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# Numerical investigation of bore hole filling volume in a coastal area

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# Introduction

- Alderney Race: one of the most promising tidal site in Europe
- Installation of foundations still faces a number of technological barriers like the filling of bore hole by drilling residuals and sediments
- Installation of the tidal turbines is carried out a few days after the drilling of the seabed
- An important filling of the bore hole can clearly complicate the installation phase
- Quantify and determine the parameters controlling the filling is necessary to reduce the installation costs

**Objective: Predict the impact of environmental parameters (tidal current magnitude and intensity, seabed morphology, ambient sediments) on the filling of a foundation.**

# Numerical modeling

## ➢Coastal model (MARS):

1. Primitive hydrostatic equations.
2. Boussinesq assumption.
3. Terrain-Following Sigma Coordinate (σ)

## ➢Discrete Element Model (YADE): Lagrangian tracking

$$\frac{d^2\vec{x}}{dt^2} = \vec{F}_c + \vec{F}_g + \vec{F}_{f\rightarrow p}$$

$\vec{F}_c$: contact forces; $\vec{F}_g$: gravity; $\vec{F}_{f\rightarrow p}$: Fluid to particle

MARS

$\eta, \sigma, and\ (u, v, w)$

**Forçing time: 2 minutes**

YADE

$\vec{F}_{f\rightarrow p}$

η, σ: used to compute the index of fluid cell containing the particles

$(u, v, w)$: used to compute the forces exerced by the fluid on the particles

**Originality and relevance:** Use of realistic tidal currents and seabed morphology to generate sediment-scale information.

# Calculation of forces

$\vec{F}_c$: Linear spring dashpot model;

$\vec{F}_{f\rightarrow p} = \vec{F}_b\ (Buoyancy) + \vec{F}_d\ (Drag)$

$\vec{F}_d$ is 3D and calculated using the correlation formulated in (Di Felice, 1994), which is valid for both dense and dilute granular flow.

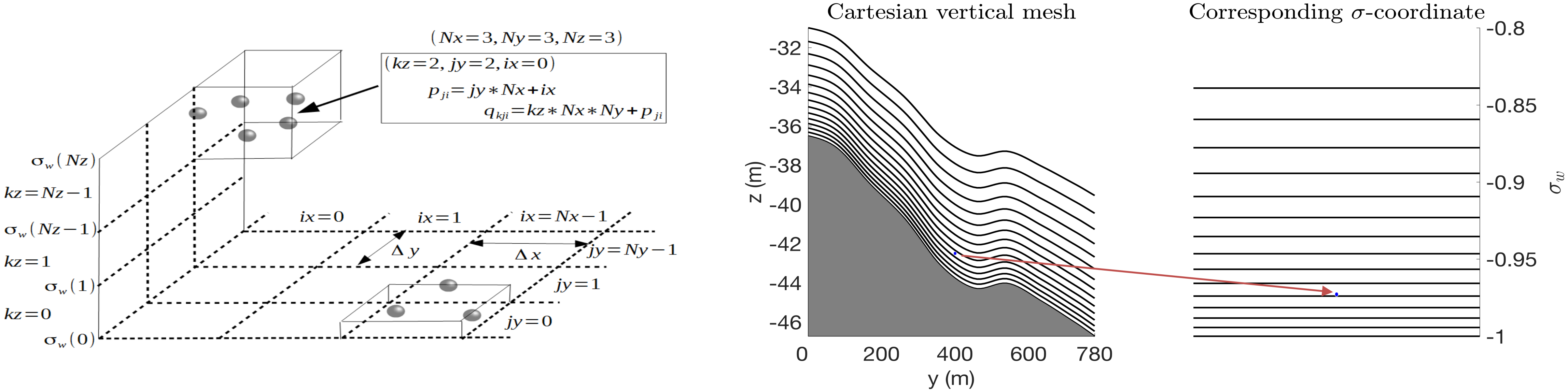
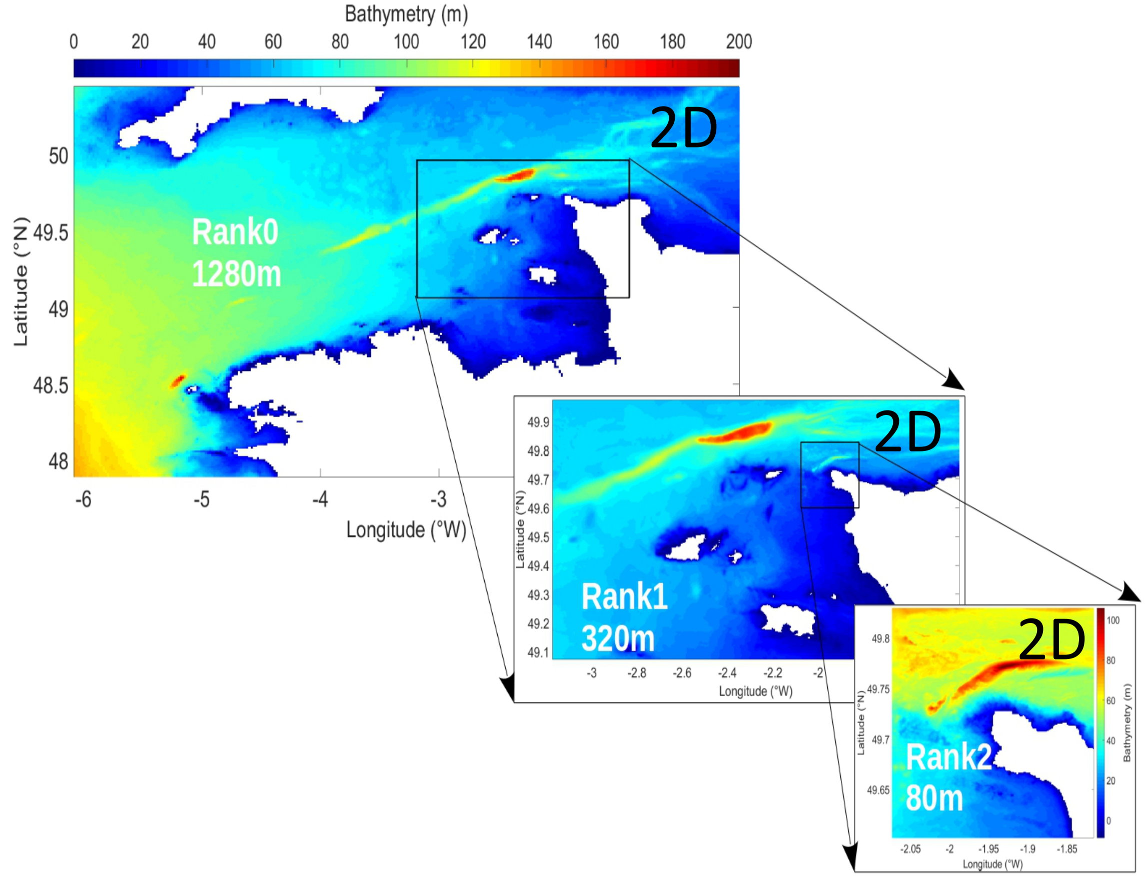



Fig1. Illustration of numbering index used for the three dimensional calculation of drag force (a). Corresponding mapping using the sigma levels (b).

