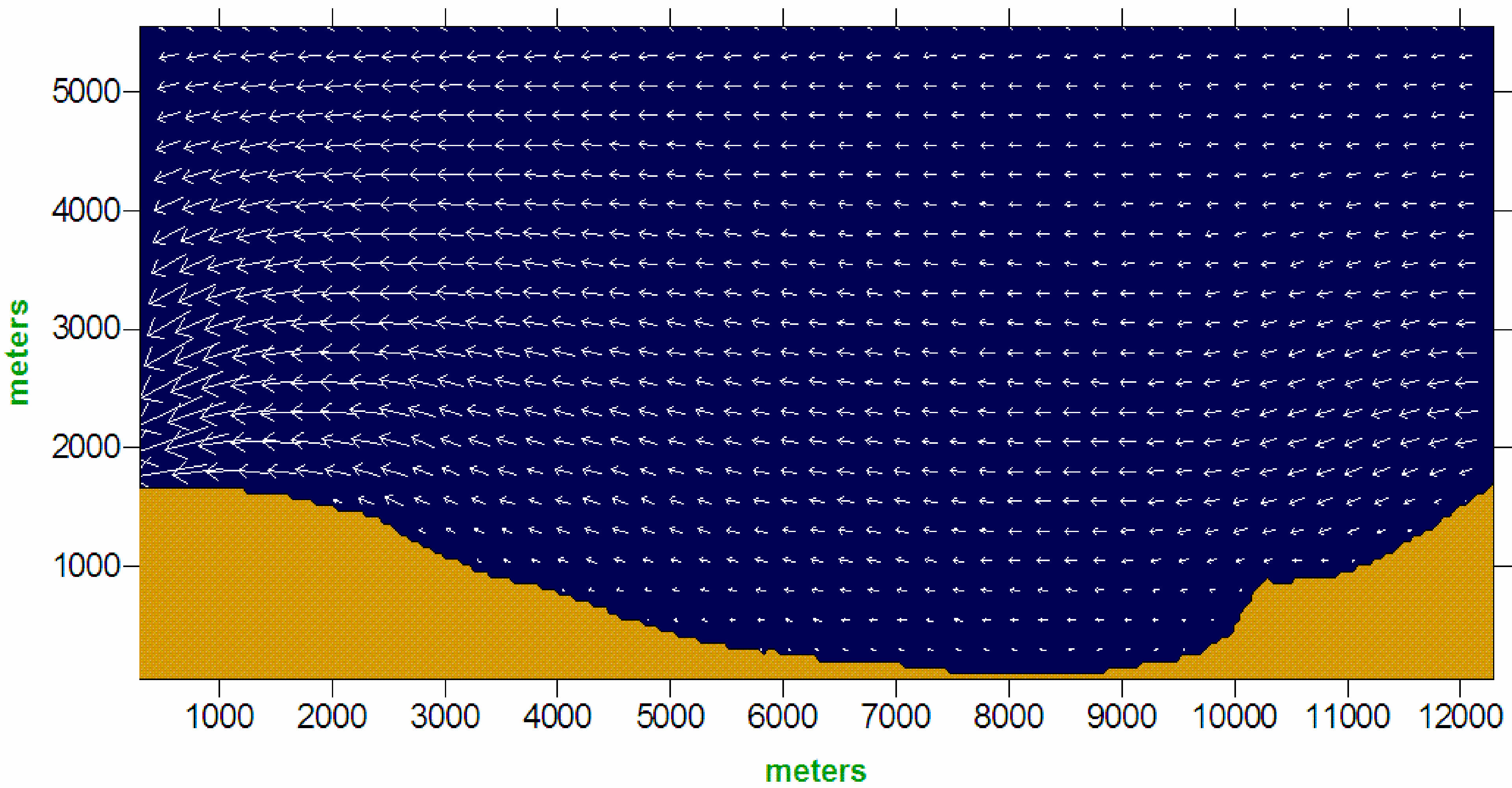
Time=4 h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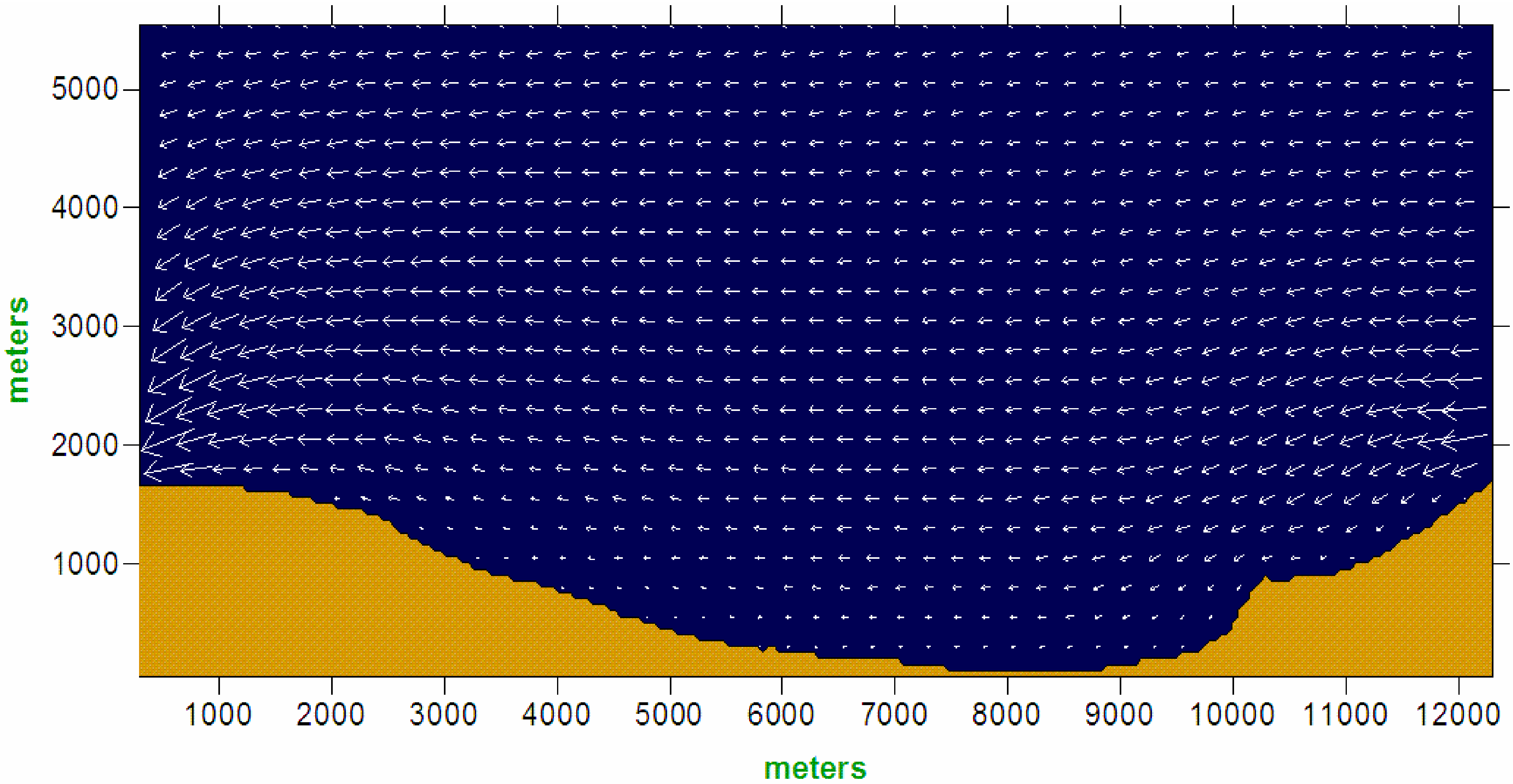
Time=6 h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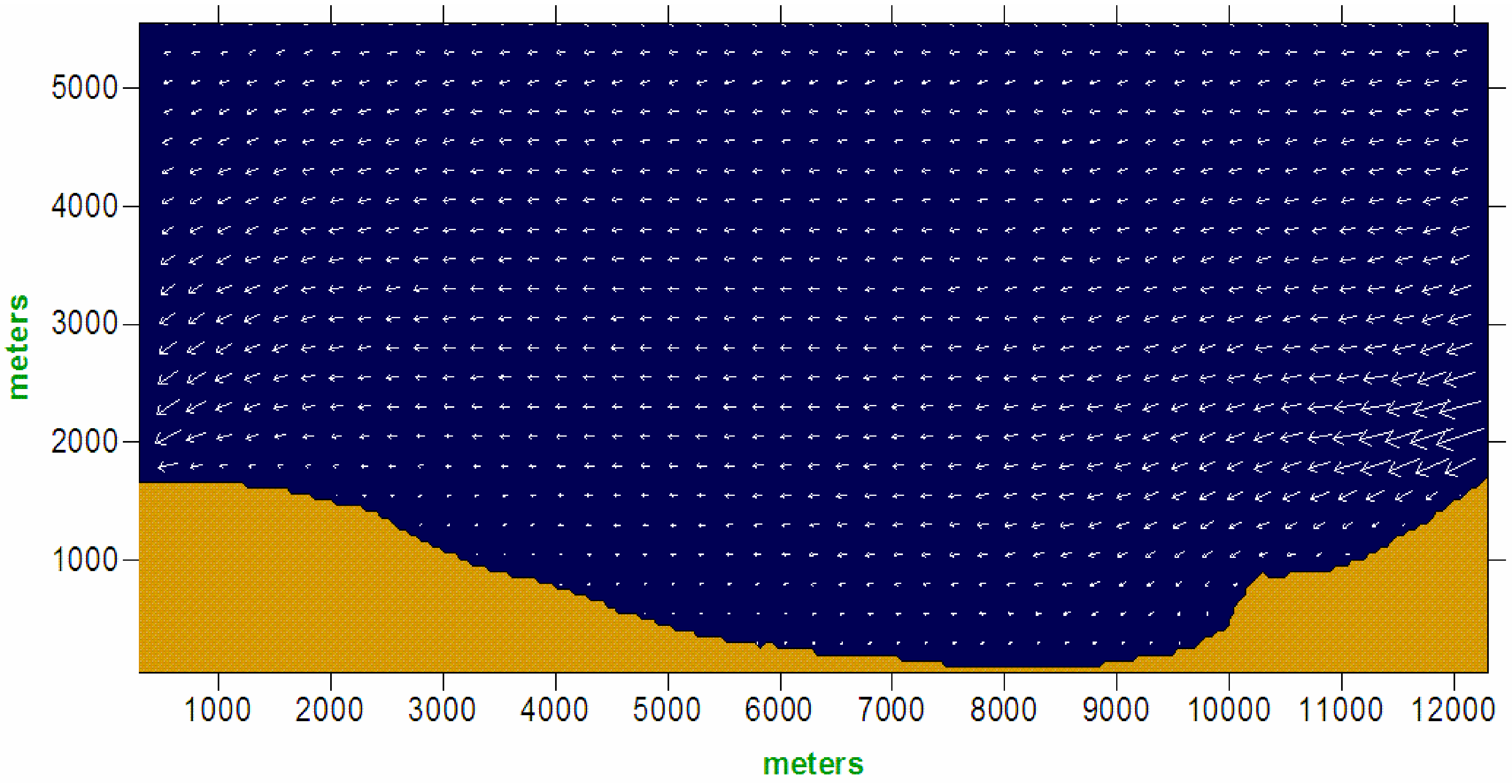
Time=8 h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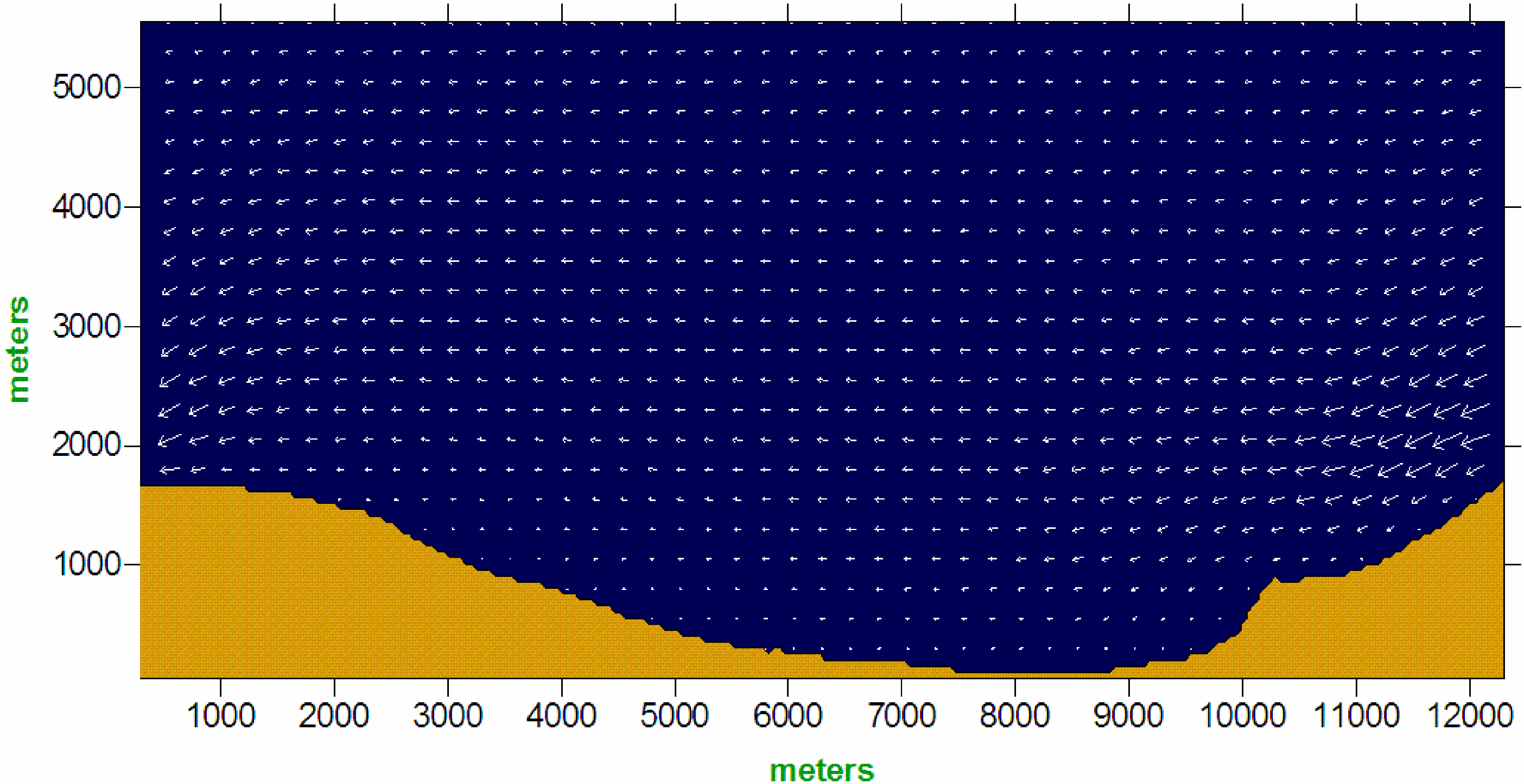
Time=10 h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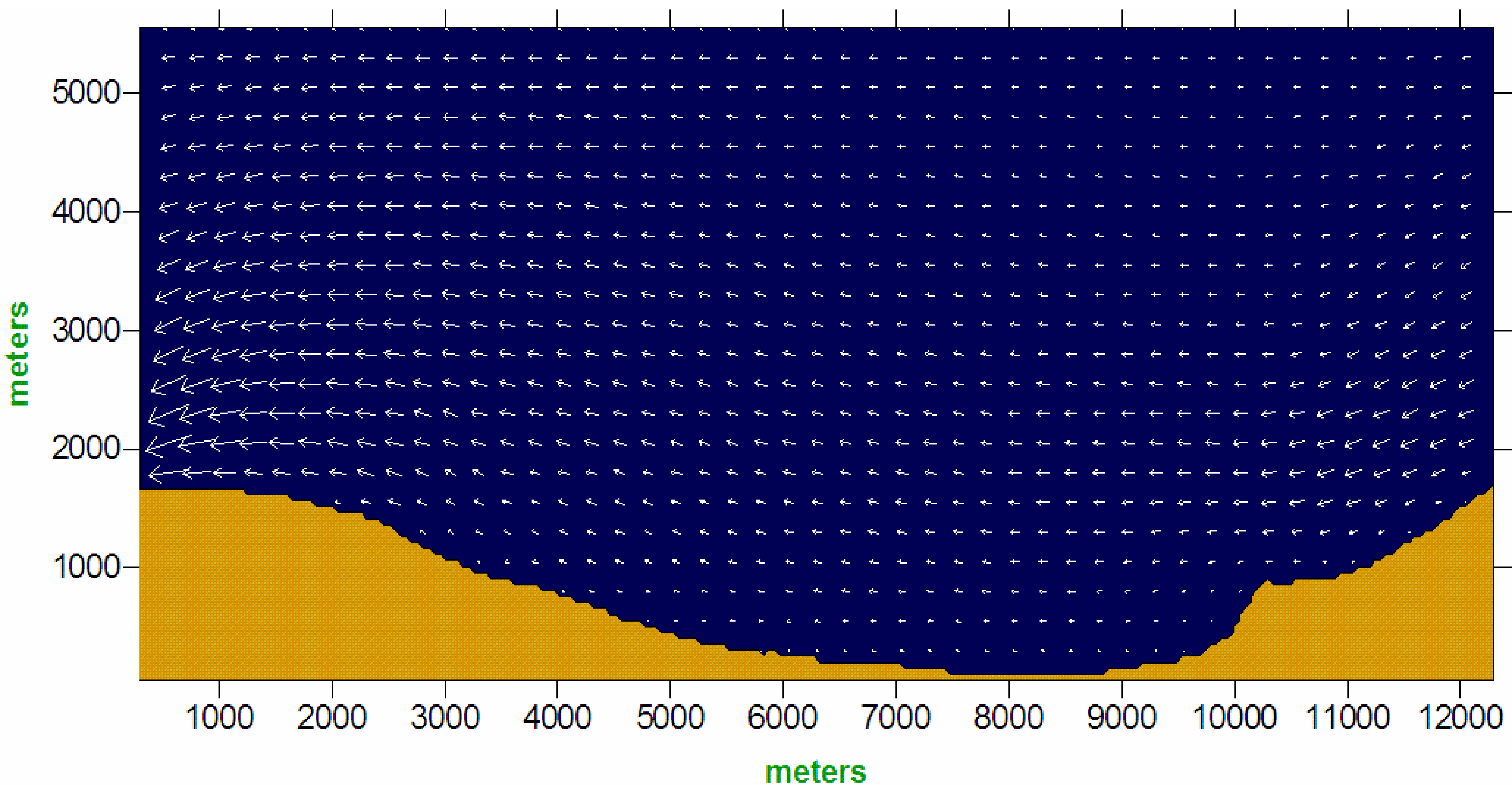
Time=12 h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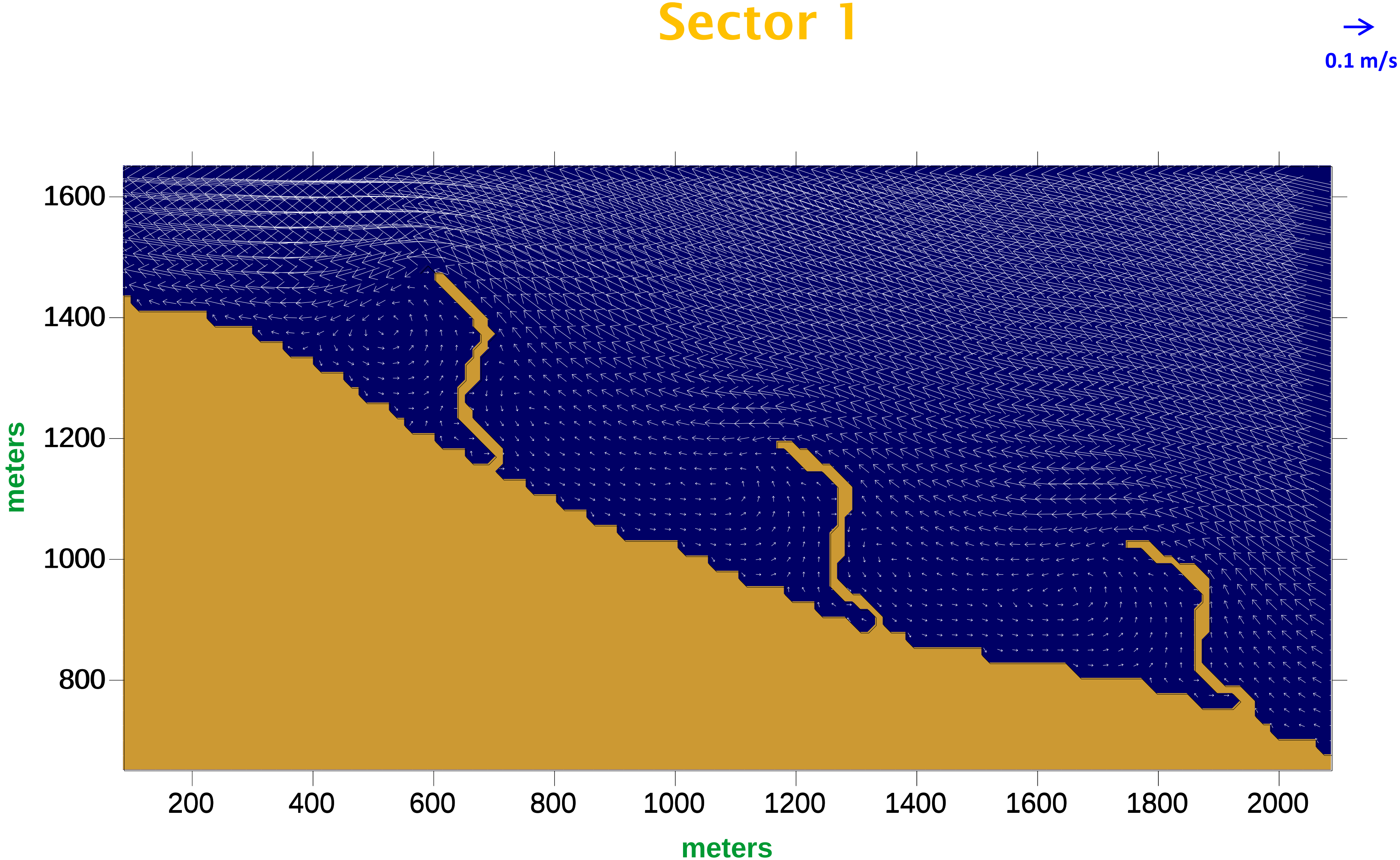
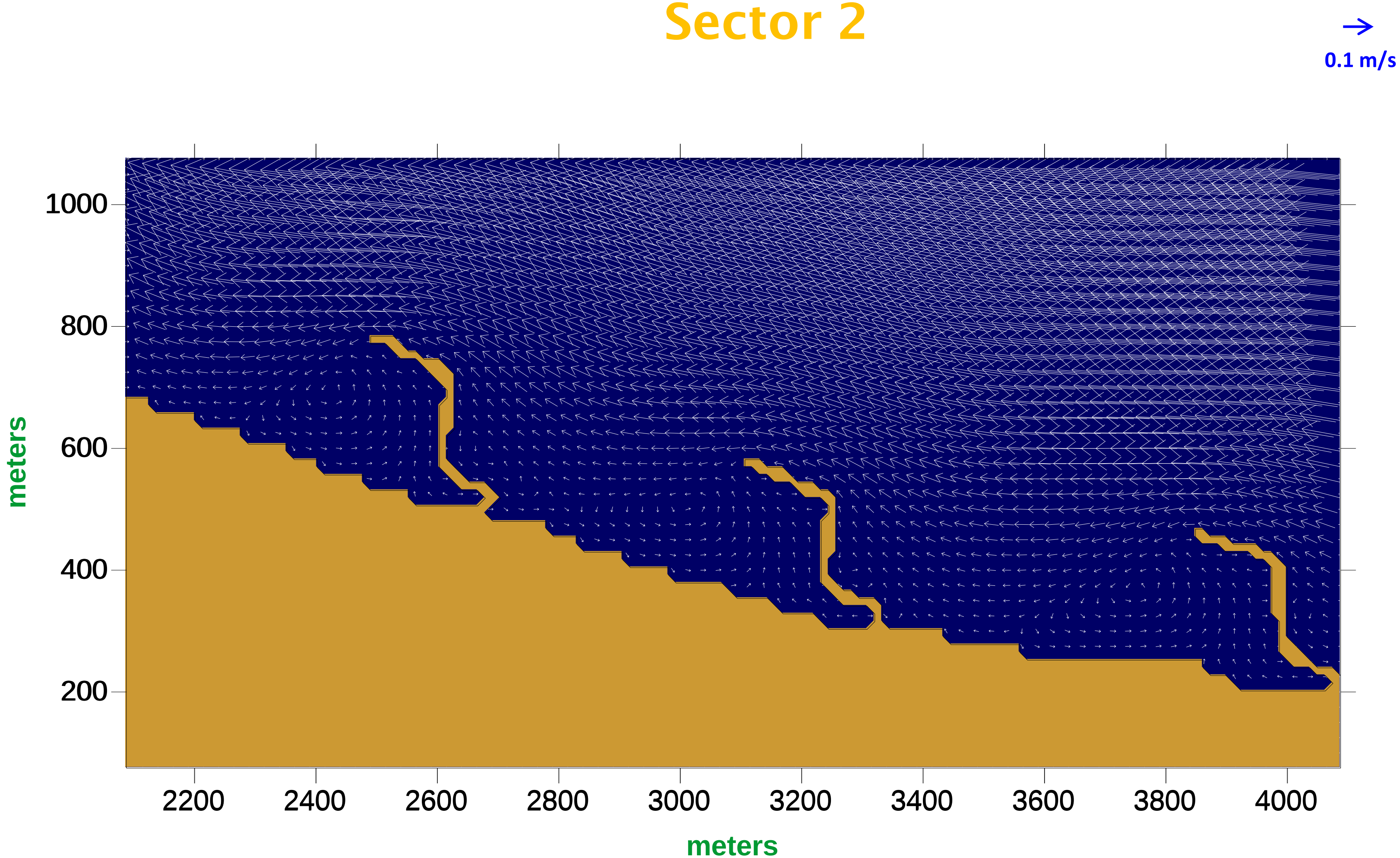
Simulations in domain 2