# Tidal current calculation: Grid Nested Approach



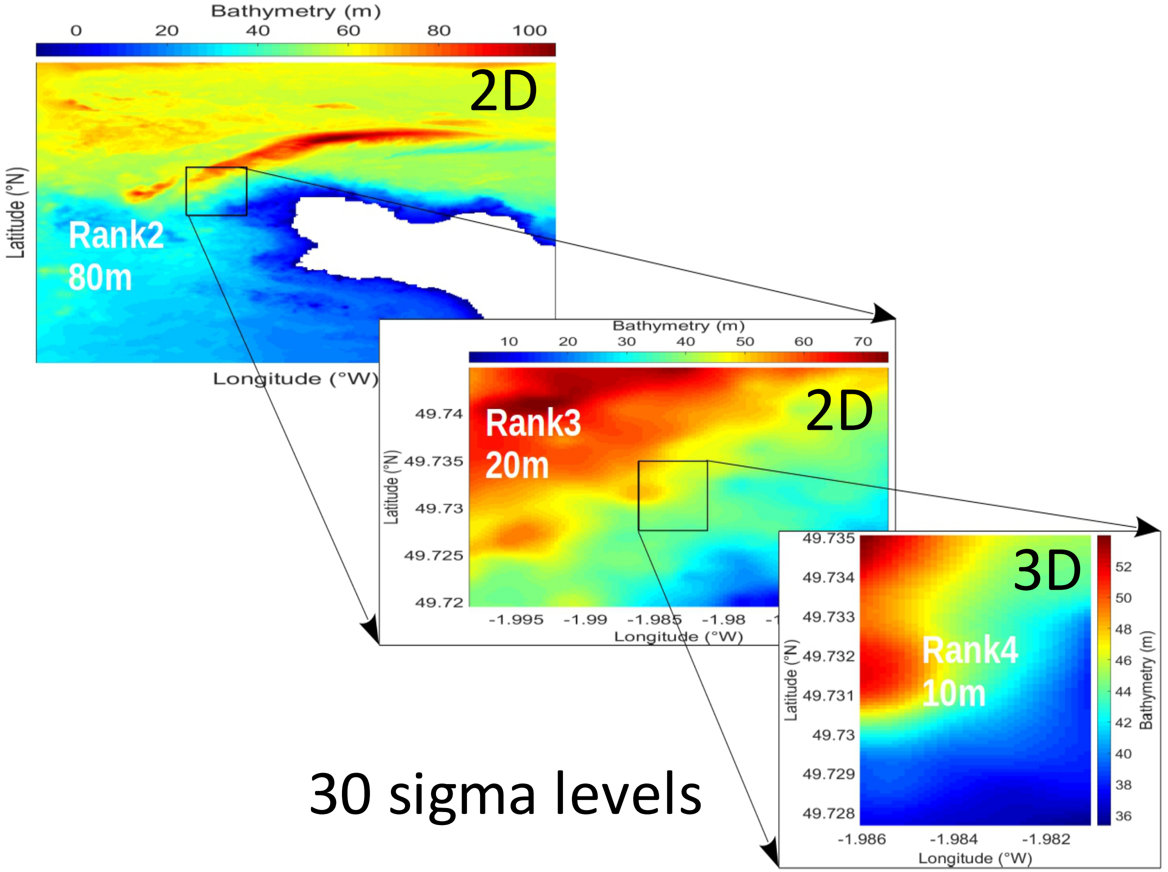




Fig2. *Computational domains used for MARS simulations (ranks 0, 1, 2,3, 4).* The barotropic model is applied to the parent grid (ranks 0, 1, 2 and 3) to generate the boundary conditions for the 3D Child grid (rank 4) where the sediment transport is simulated by the coupling method.

# Tidal currents in the region of interest

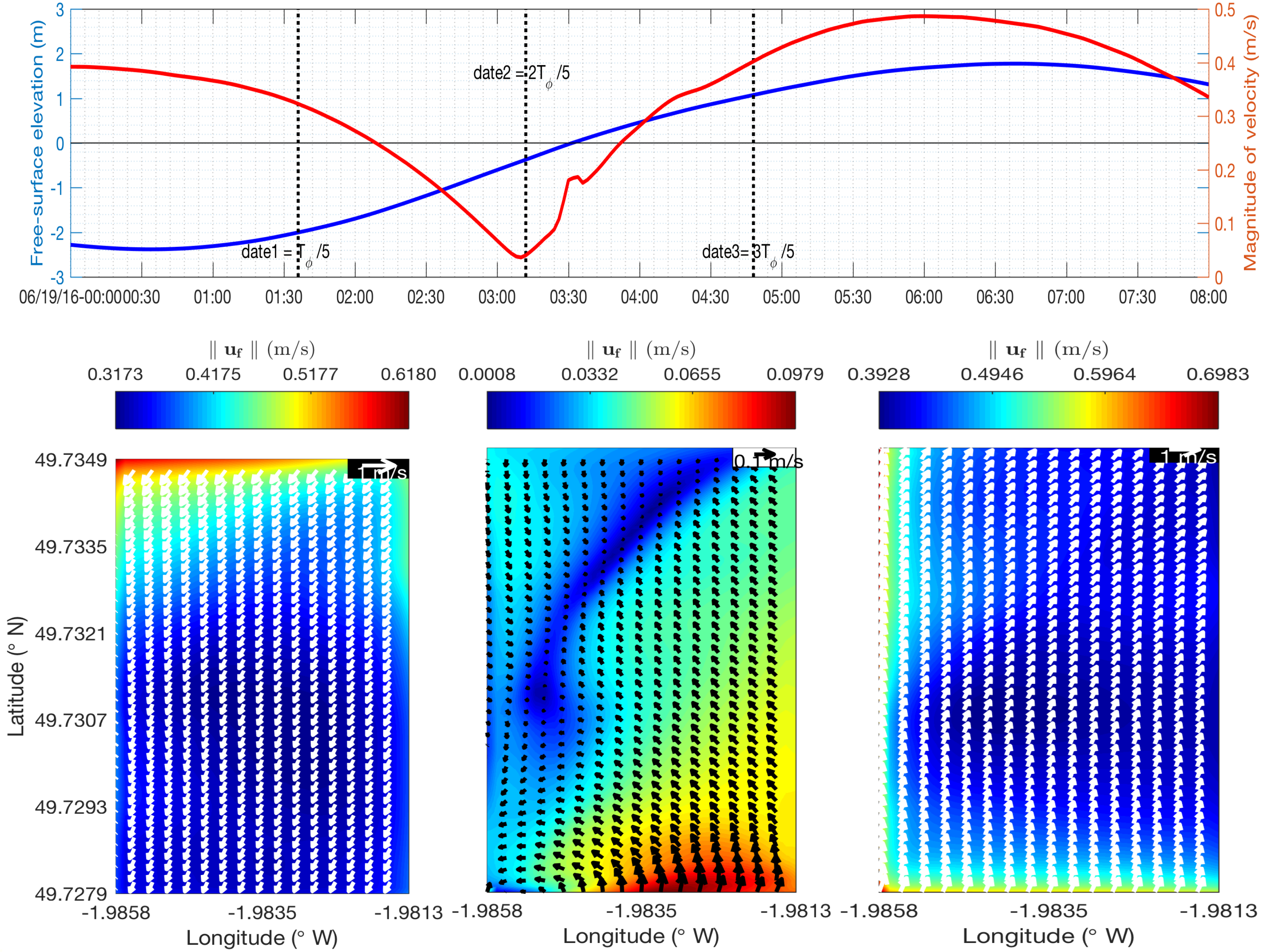



Fig3. *Time evolution of free-surface elevation (blue line) and of velocity magnitude (red line) near the seabed. Colored contours represent the magnitude of tidal current near the seabed at three dates denoted date 1, date 2 and date 3.*

Date1: negative free surface + Southwestward currents . Near-bed velocity ranges from 0.3173 m/s to 0.6180 m/s

Date2: reverse occur. Weak tidal current is observed with a near-bed velocity smaller than 0.0979 m/s

Date3: positive free surface + Northeastward. currents. Near- bed velocity ranges from 0.3928 m/s to 0.6983 m/s

# Drilling residuals: initial disposition, shape and size

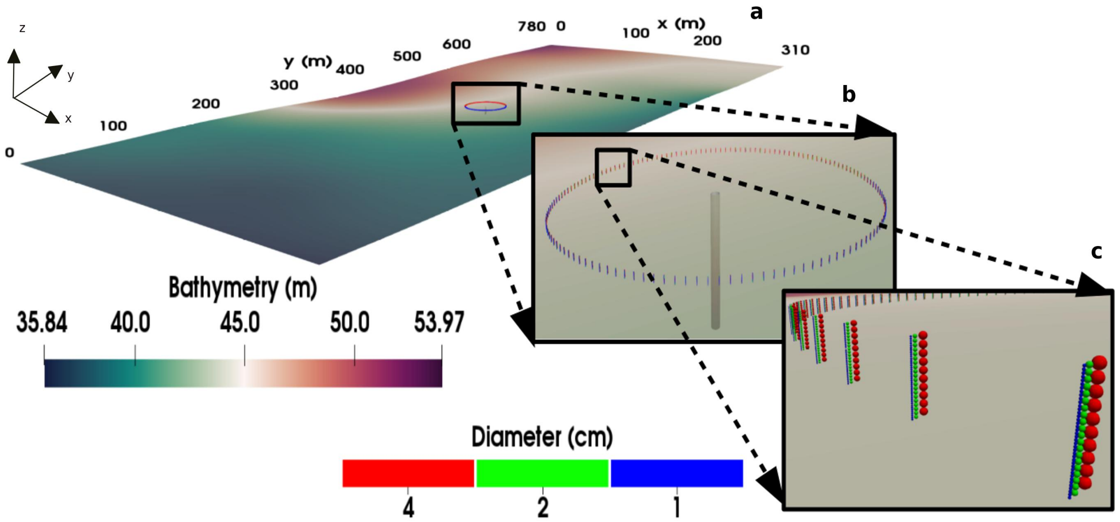



*Fig4. Monopile: Initial locations of drilling residuals around the bore hole (gray cylinder in (b)) and along three concentric circles.*

| Diameter | Number |
|---|---|
| 0.01 | 5720 |
| 0.02 | 2860 |
| 0.04 | 1430 |

**Total number: 10010**

**Particle total volume: 0.28 m$^3$**

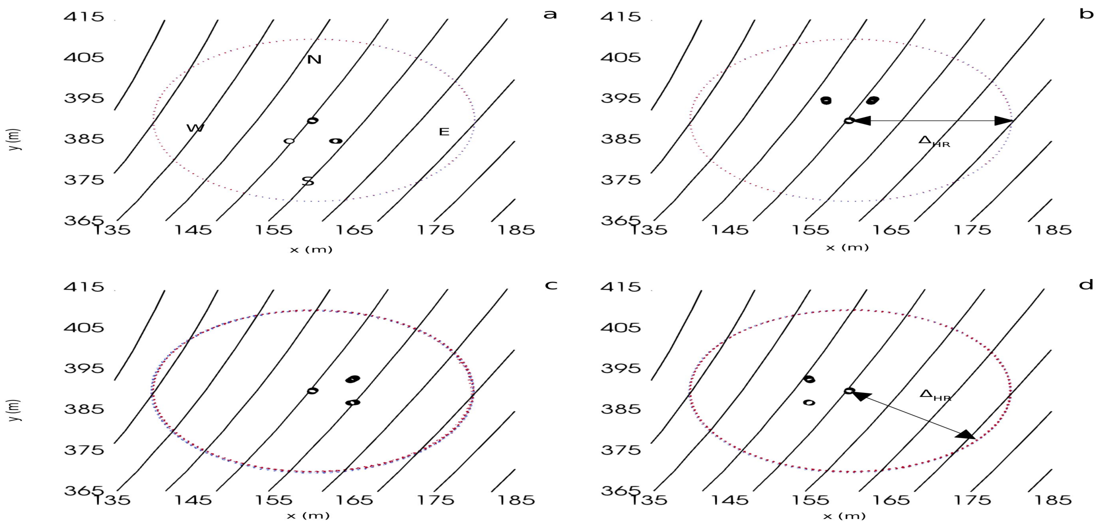



Fig5. Tripod: The distance between residuals and hole (ΔHR parameter) is set from the central hole. Each configuration represents a different position of the two additional holes.

**Hole radius = 1.2m, depth = 10m and volume = 15.4 m$^3$**

# Bed roughnesses and ambient sediment modelling

Residuals + Roughnesses

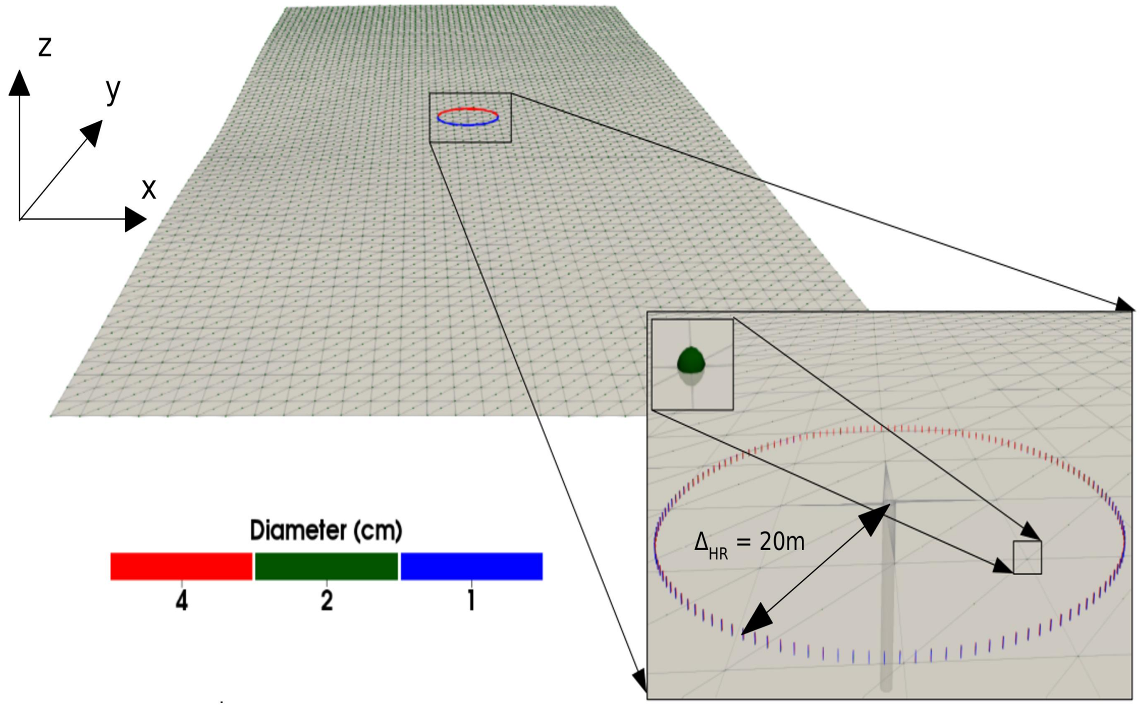



Fig6. Initial disposition of residuals and fixed particles allowing the modelling of bed roughness effects (in green) for ΔHR = 20m.

Residuals + Roughnesses + Sediments (purple)

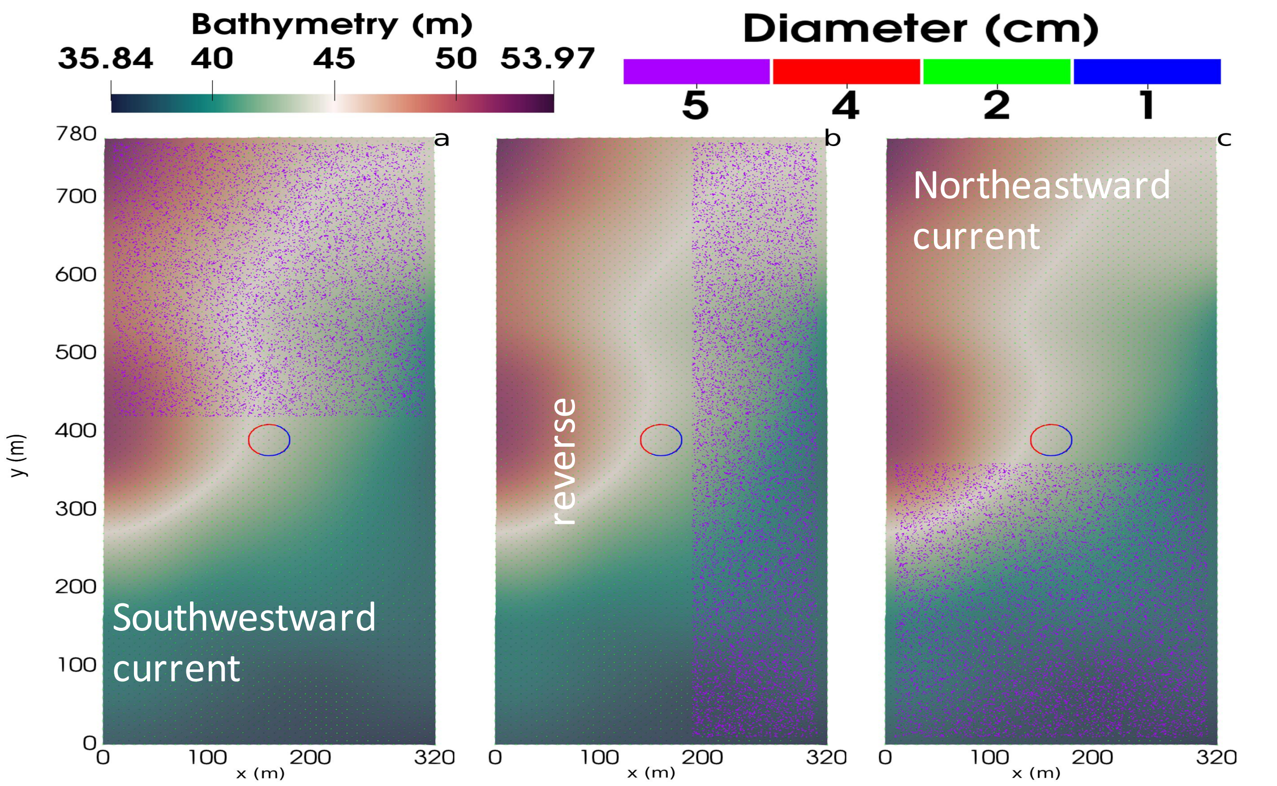
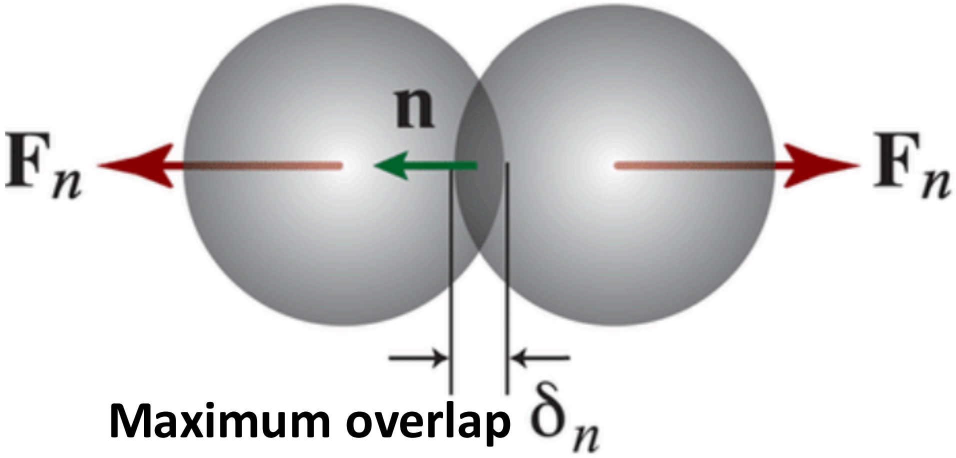