- Simulations in this session are the core of this work
- Starting from the boundary conditions got from the results for domain 1, we have forced the domain 2
- We have compared the results for the mean flow in a situation without breakwaters with those with the introductions of breakwaters
- For the simuation with breakwaters and with tidal effects, the evolution of the currents near 3 breakwaters is also shown
- Finally, a preliminary sketch of the effects of breakwaters on the propagation of waves is depicted

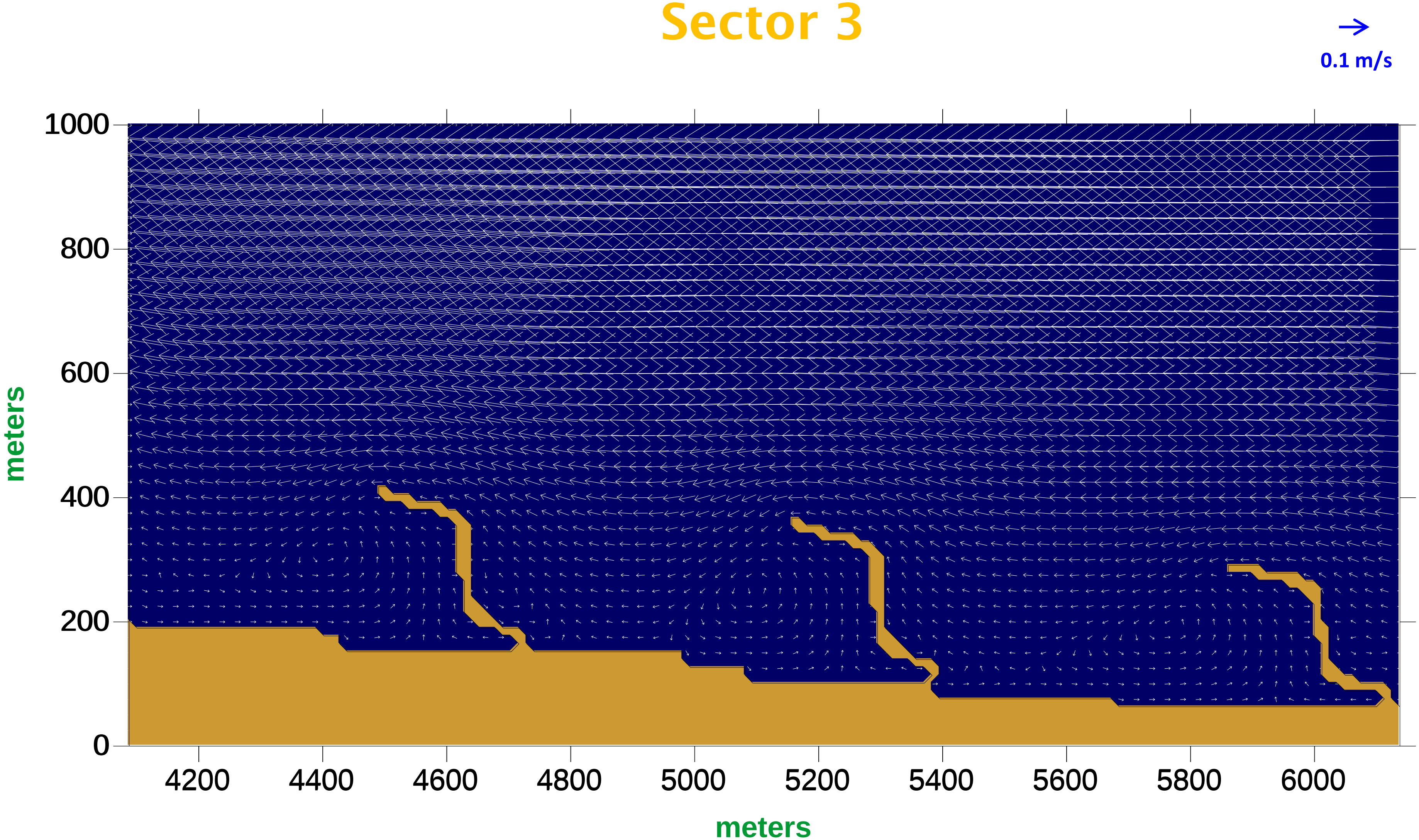
Mean flow near beakwaters