Fig7. Top view of the initial location of sediments (purple dots) and drill residual at: (a) tinit = date 1, (b) tinit =date 2 and (c) tinit =date 3.

# Maximum overlap parameter

Tab1. Physical properties of the drilling residuals and seabed.

| **Drilling residuals and Seabed (Limestone)** | |
|---|---|
| Diameter | 0.01, 0.02, 0.04 m |
| Young modulus | $20 \times 10^9$ Pa |
| Poisson ration | 0.25 |




The Young modulus is not suitable to investigate the integral bore hole filling volume with a reasonable computational time cost.

We choose to reduce the Young modulus (or spring stiness) by the use of the maximum acceptable inter-particle.

**Idea:** used a small values of stifness which can satisfactorily reproduce the macroscopic behaviour of the granular flow, even though the microscopic contact parameters are altered signicantly. We tested $\delta n$ = 1%dps, 3%dps and 5%dp. dps = diameter of smallest particle.

# Effect of maximum overlap on the granular flow

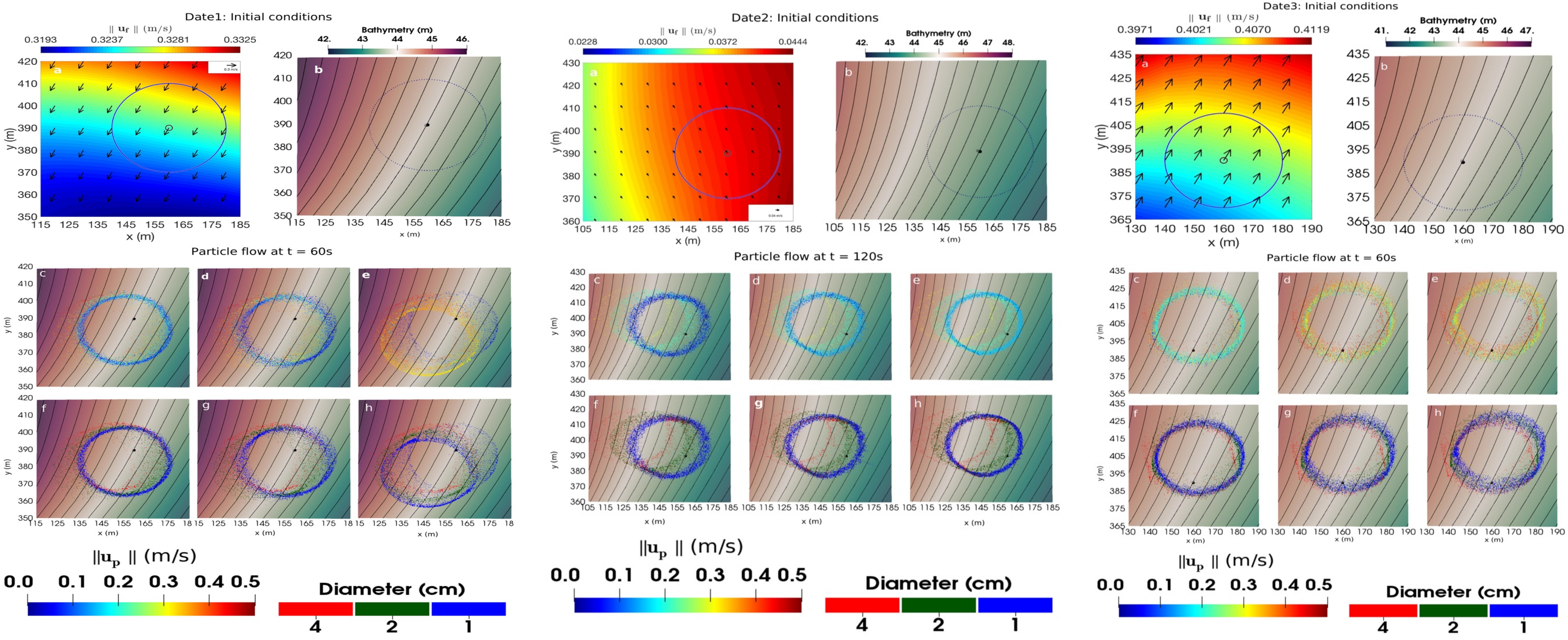



Fig9. Position and velocity of residuals at t=60s for δn = 0.01dps (first column), 0.03dps (second column) and 0.05dps (third column).