Sector 1



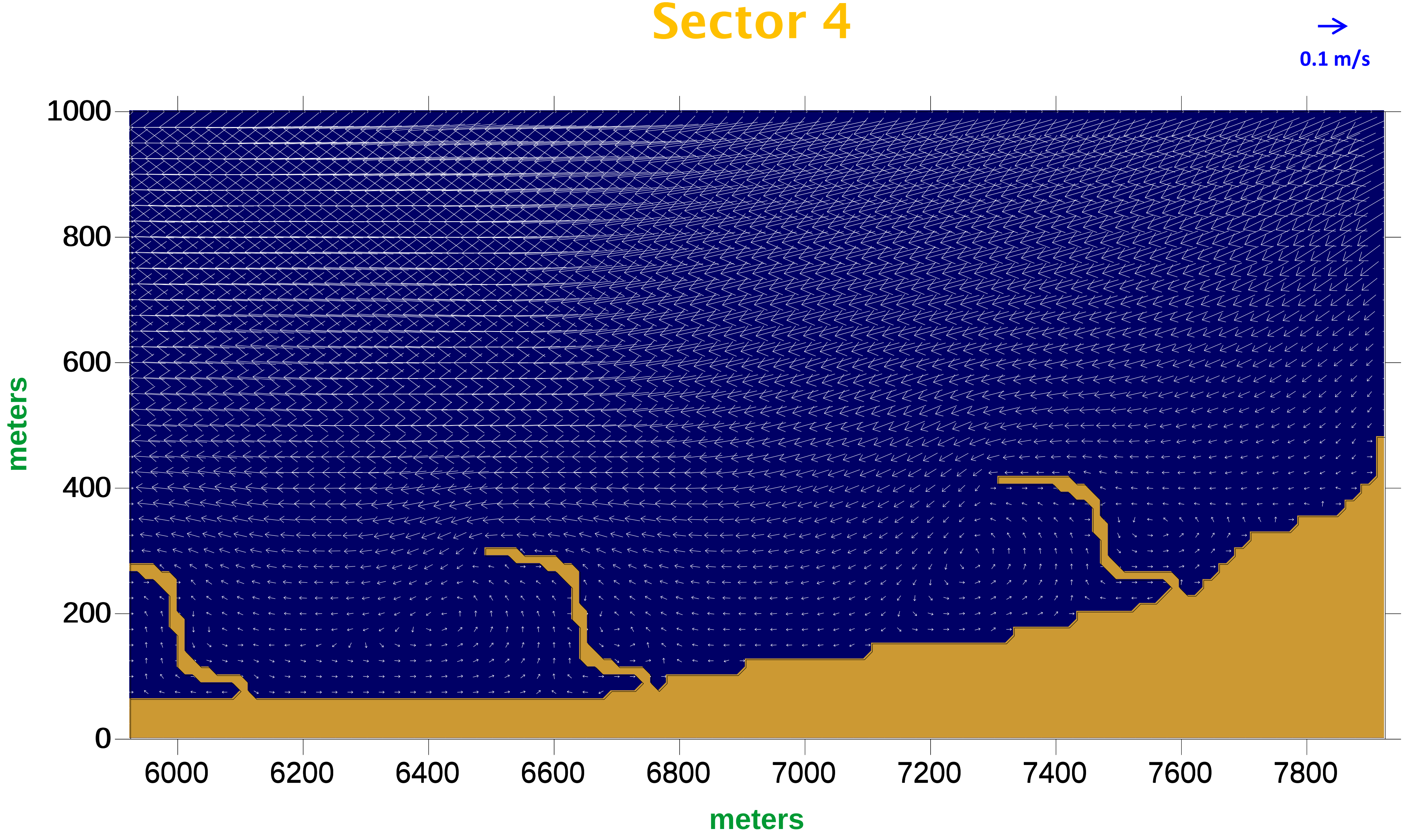
Mean flow near beakwaters
Sector 2



Mean flow near beakwaters
Sector 3

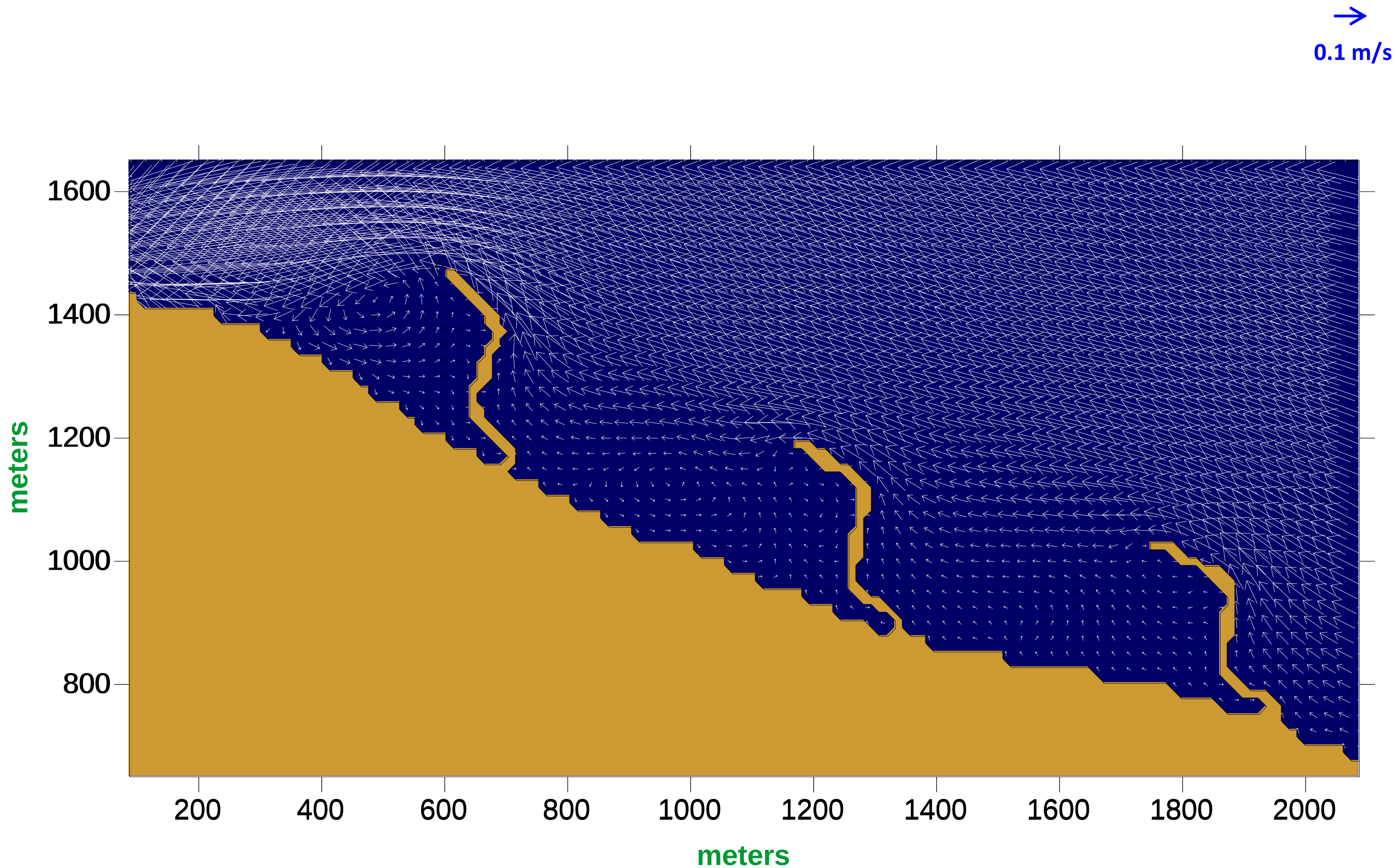


Mean flow near beakwaters
Sector 4

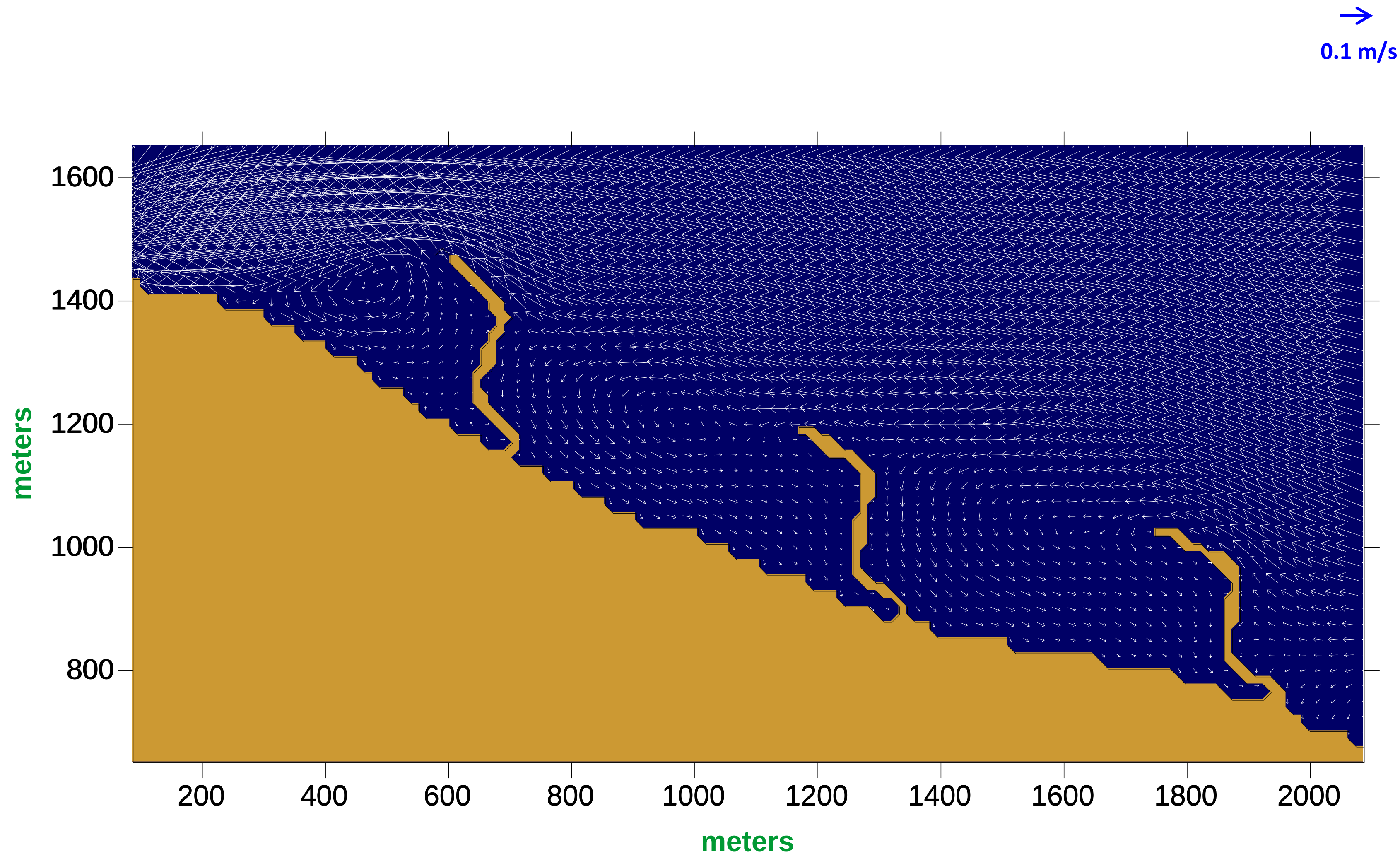


SECTOR 1

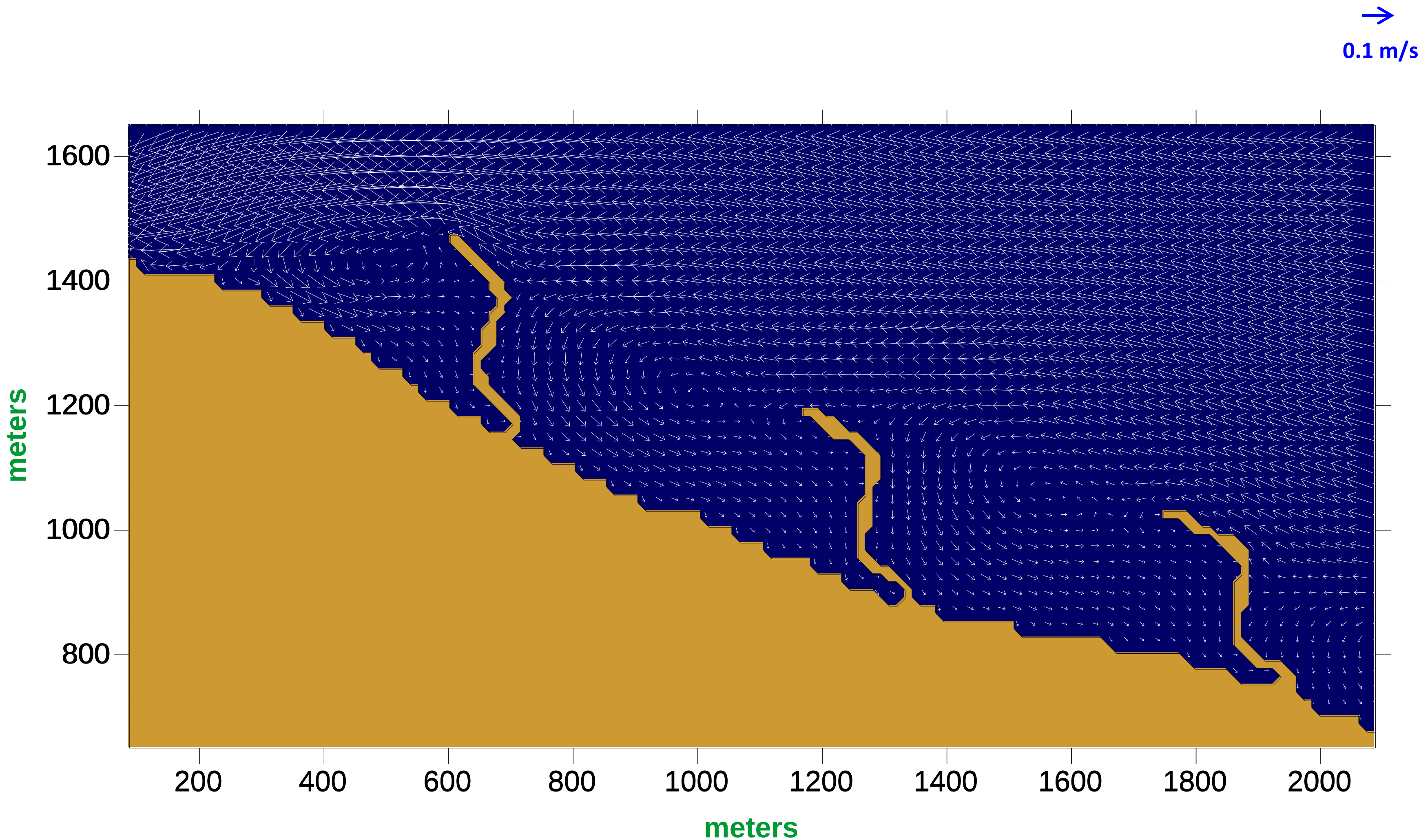
Evolution of the current near breakwaters (t=0 h) Sector 1



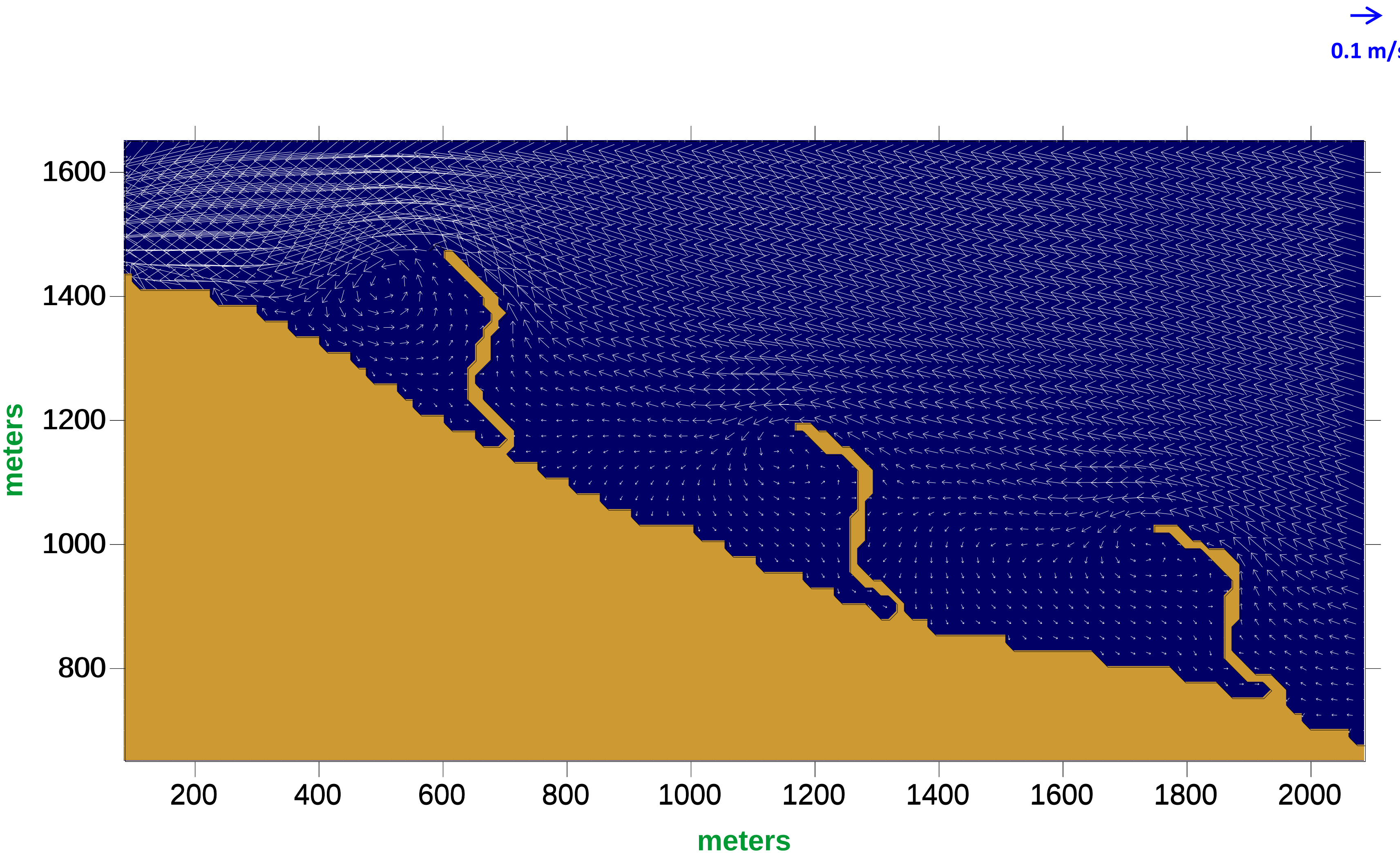
Evolution of the current near breakwaters (t=3 h)
Sector 1



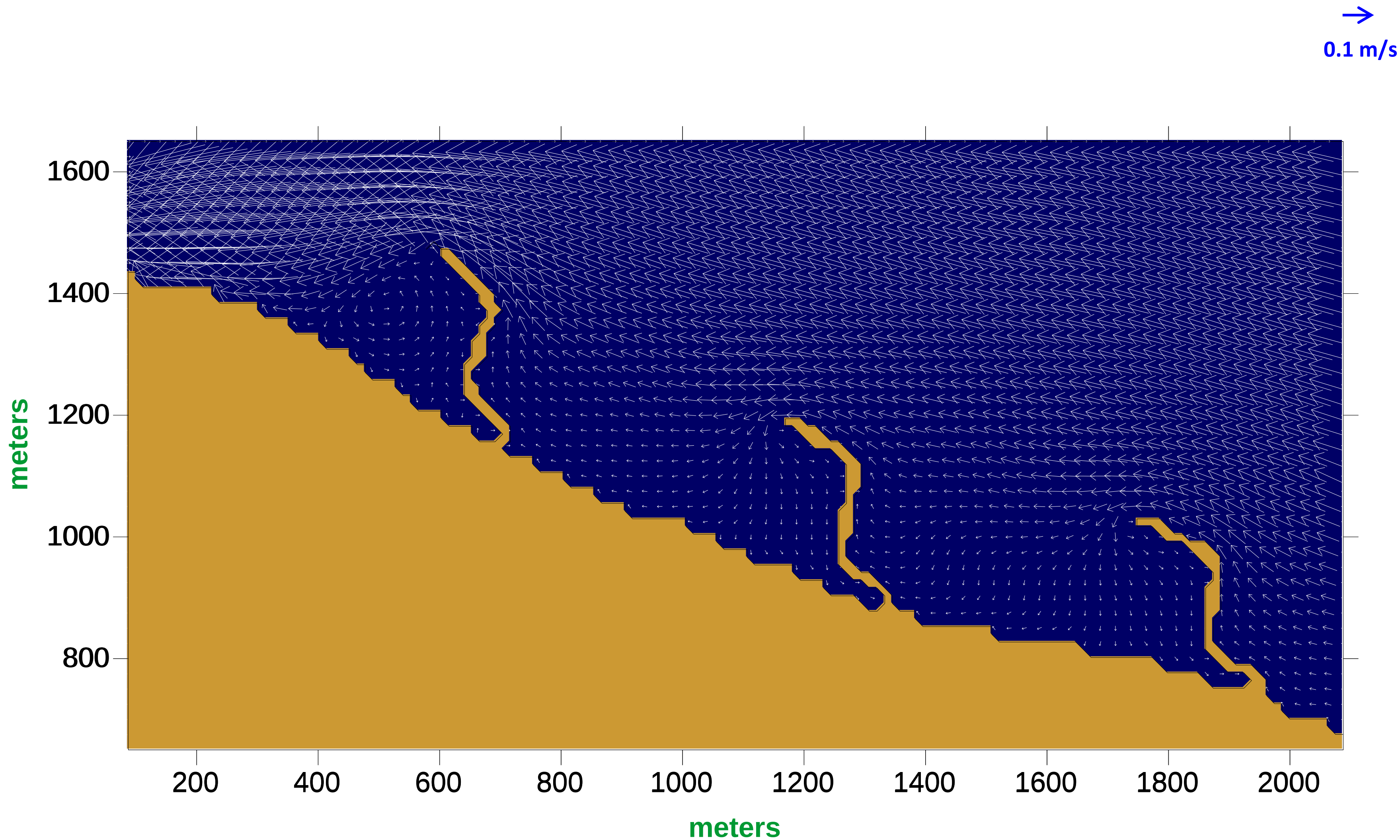
Evolution of the current near breakwaters (t=6 h)
Sector 1