# Effect of maximum overlap on the filling

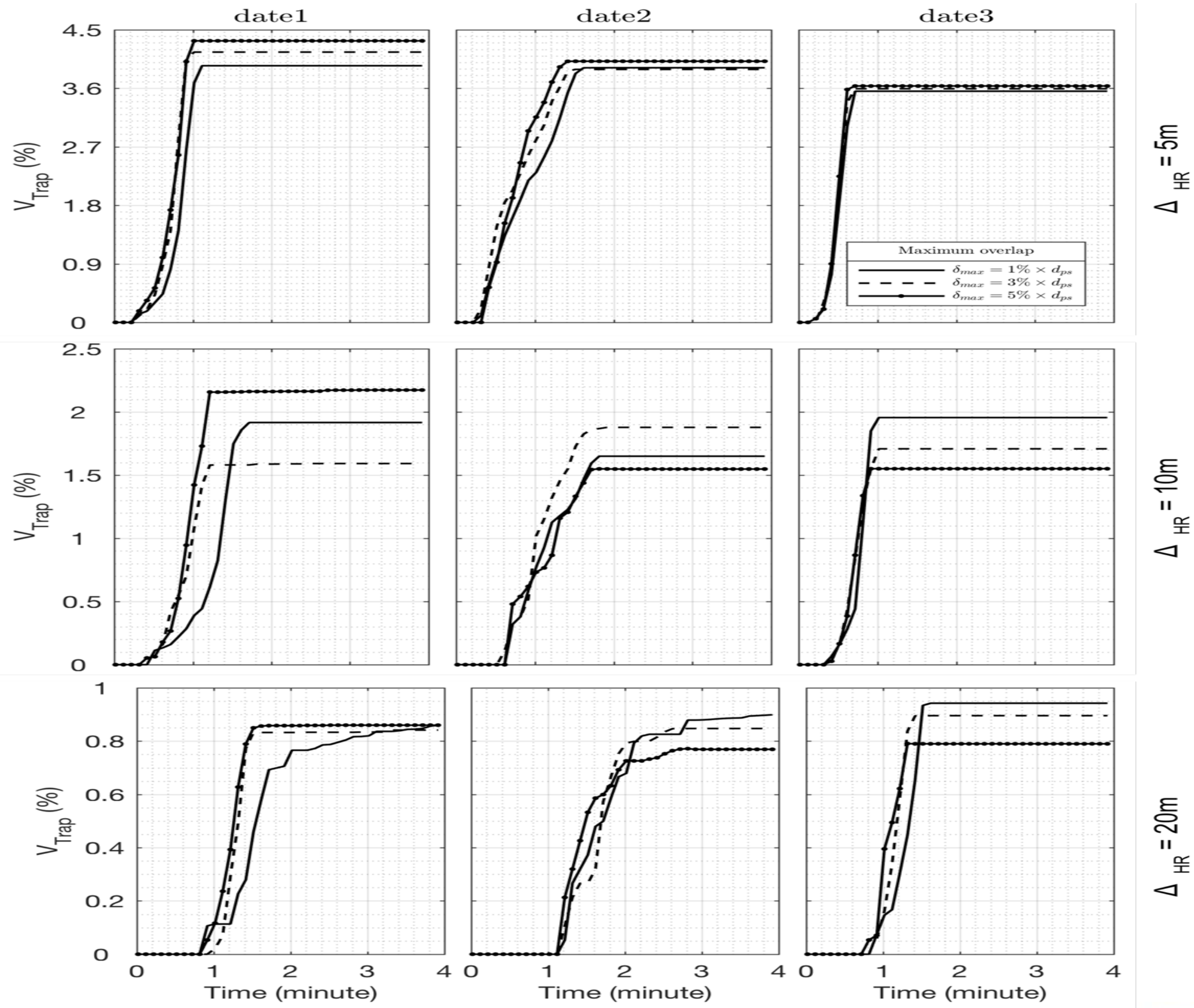



Fig10. Time evolution of for three different initialization date: date1 (first column), date2 (second column), date3 (third column).

1. Ìn the limit of ΔHR ≤20 m, the change in the maximum overlap did not significantly influences the macroscopic particle flow during the filling.
2. There is no significant difference of filling volume: this difference is smaller than 0.5%

$$V_{trap} = 100x \frac{\text{volume trapped by the hole}}{\text{total volume modelled}}$$

# Effect of distance bore hole to residuals (ΔHR parameter)

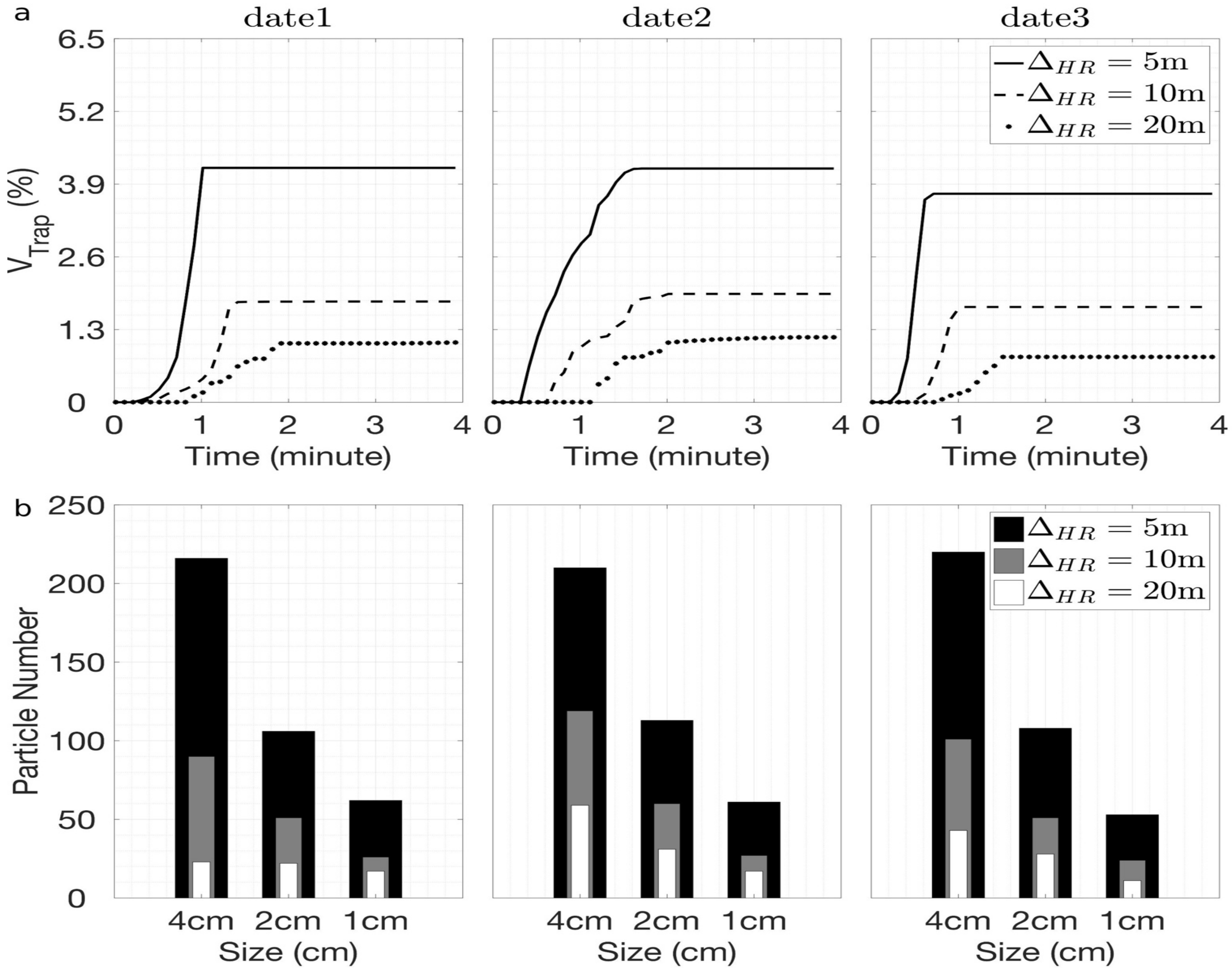



Fig11. Time evolution of volume trapped for three values of parameter ΔHR (first row) and corresponding particle distribution inside the hole (second row).

- The increase of ΔHR leads to reduce the volume trapped. This reduction is not only due to one particle class
- ΔHR = 20m is the value minimizing the filling volume
- ΔHR is the key parameter for the bore hole filling by drilling residuals

# Tripod technology: date 1

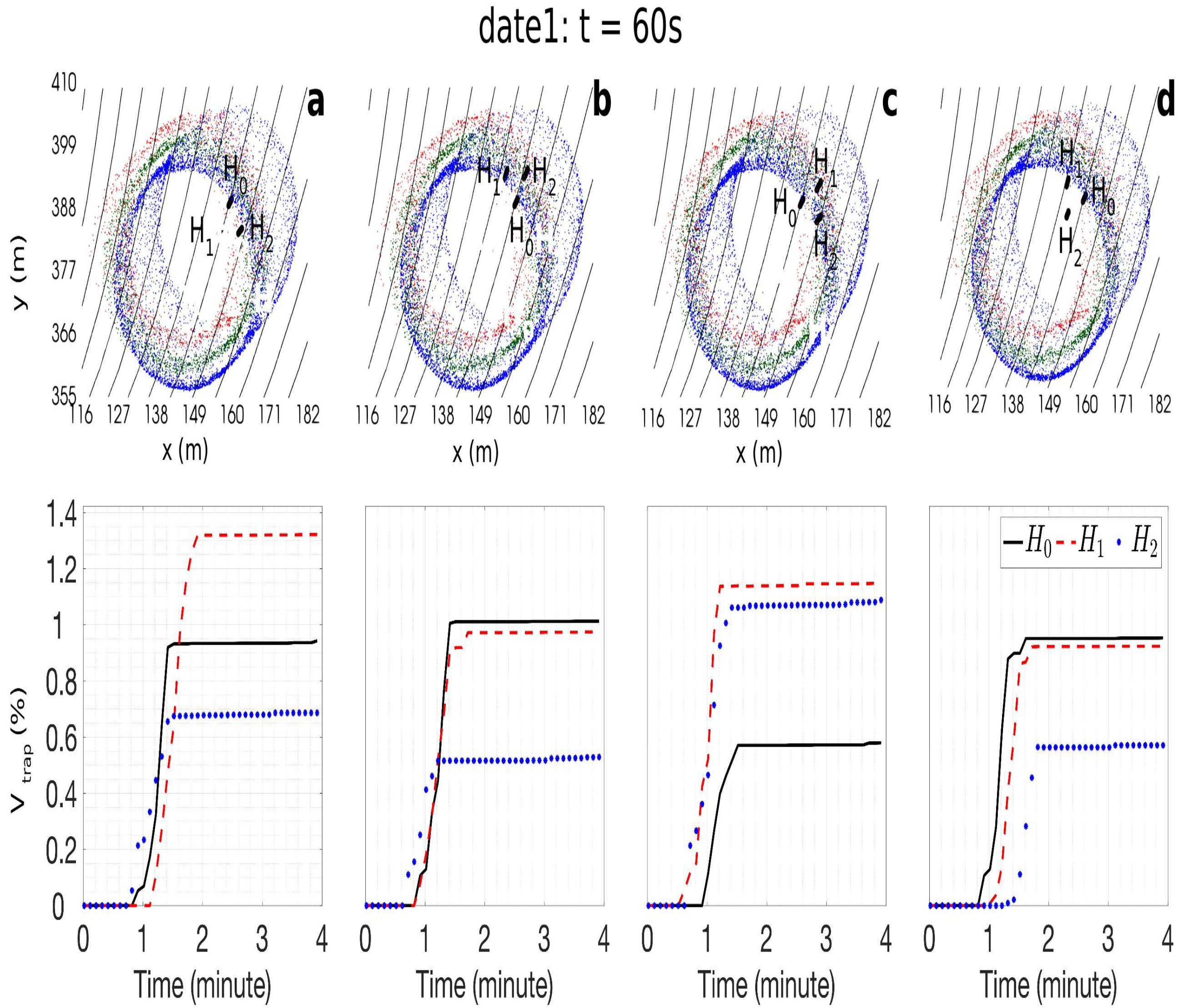



Fig12. date1: Particle position (top view) at t=60 s and evolution of the filling volume for our four tripod configurations. Additional bore holes (H1 and H2) are placed at South (a), North (b), East (c) and West (d) from the central hole (H0).

- The best strategy to reduce the filling volume of the central hole is to locate the two additional holes at East: config (c)
- A part of residuals moving towards the central hole are fall into H1, modifying the trajectory of particle flow. The residuals will be essentially trapped in the two additional holes due to tidal current direction

# Tripod technology: date 2

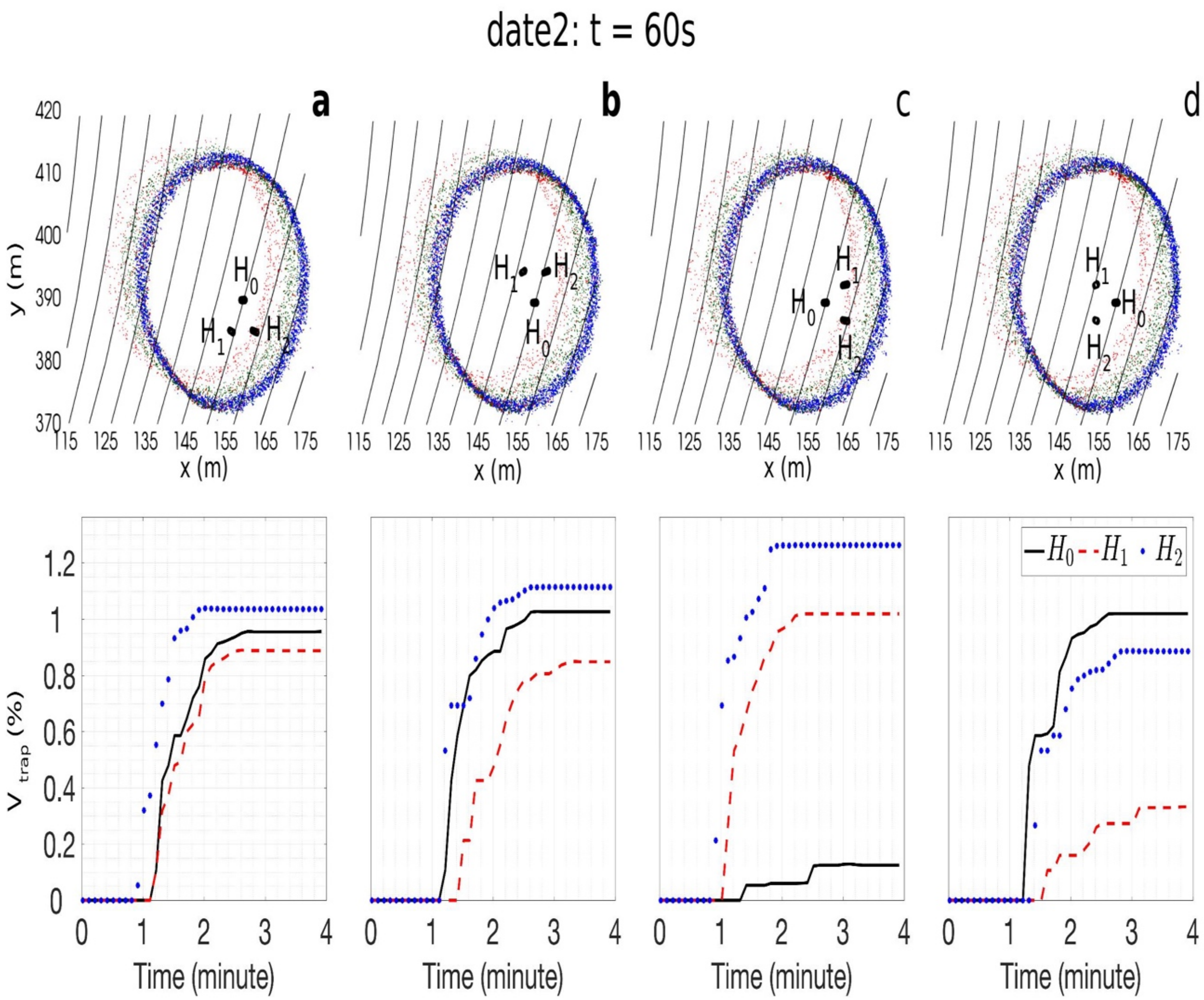



Fig13. date2: Particle position (top view) at t=60 s and evolution of the filling volume for our four tripod configurations. Additional bore holes (H1 and H2) are placed at South (a), North (b), East (c) and West (d) from the central hole (H0).

- The best strategy to reduce the filling volume of the central hole is to locate the two additional holes at East : config c
- A part of residuals moving towards the central hole are fall into H1 and H2, modifying the trajectory of particle flow: the residuals will be essentially trapped in the two additional holes due to tidal current direction