Evolution of the current near breakwaters (t=9 h) Sector 1

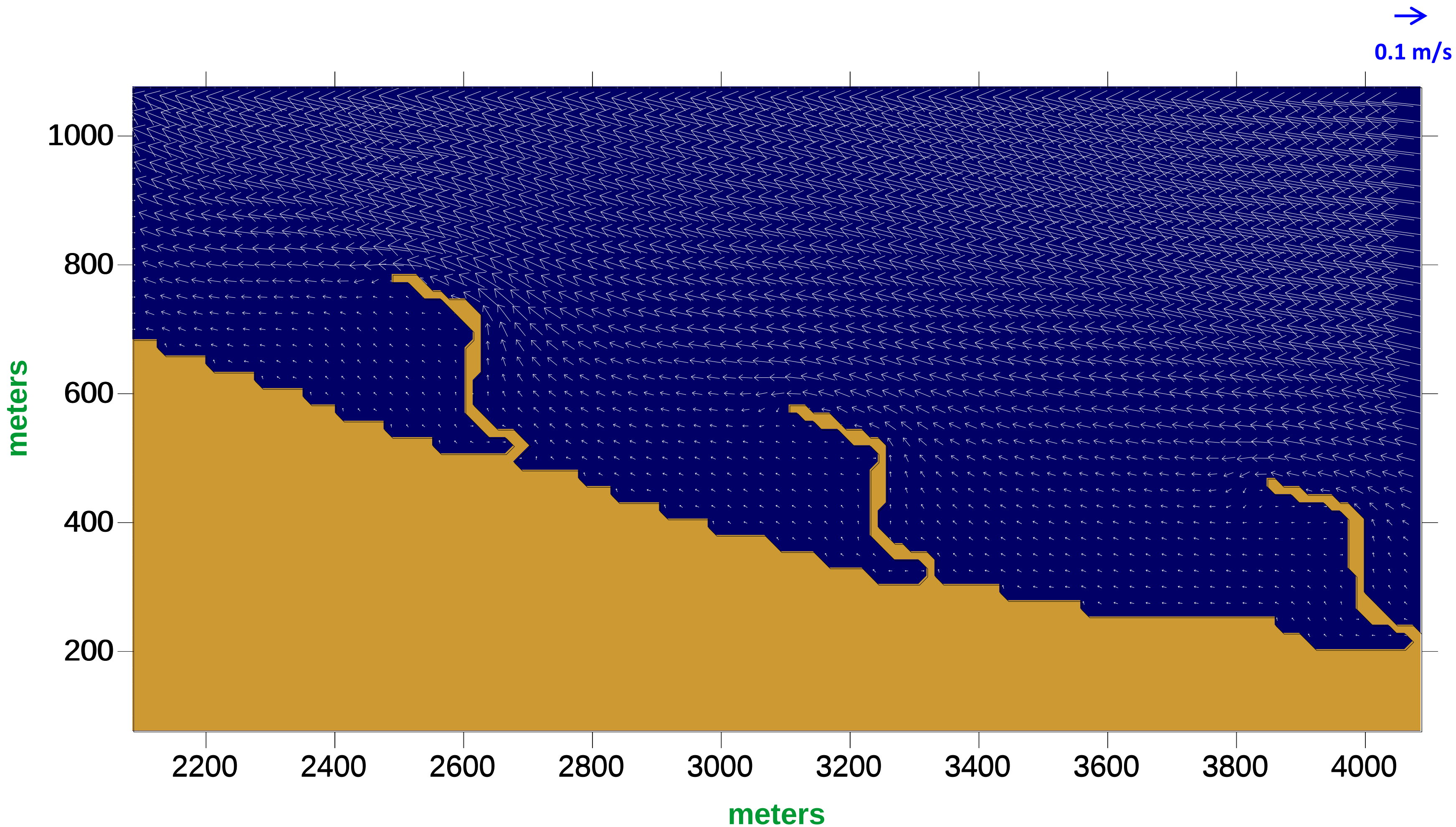


Evolution of the current near breakwaters (t=12h) Sector 1

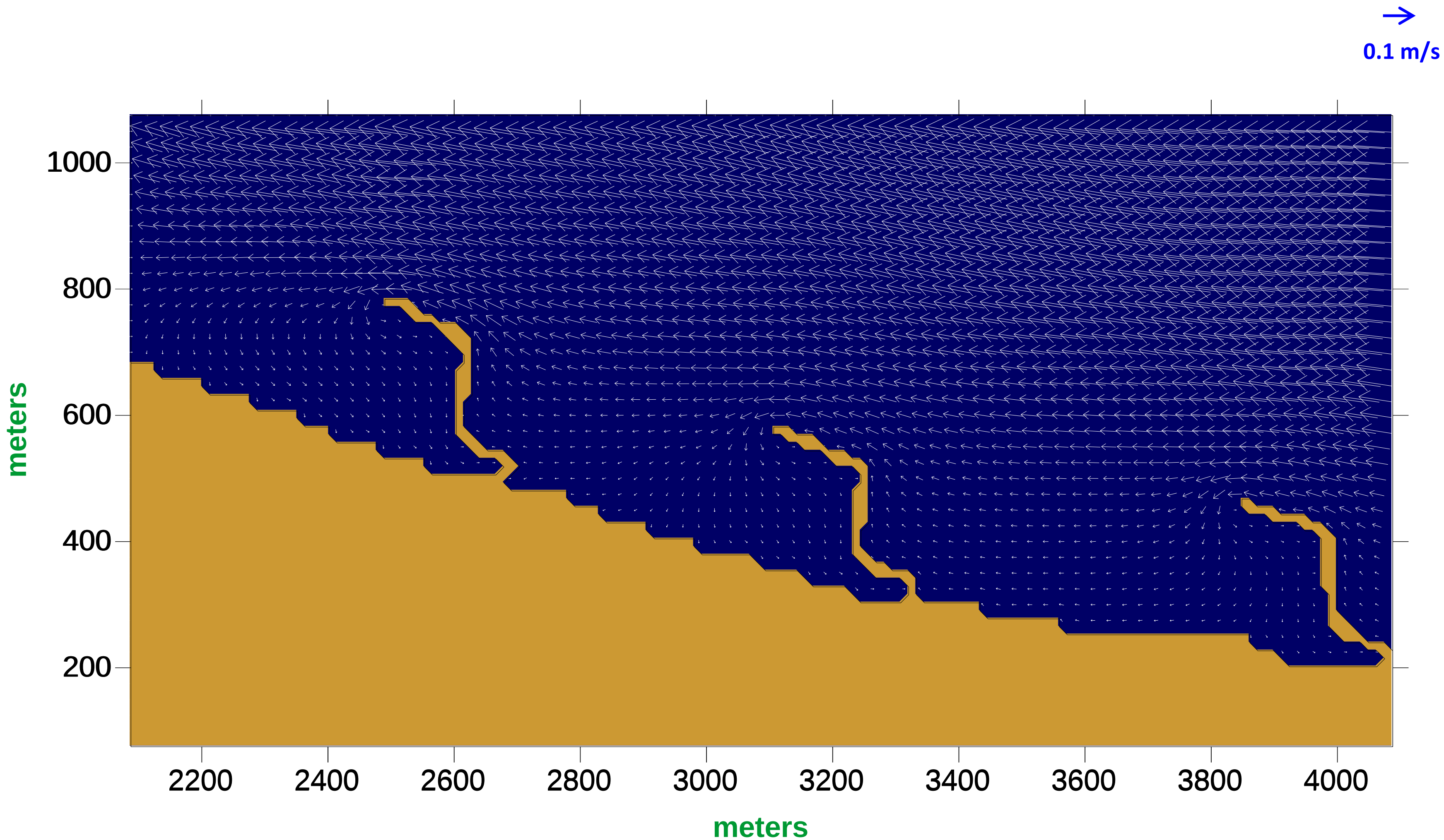


SECTOR 2

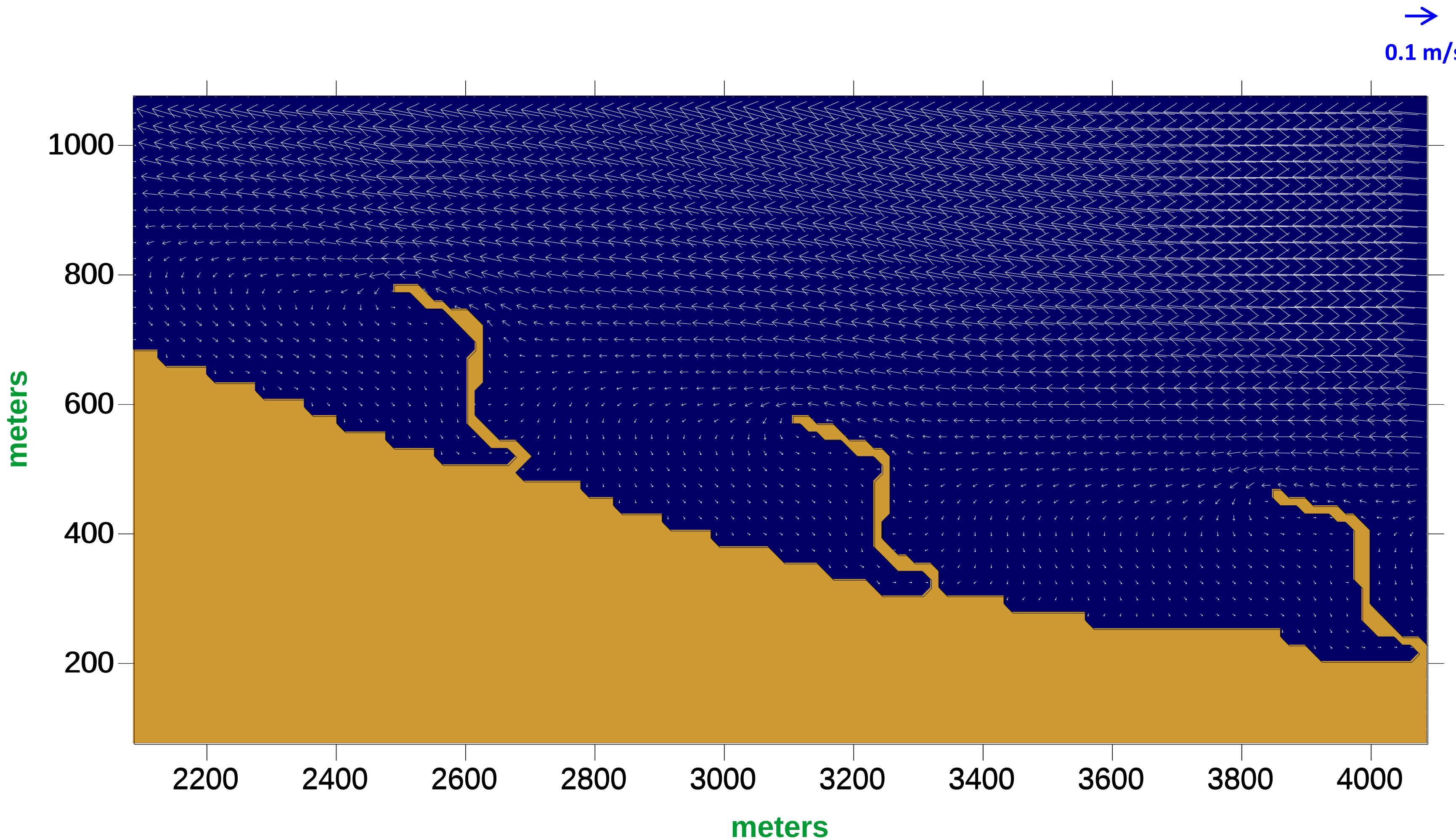
Evolution of the current near breakwaters (t=0 h) Sector 2



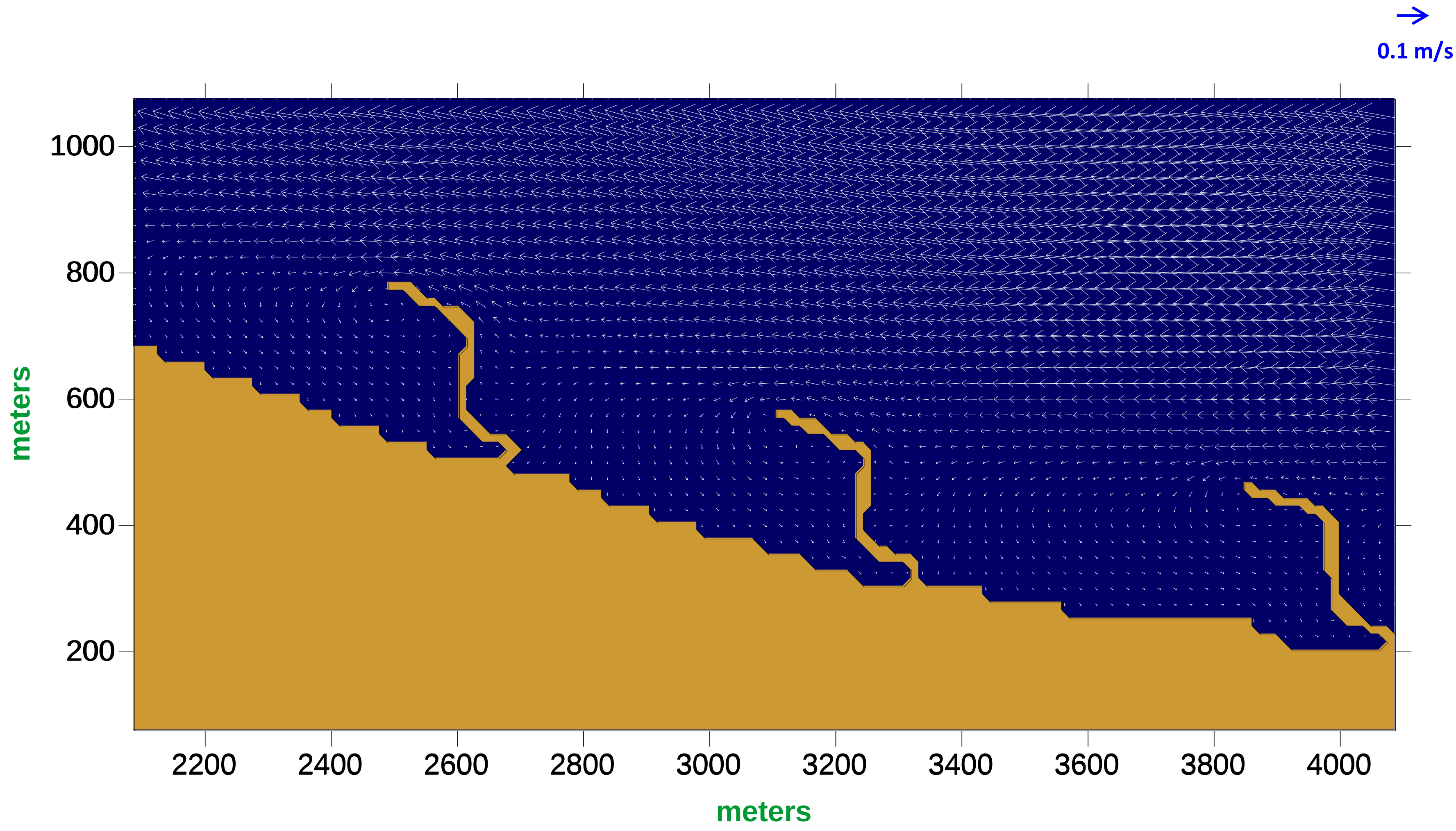
Evolution of the current near breakwaters (t=3 h) Sector 2



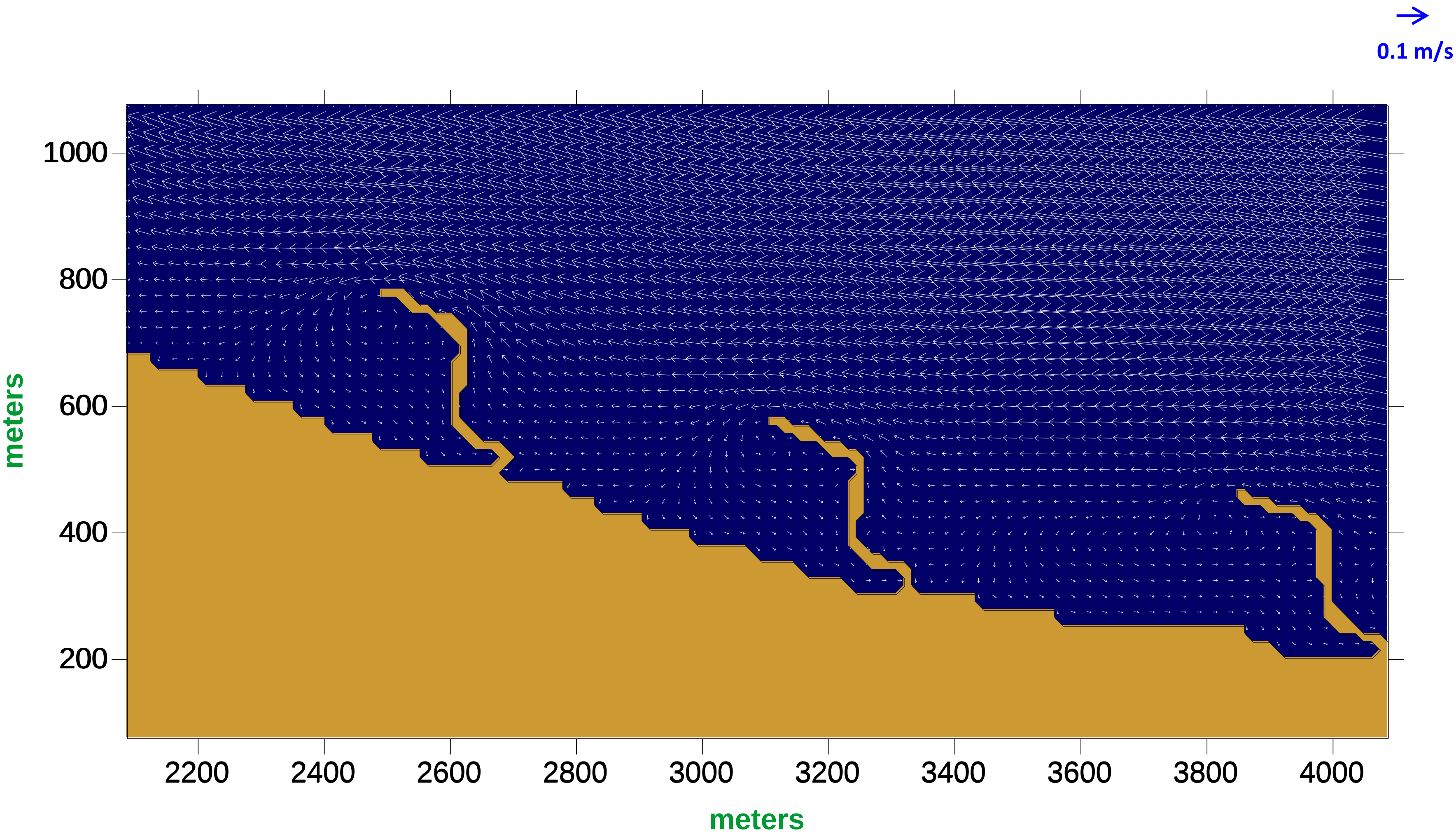
Evolution of the current near breakwaters (t=6 h)
Sector 2



Evolution of the current near breakwaters (t=9 h)
Sector 2

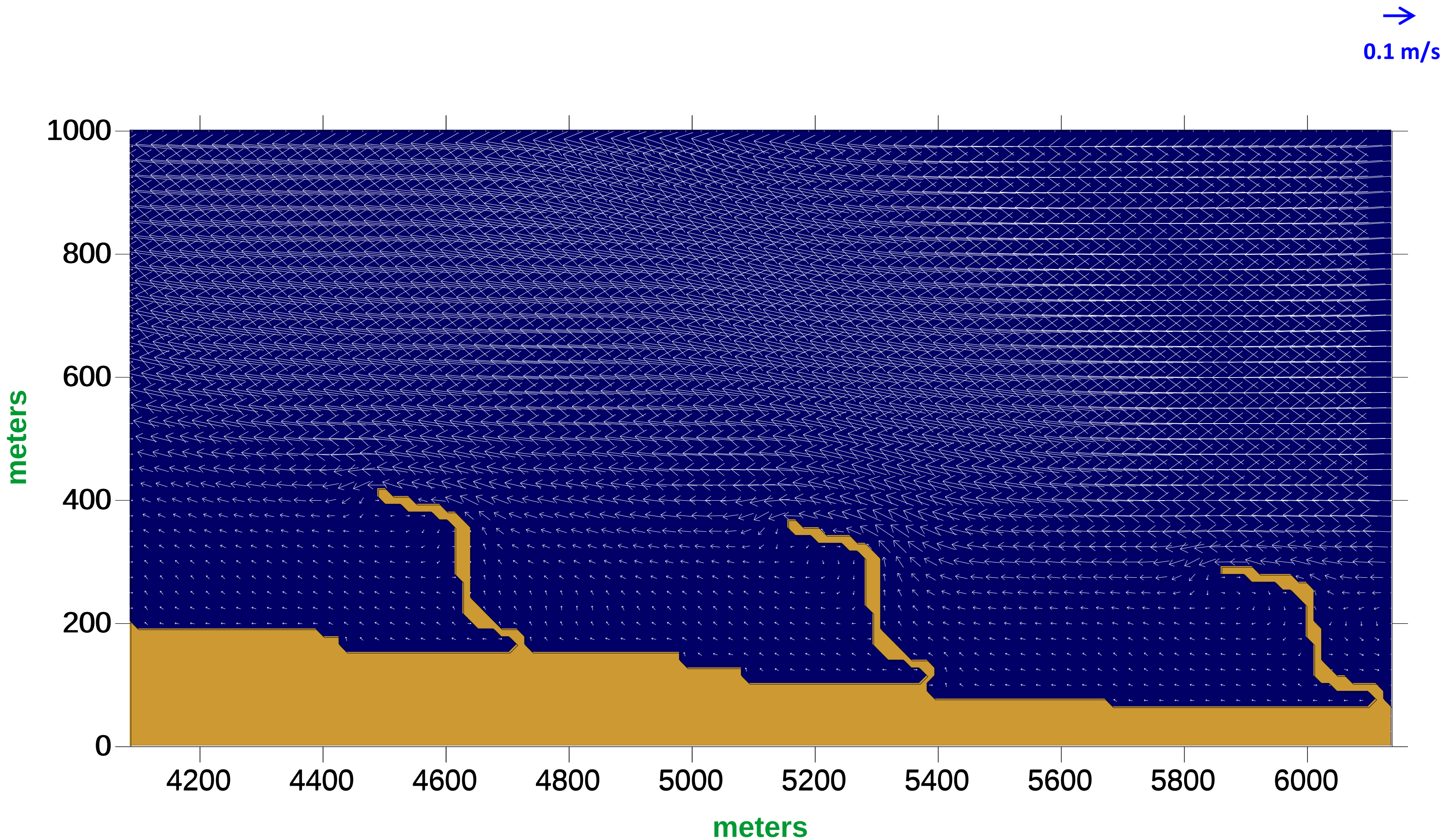


Evolution of the current near breakwaters (t=12h) Sector 2

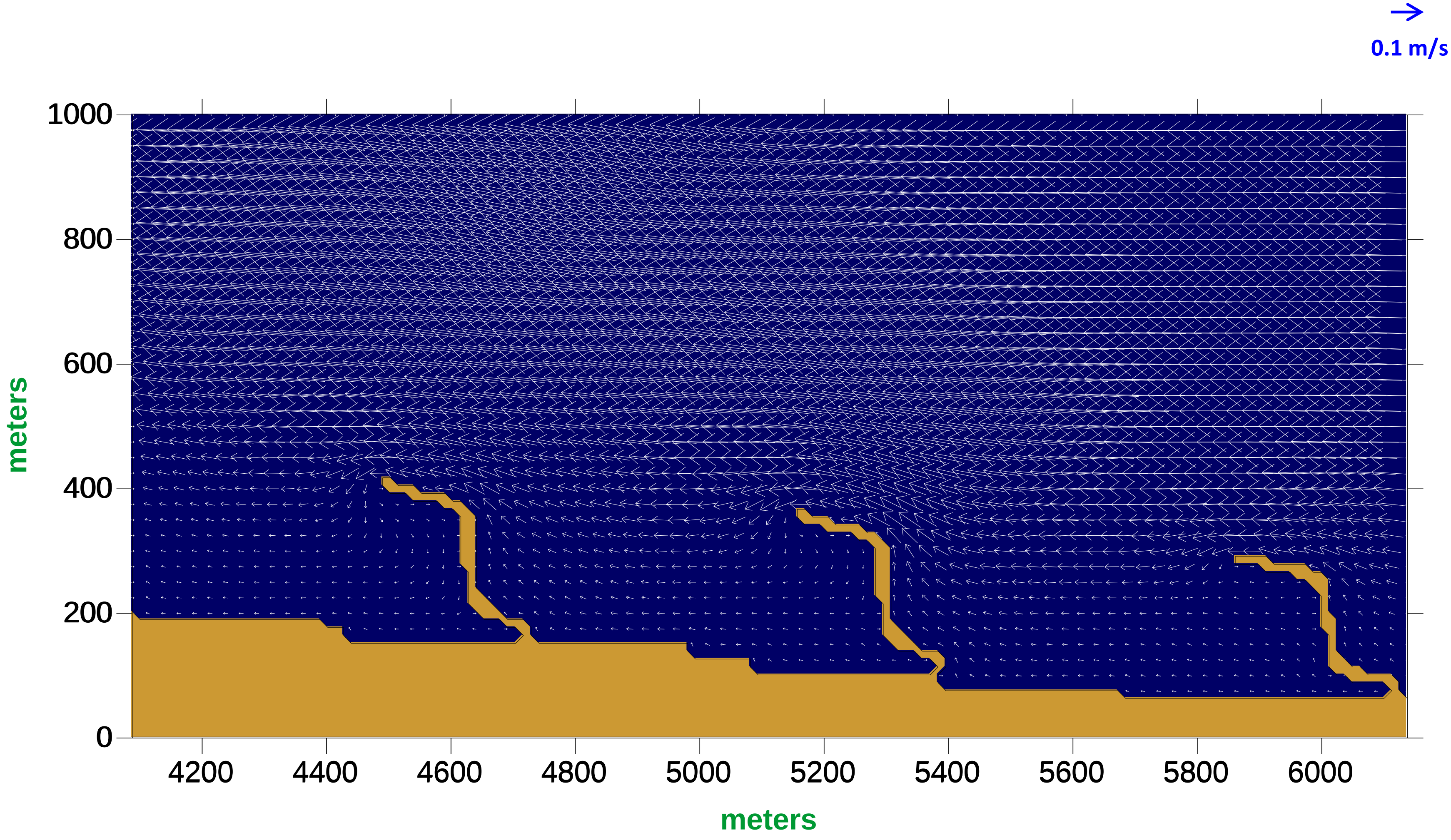


SECTOR 3

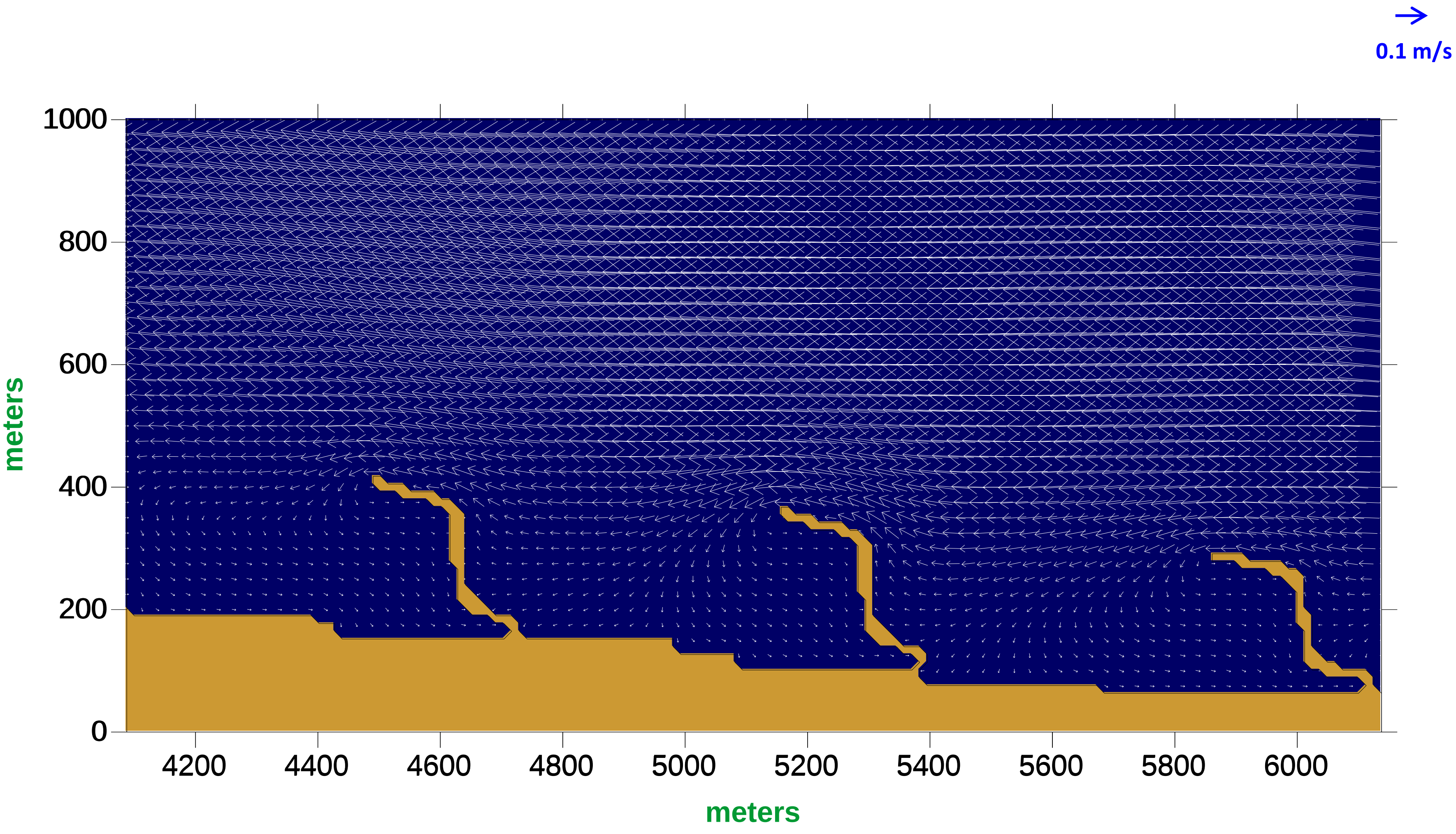
Evolution of the current near breakwaters (t=0 h) Sector 3



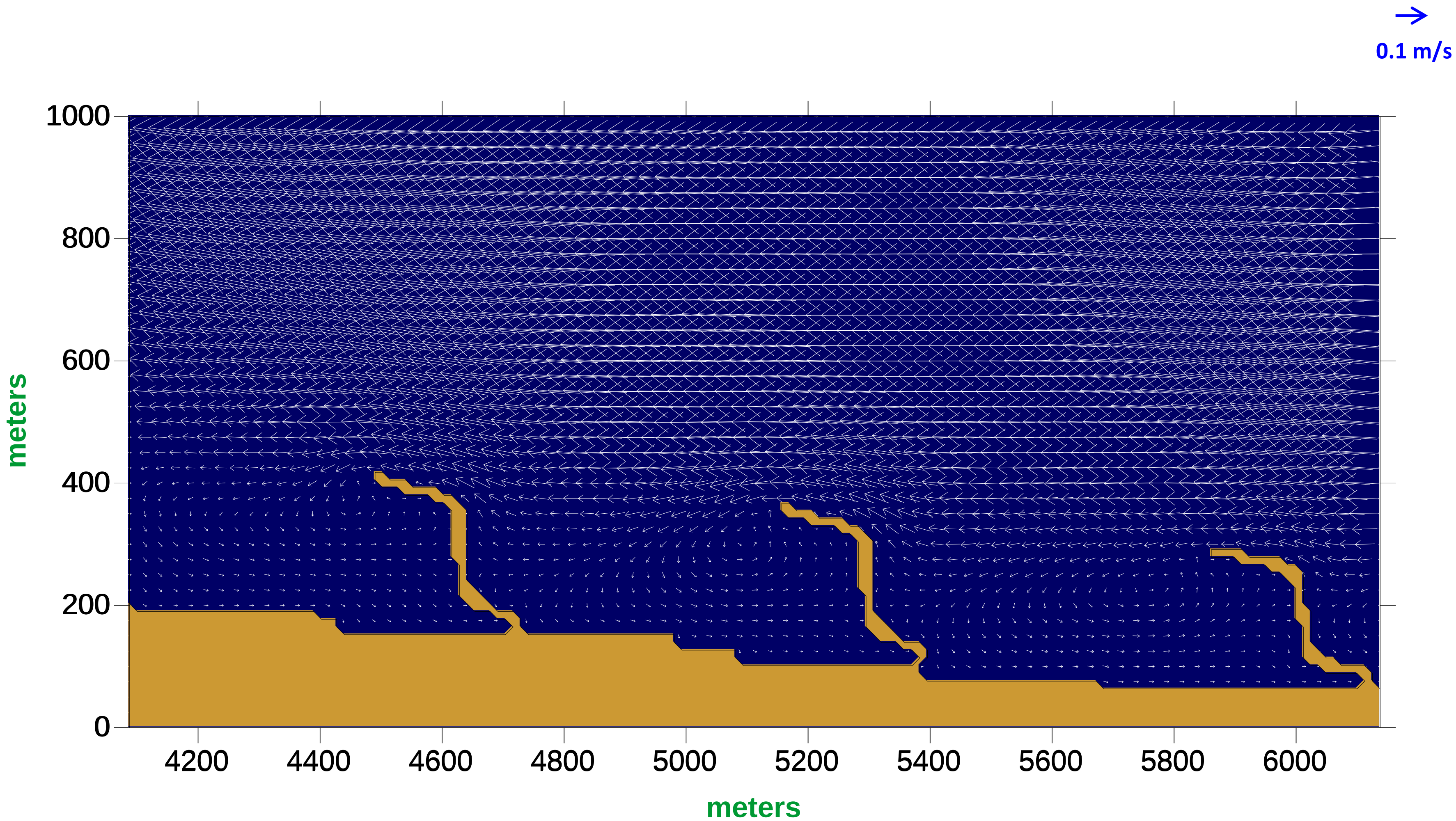
Evolution of the current near breakwaters (t=3 h) Sector 3