# Tripod technology: date3

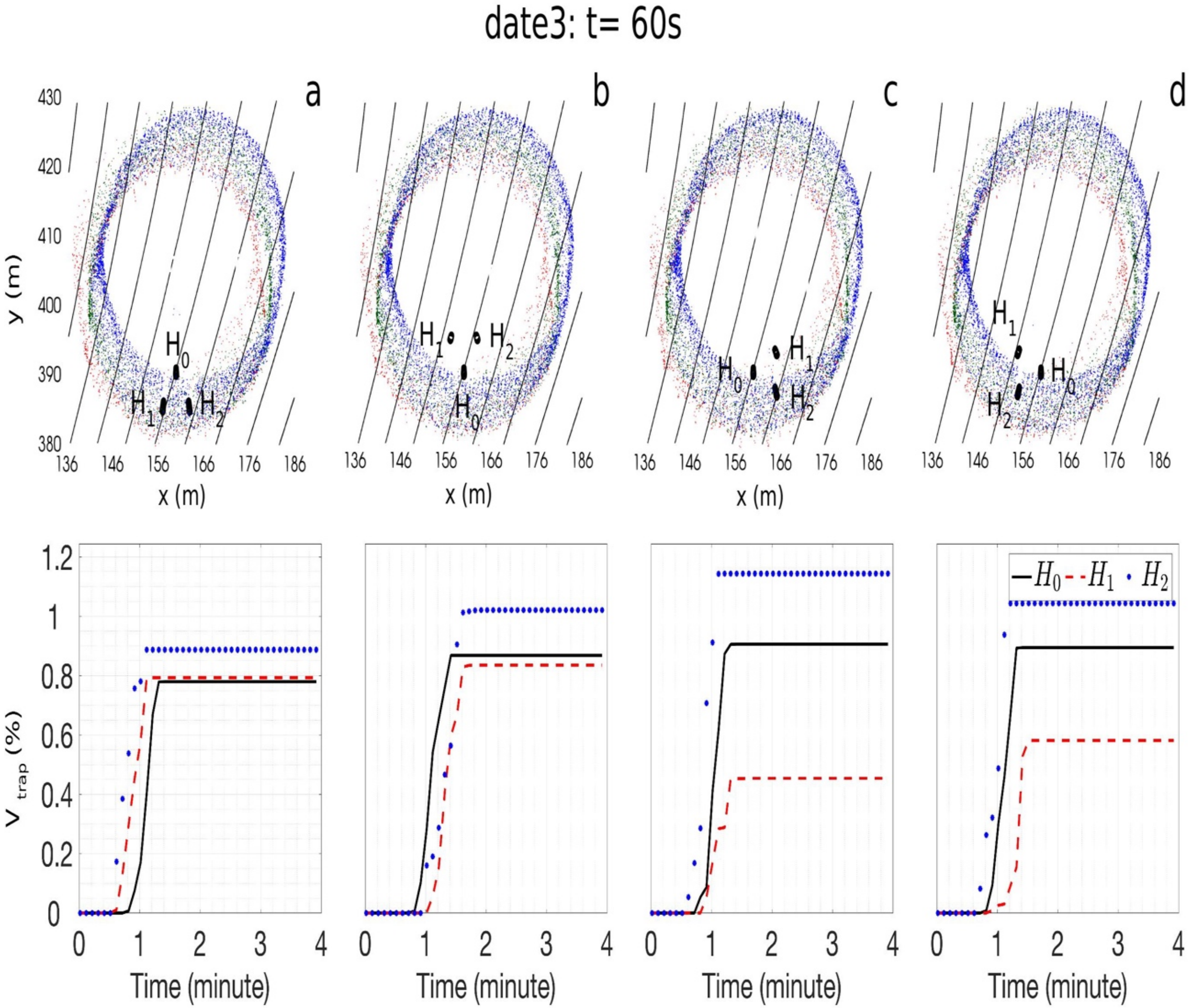



Fig14. date3: Particle position (top view) at t=60 s and evolution of the filling volume for our four tripod configurations. Additional bore holes (H1 and H2) are placed at South (a), North (b), East (c) and West (d) from the central hole (H0).

- The filling volume of the central hole is minimized using two additional holes located at East of the central hole: config c.
- The principle is similar to Southwestward currents (date1): a part of residuals moving towards the central hole falls into H1 and H2.

# Bed roughnesses effect

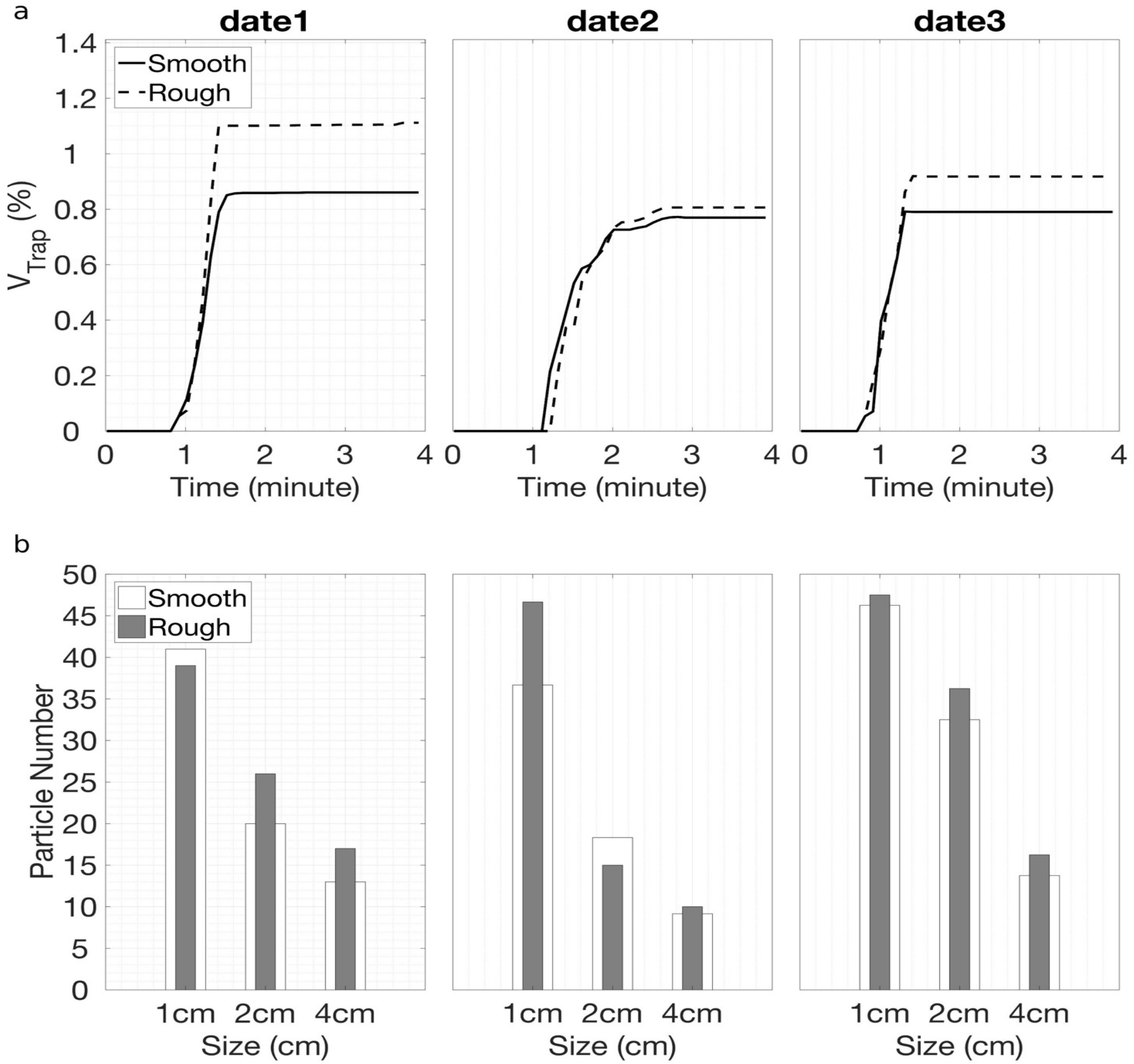



Fig15. Roughness effect: time evolution of volume trapped (top row) and size distribution of trapped particles (bot- tom row) for three different initialization times: date1 (first column), date2 (second column) and date3 (third column).