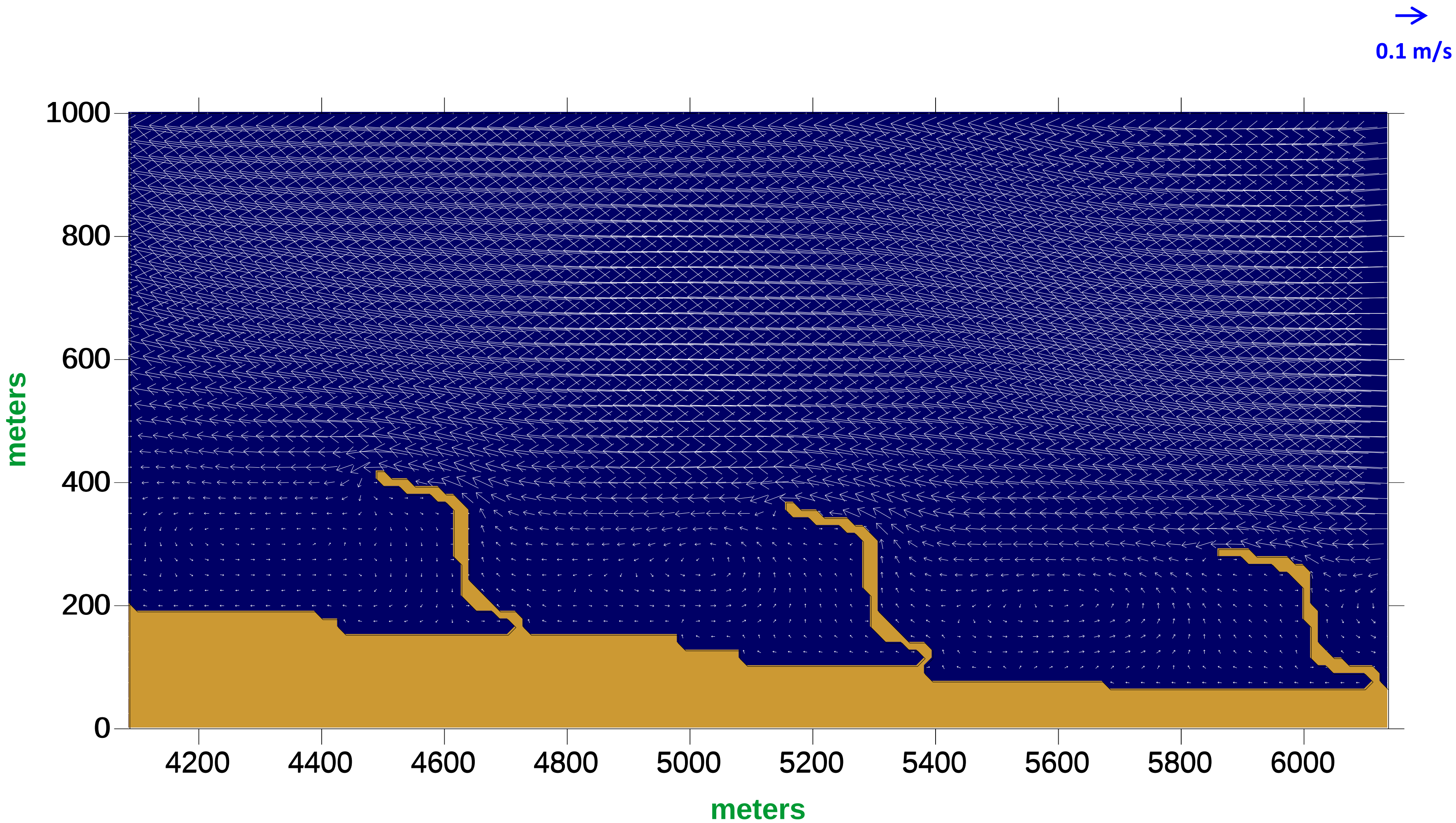
Evolution of the current near breakwaters (t=6 h)
Sector 3



Evolution of the current near breakwaters (t=9 h) Sector 3

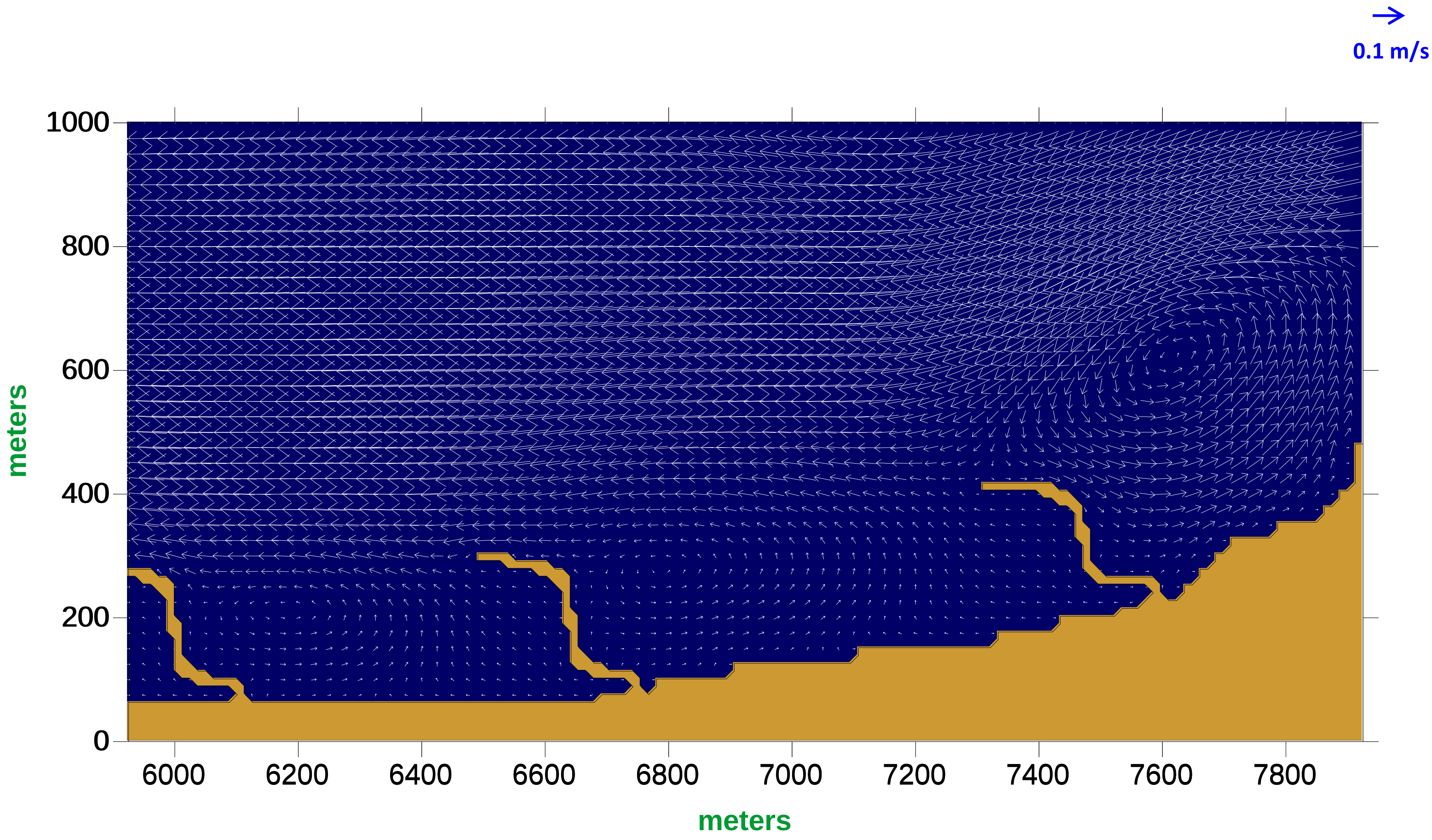


Evolution of the current near breakwaters (t=12h) Sector 3

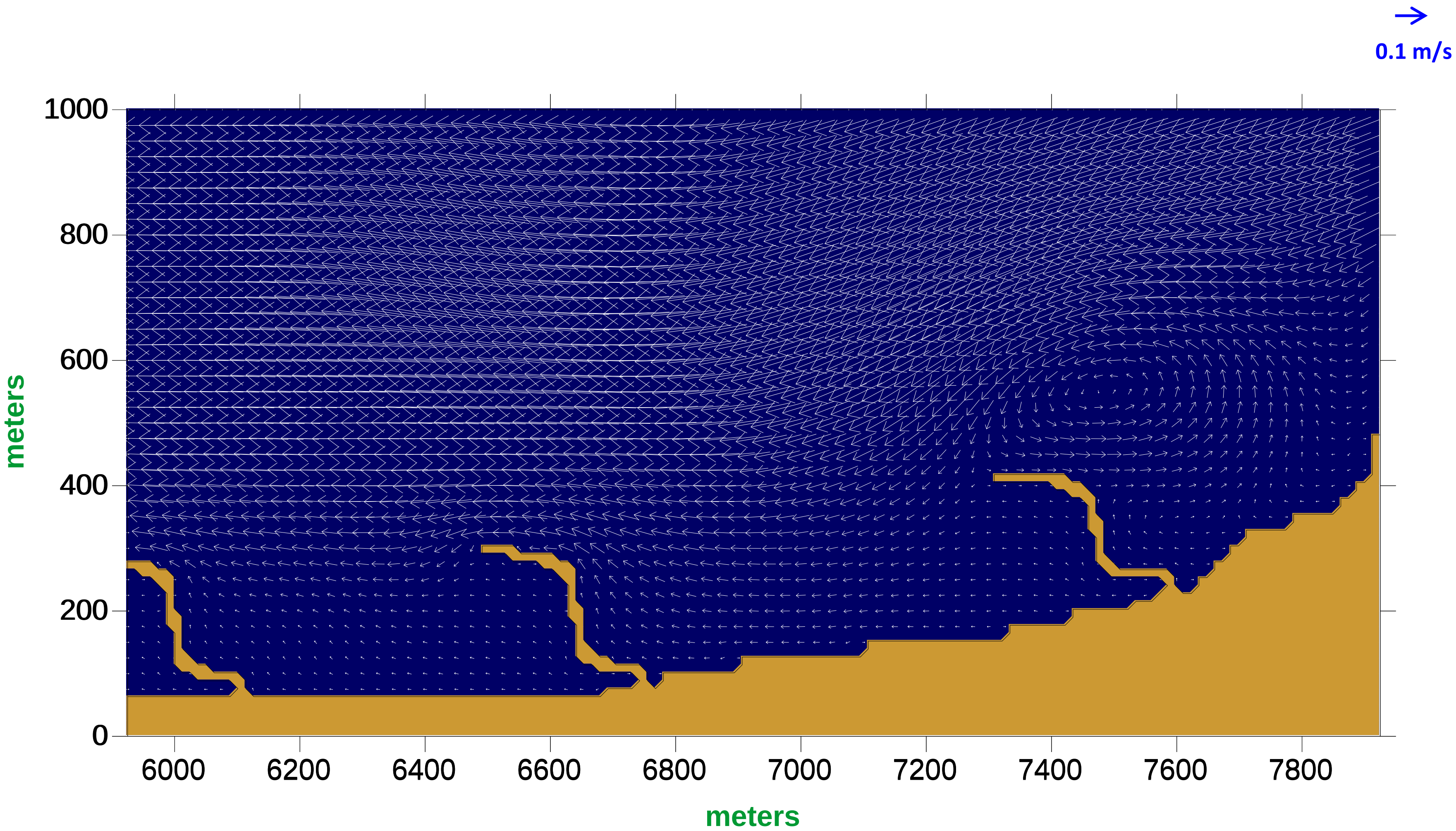


SECTOR 4

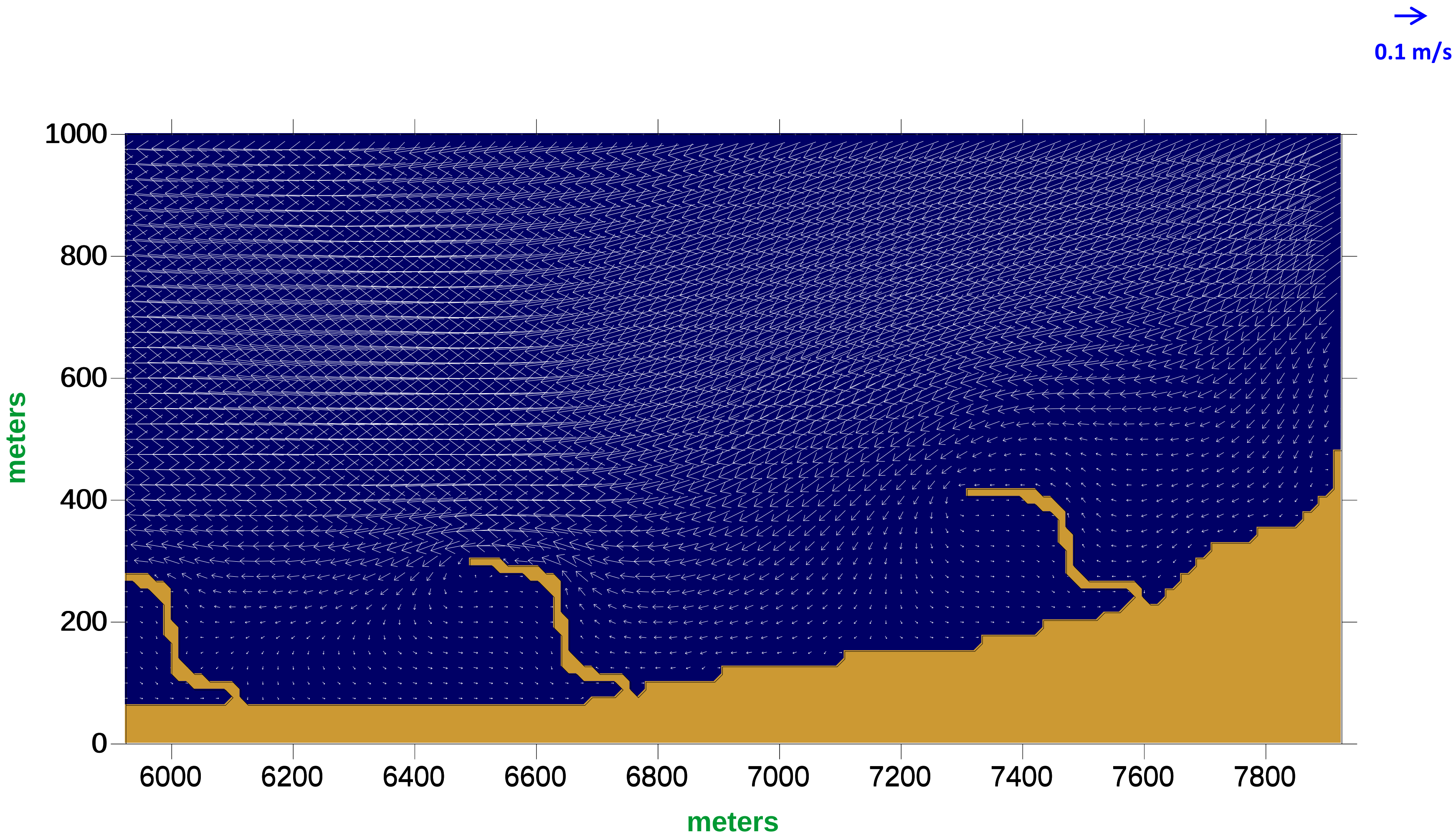
Evolution of the current near breakwaters (t=0 h)
Sector 4



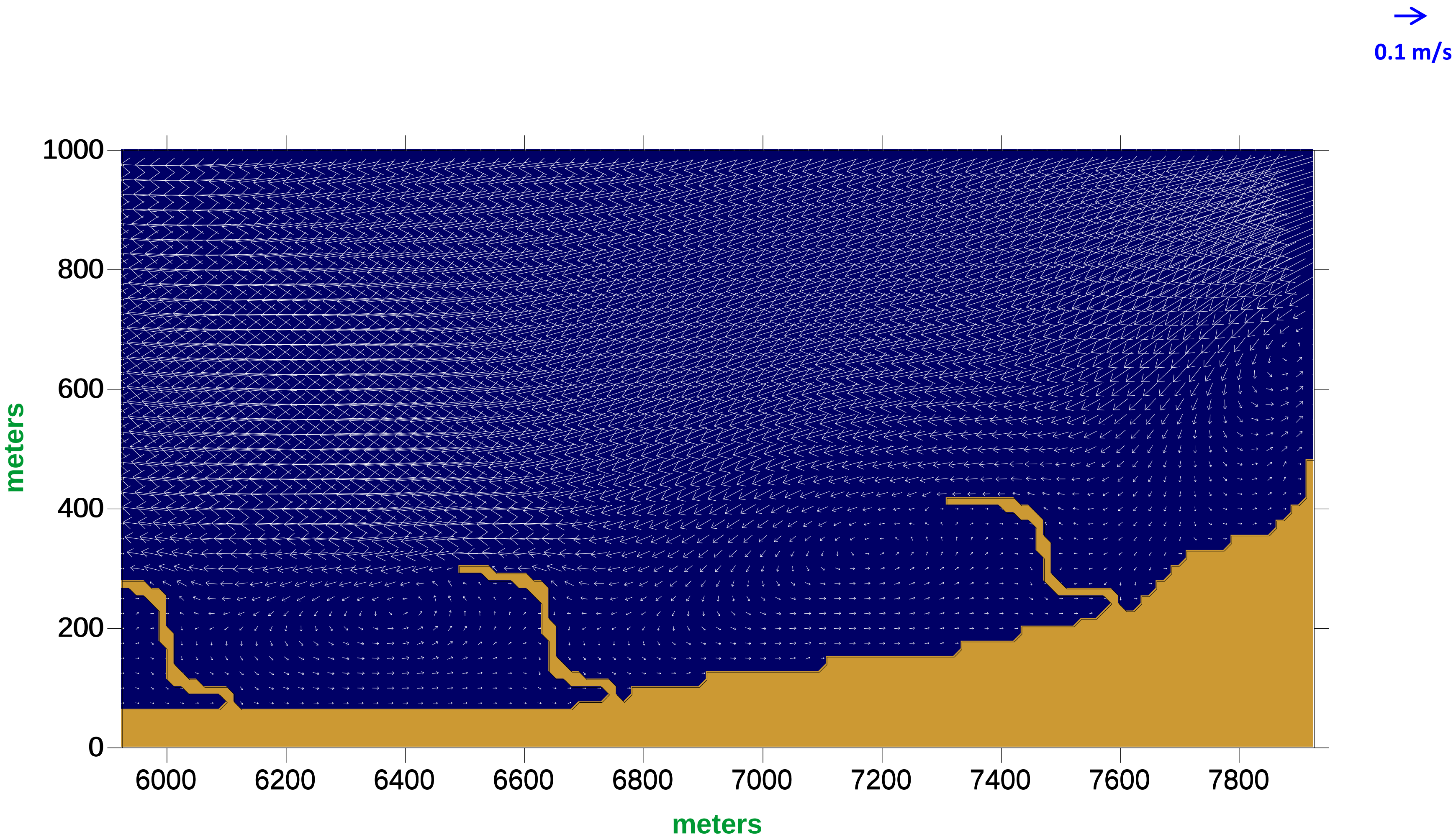
Evolution of the current near breakwaters (t=3 h) Sector 4



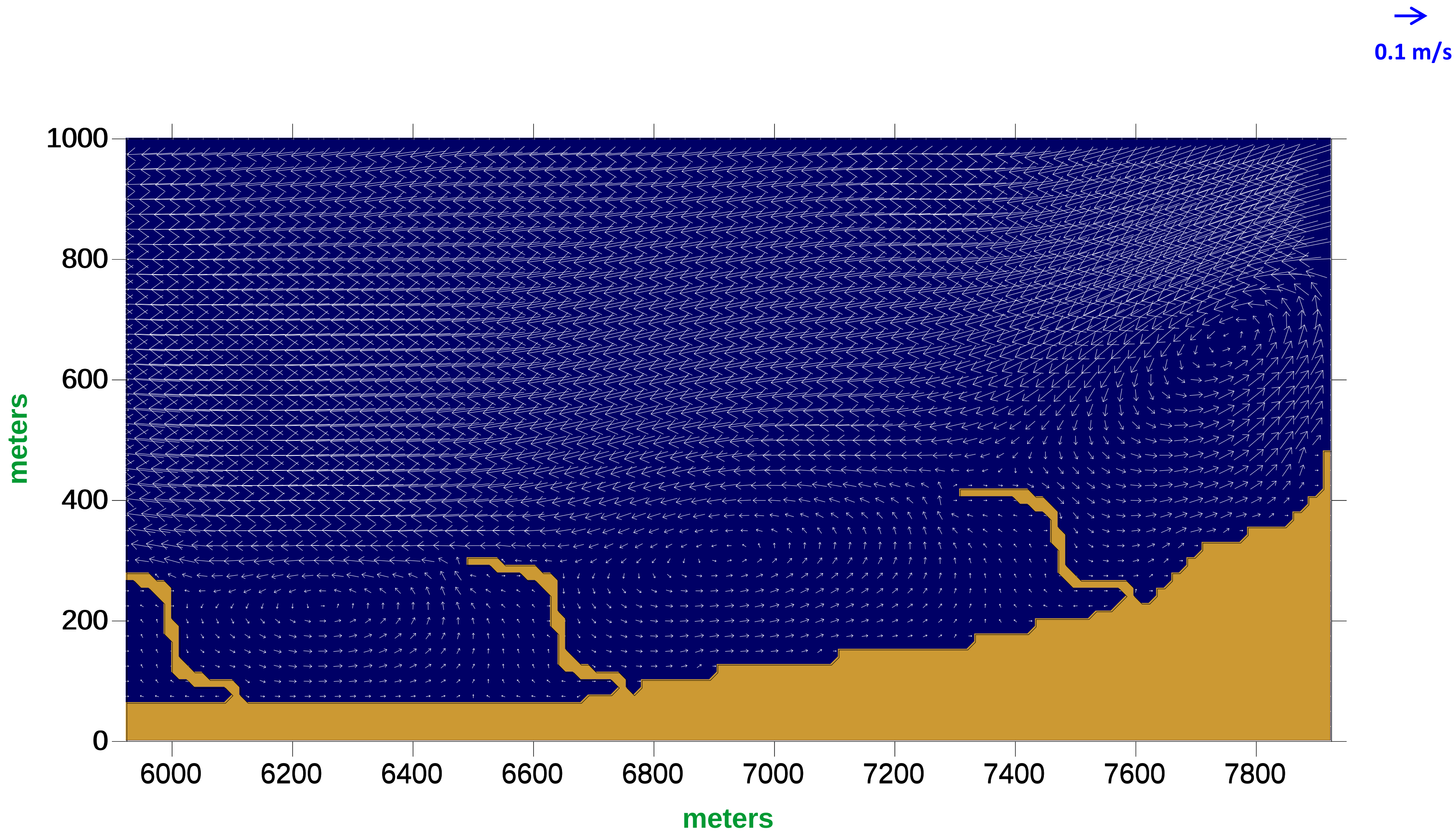
Evolution of the current near breakwaters (t=6 h) Sector 4



Evolution of the current near breakwaters (t=9 h) Sector 4



Evolution of the current near breakwaters (t=12h) Sector 4



Effects of breakwaters on the propagation of waves

- The generation of waves has been introduced imposing, on the north boundary, a wave-maker condition with period ***T*** and amplitude ***a***

$$\eta_i(t)=a(\sin\frac{2\pi}{T}\Delta t)$$

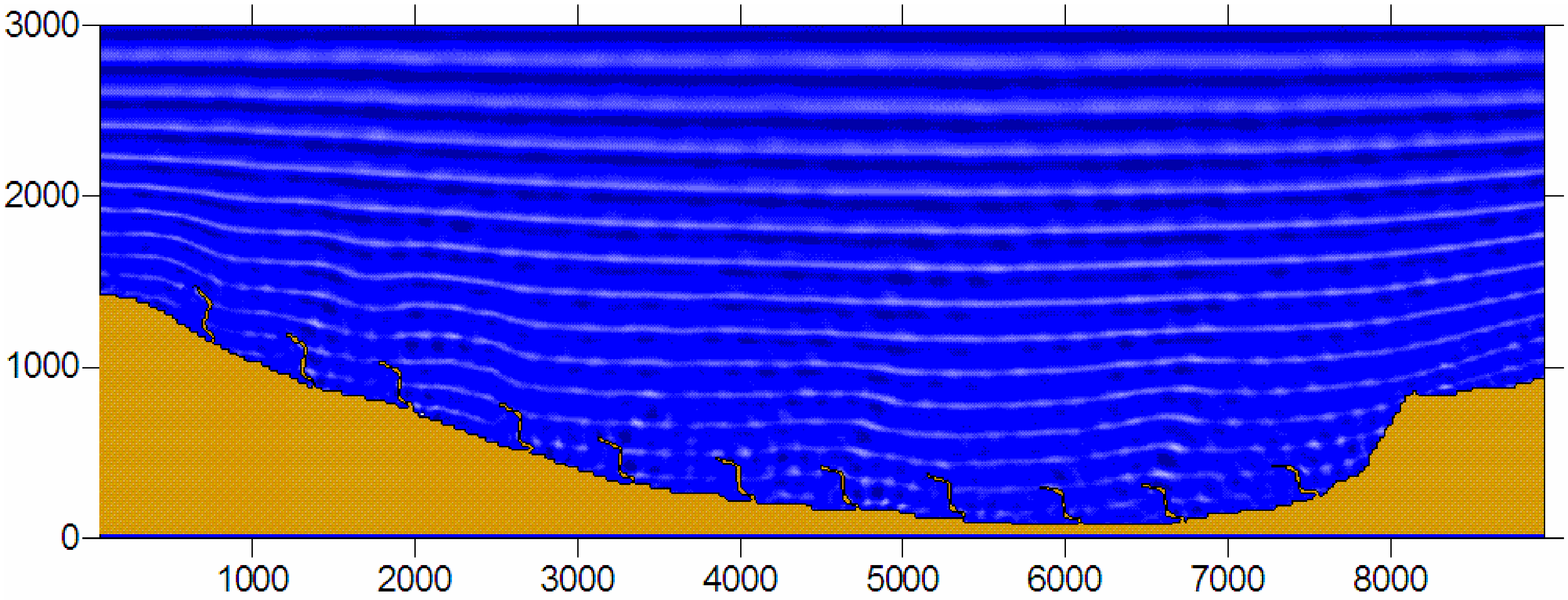
- The propagation is guaranteed imposing radiation conditions for the velocity on the north boundary

$$u_i = 2u_i^{BC} + \sqrt{\frac{g}{H_i}}\eta_i$$

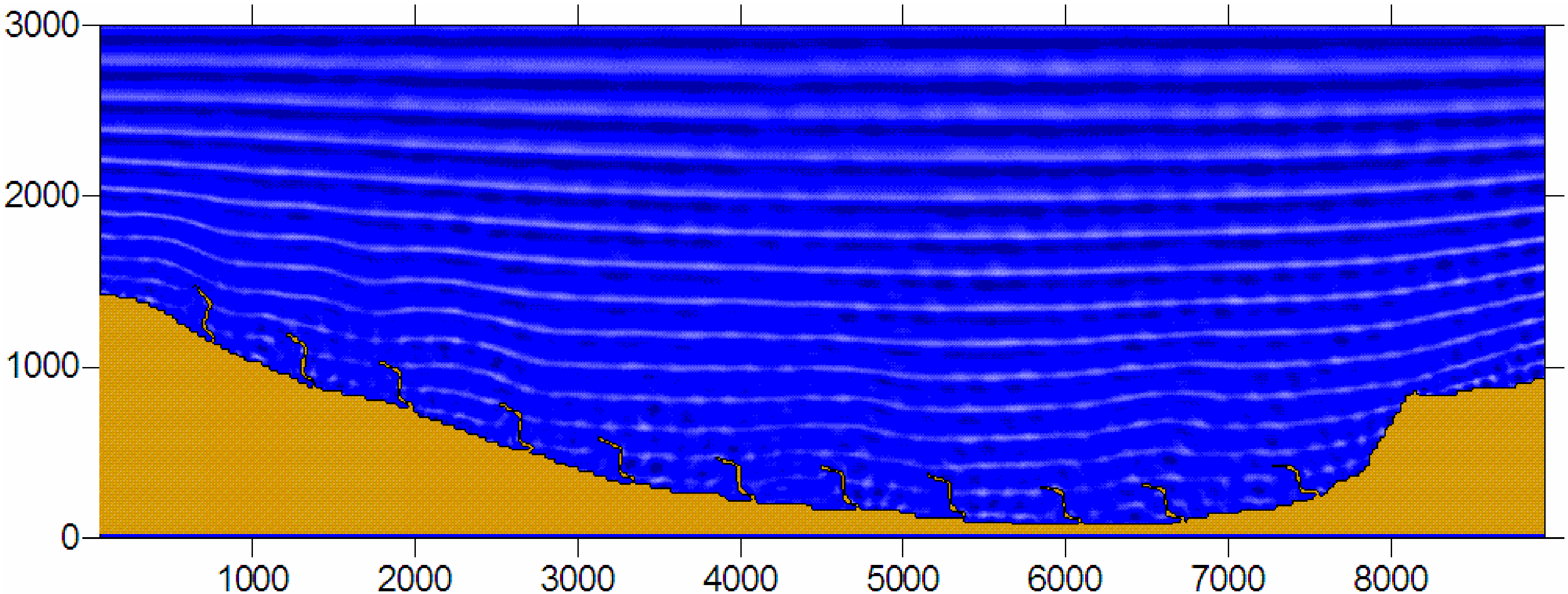
η_i = imposed elevation of free surface
u_i^{BC} = velocity boundary conditions obtained from results in domain 1
u_i = velocity boundary conditions

- In our context, such an approach needs to be improved since, for the moment (for reasons of time), Δt=3 *sec* and ***T***=4 *sec* leading to an inaccurate sampling of the wave

Time = 0 sec



Time = 2 sec



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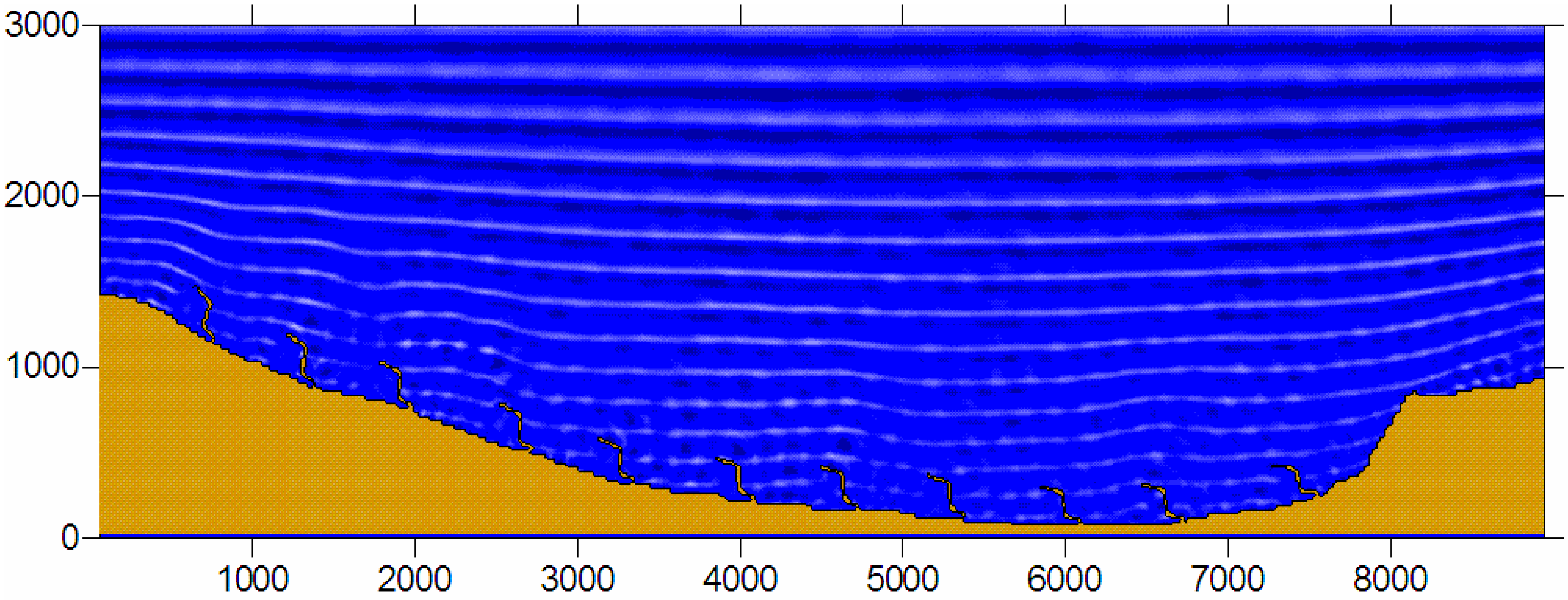

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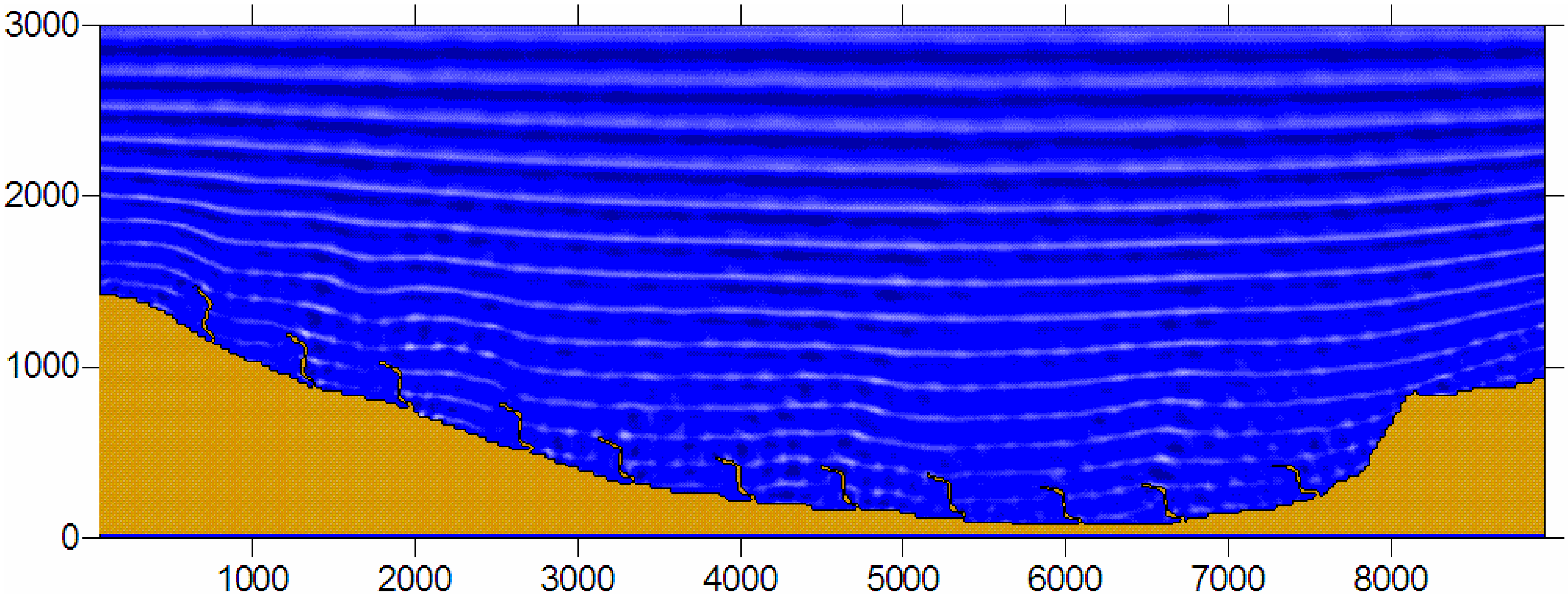