Effects of both seabed morphology and tidal currents direction:

1. Case1: Combined effects of seabed morphology and Southwestward current (date 1)
2. Case2: Dominant effect of seabed morphology (date 2)
3. Case3: Opposing effects between the seabed morphology and the North- eastward current (date 3)

# Bed roughnesses and ambient sediment effect

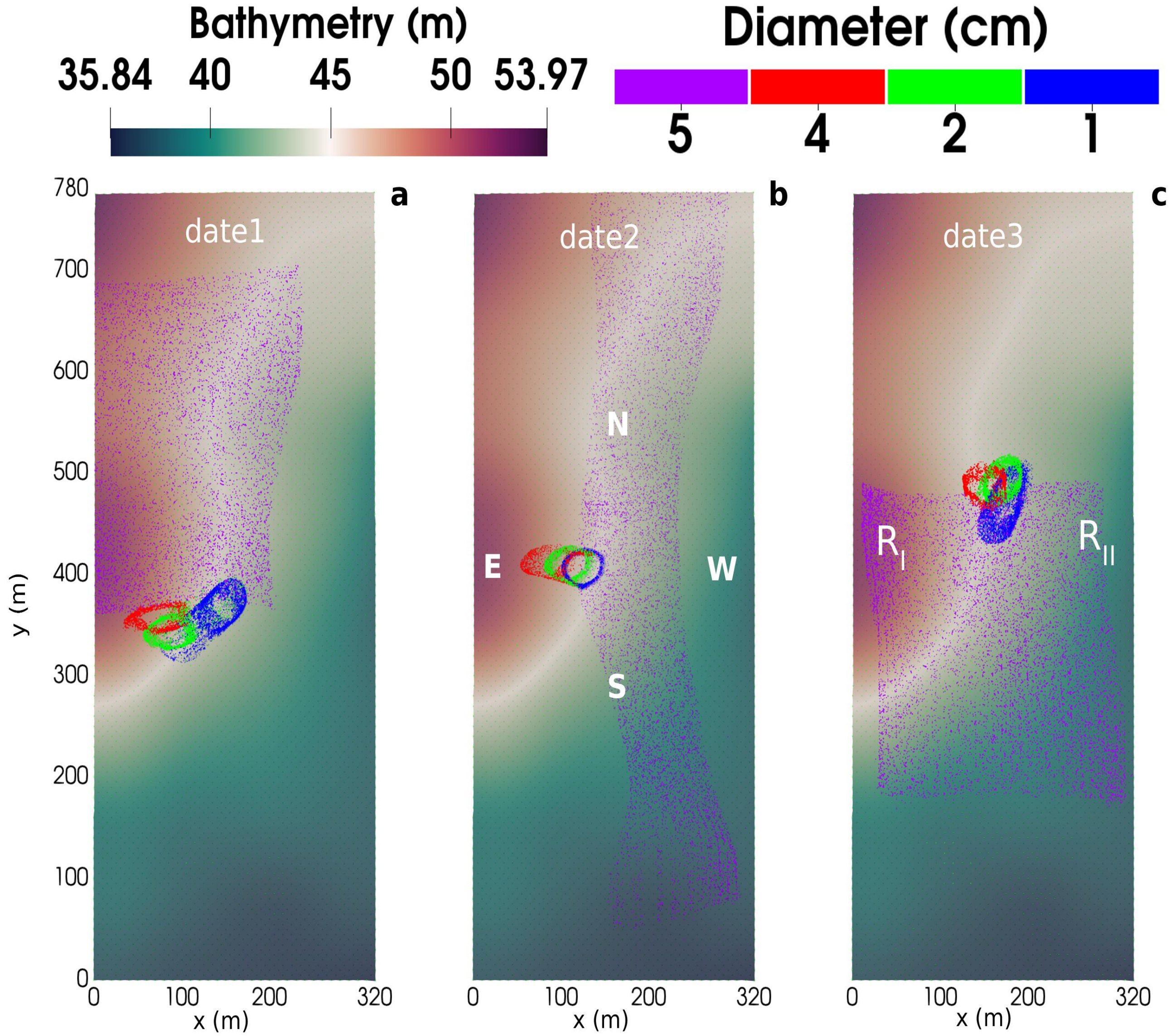



Fig16. Position of ambient sediments and drill residuals for three different initialization times: date1 (first column), date2 (second column) and date3 (third column). The labels N, S, E and W represents the North, South, East and West, respectively.

Date1: Seabed morphology + tidal current, leading to South-West granular flow (a)

Date2: Small tidal current effect, leading to a granular flow dominate by the seabed morphology (b)

Date3: Opposite effect: seabed morphology and the Northeastward current (b).

RI: dominated by the seabed morphology

RII: controlled by the tidal current direction

# Bed roughnesses and ambient sediment effect

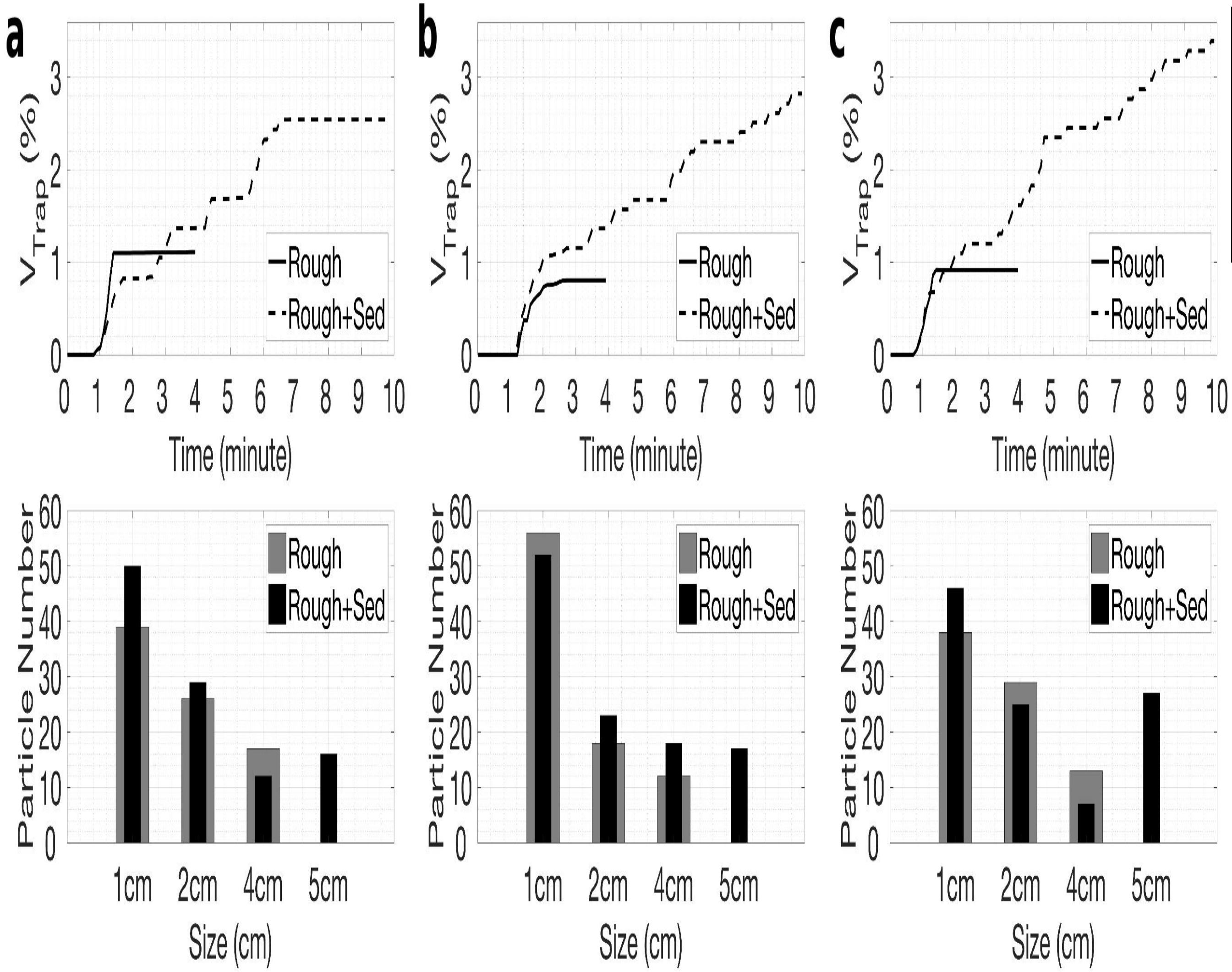



Fig17. Time evolution of volume trapped with drilling residual, bed roughness and ambient sediment (first row) and corresponding particle distribution inside the hole (second row).

Configuration minimizing the filling is for the date 1, where we have a combined effects of seabed morphology and tidal currents

# Conclusions and perpectives

## Conclusions

- The increase of the distance between the residuals and the bore hole leads to reduce the filling volume. This distance is the key parameter controlling the filling for the monopile technology.
- Tripod filling volume is strongly influenced by tidal current direction and seabed morphology.
- The effects of bed roughnesses and sediments are coupled with the effects of both seabed morphology and tidal currents direction according to three main cases of coupling: (i) Combined effects of seabed morphology and tidal current; (ii) Dominant effect of the seabed morphology; (iii) Opposing effects of seabed morphology and tidal current.

## Perspectives

- Exactly quantified the filling volume over several tidal cycles
- Use of non spherical particles like pebbles
- Application of model to investigate the impact of ambient sediments on tidal converters.

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