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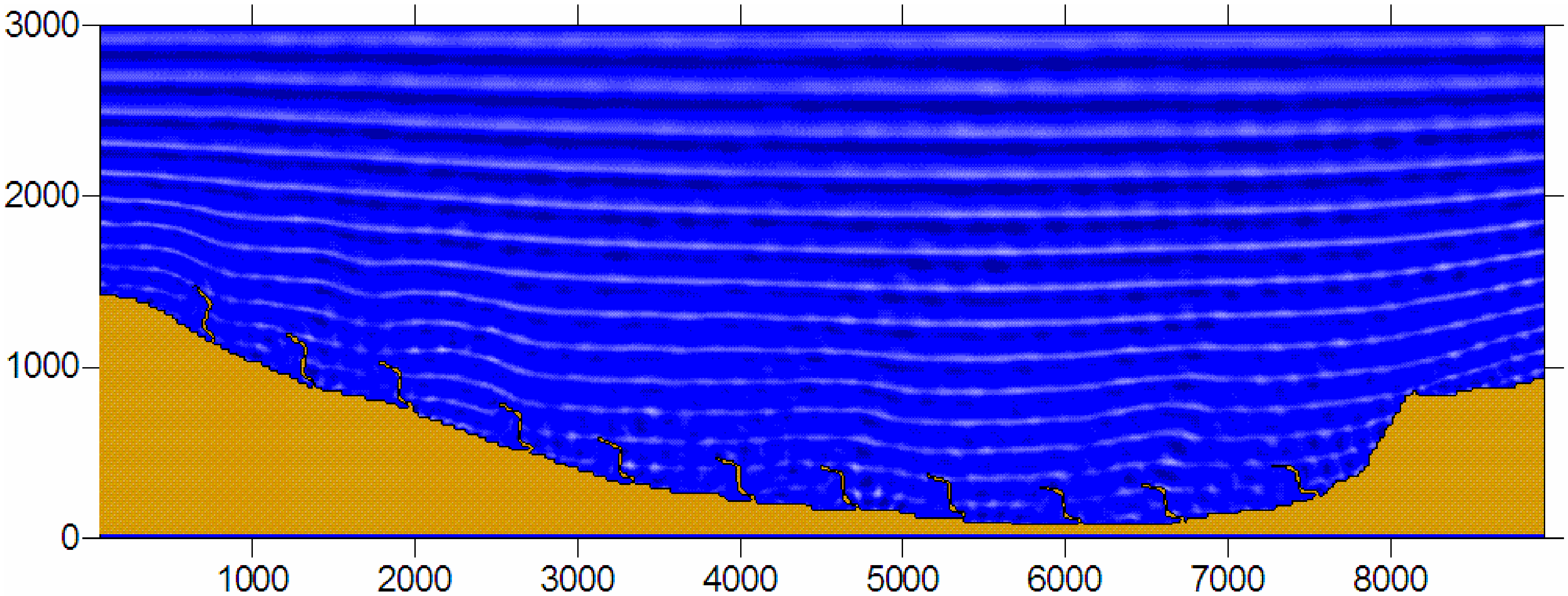

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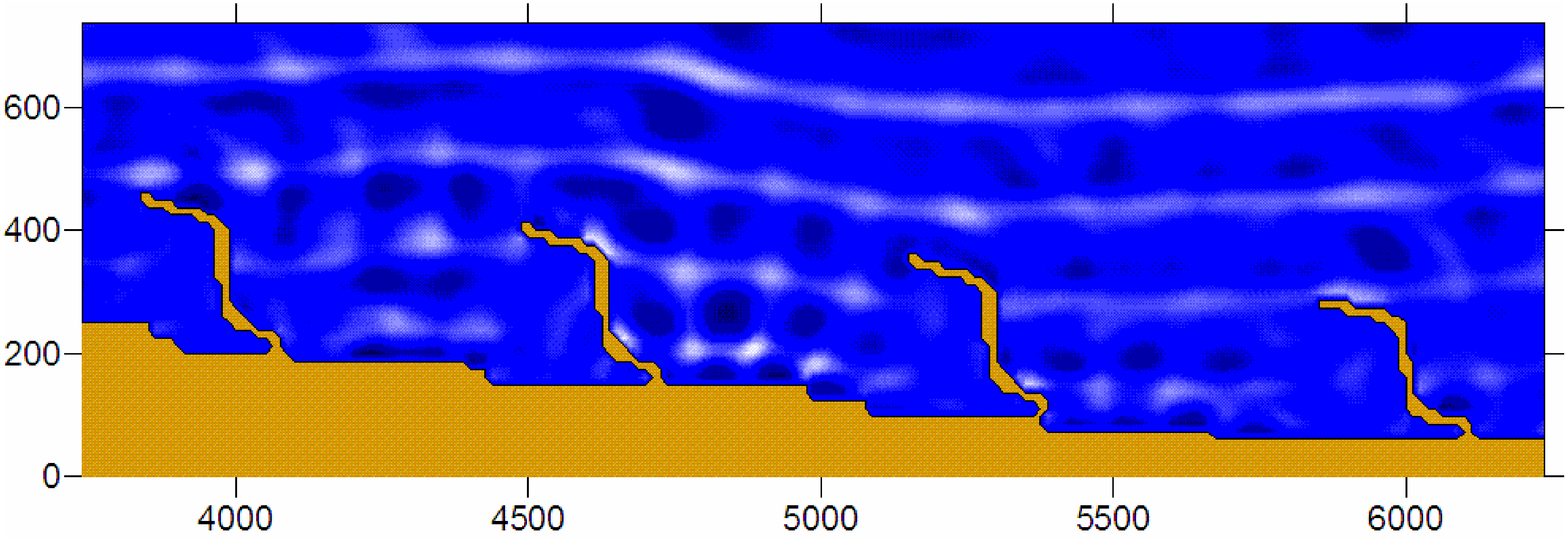

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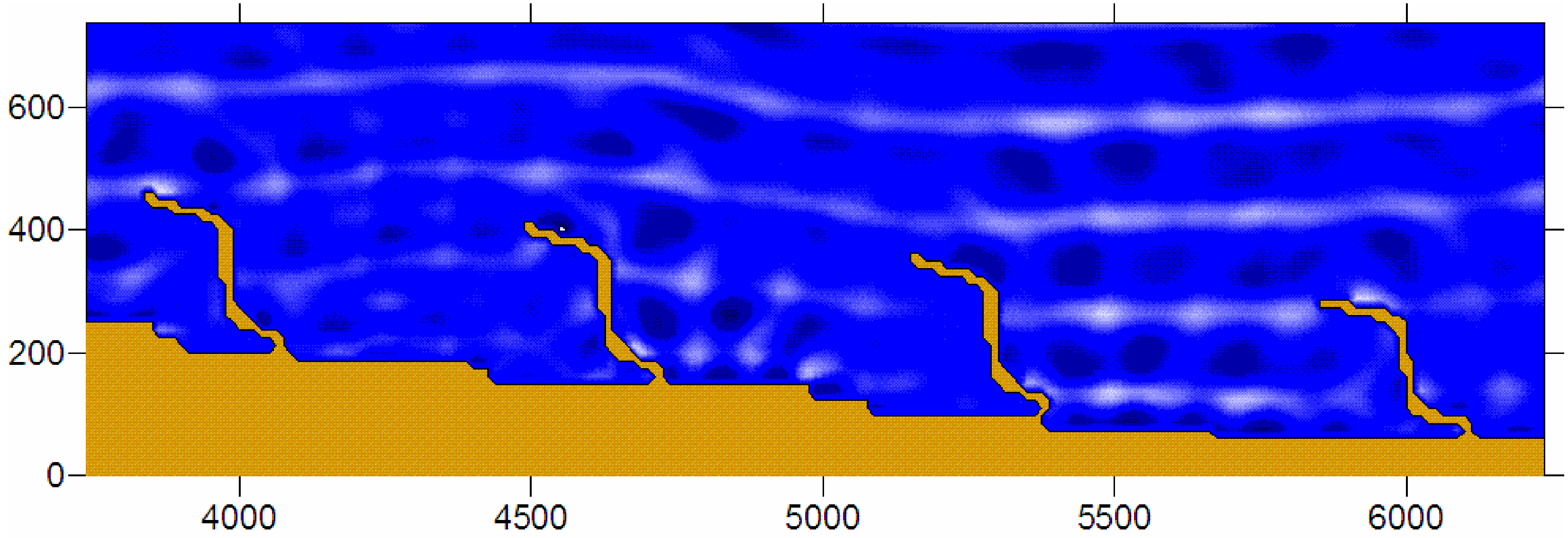

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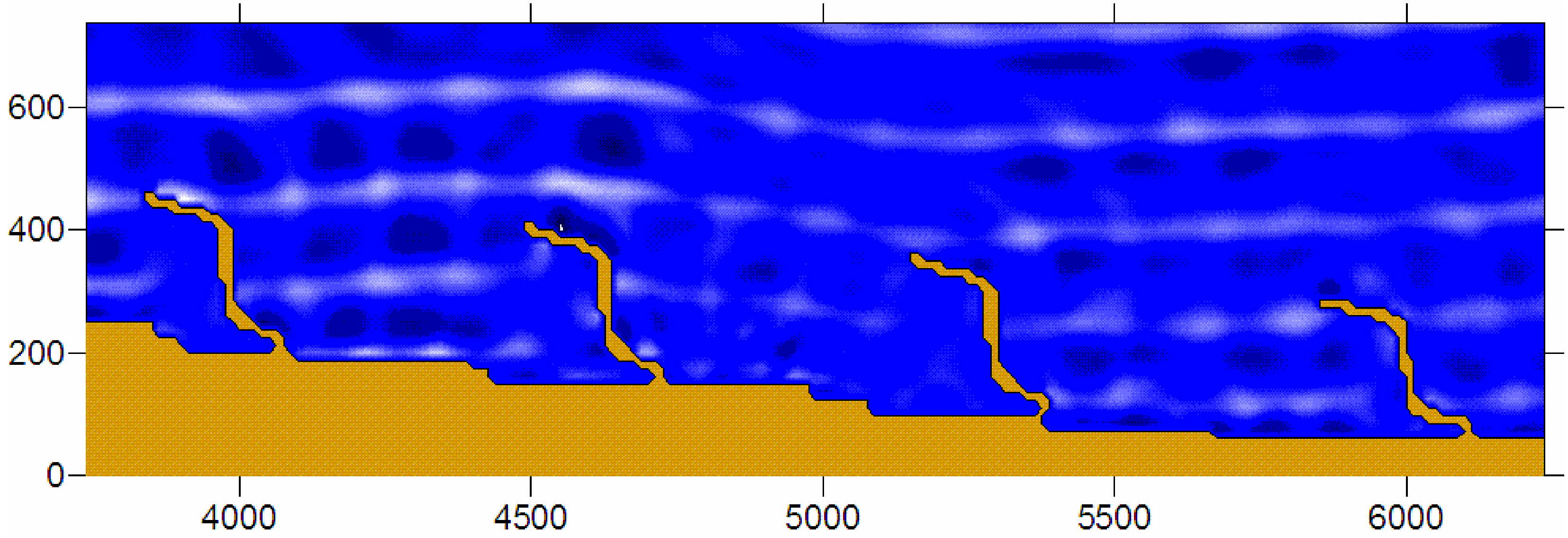

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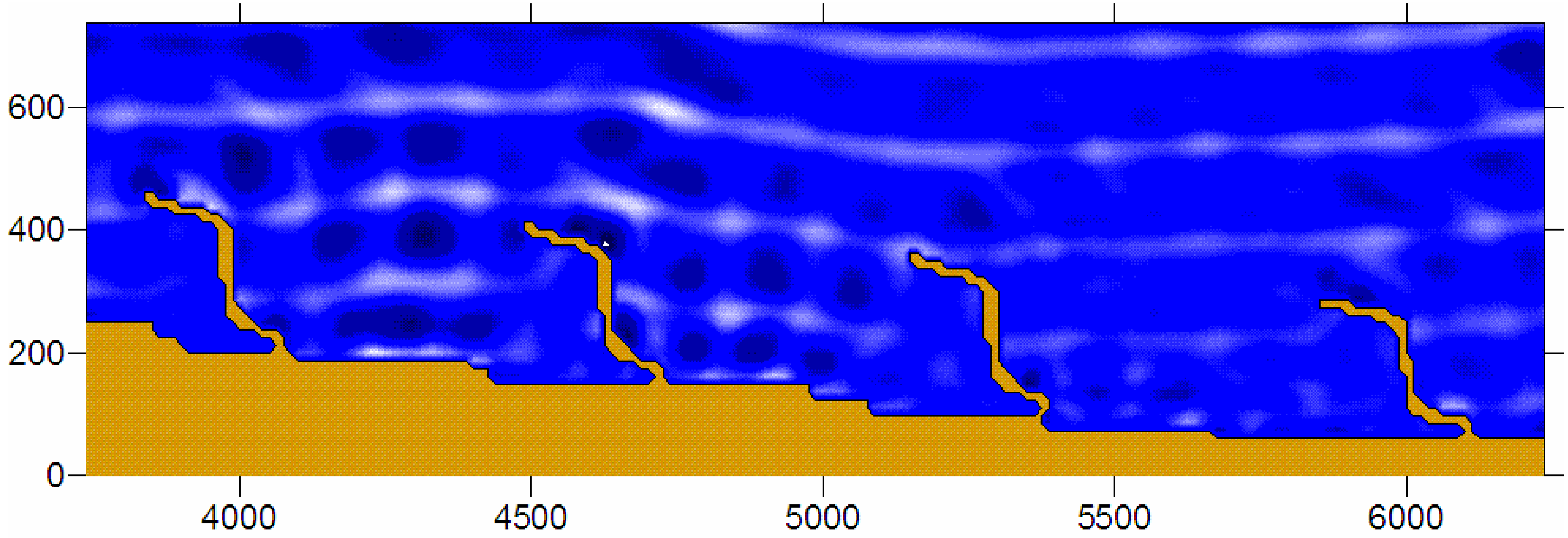

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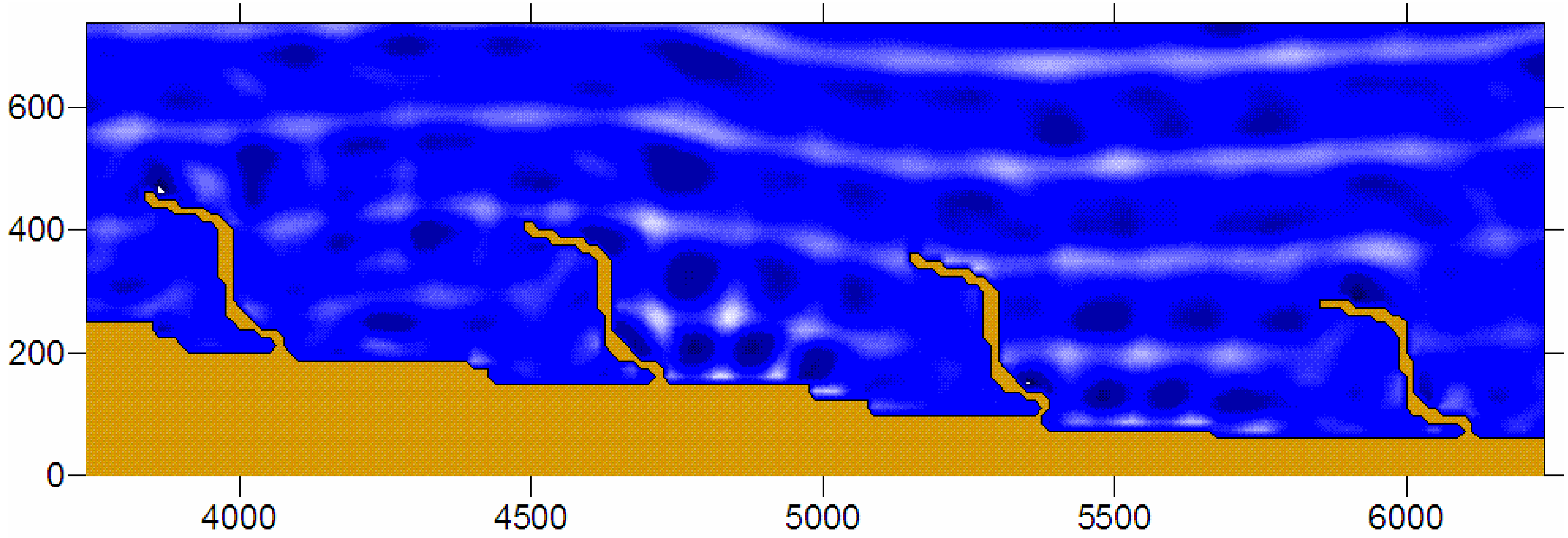

Conclusions and future prospectives

- The results show how the introduction of 11 breakwaters could influence the general circulation next to the shore

- In particular, it should be noted how such a configuration is potentially able to generate a (weak) recirculation cell between two adjacent breakwaters, that hypothetically should prevent a loss of sediment from the shore

- A preliminary sketch of the influence of breakwaters on the propagation of long gravity waves has been also depicted; however, this section could be improved both adopting more sophisticated methods in the implementation of the wave-maker and incresing the temporal resolution of the model