Shore Pollution Simulation Based on Tidal Currents and Ground Effects

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***Abstract*—Marine pollution comes from different sources including agricultural, industrial, and domestic wastewater discharge from human activities in coastal areas. Environmental simulation can represent ground and sea characteristics, modeling spreading occurring in both spaces. These characteristics are variable, due to soil capability and reaction, and sea behavior, in particular currents and tides. This work presents a heterogeneous tiling approach modeling sea behaviors in coastal areas based on tidal currents and ground effects. The ground is segmented into irregular cells following administrative divisions for collecting observations while the sea area is segmented into regular geographical tiles. The impact of the interactions is represented by messages carrying qualities and quantities of physical pollution. Channels link cells following cellular automata or distributed system paradigms. This system architecture allows to produce a synchronous message passing program suitable for massive parallel execution. The status of cells and messages are produced step by step and can be interpreted graphically. Green tides caused by eutrophication appear when nutrients circulate in high concentrations in coastal waters. These nutrients come from land use, accumulate, and propagate to the shores mainly through rivers end up joining the sea or the oceans. Our simulations show when and where tides are able to increase concentration levels, producing space and time characteristics.**

***Keywords*—environment simulation, monitoring shores, distributed systems, hybrid systems, tidal currents**

I. INTRODUCTION

Coastal interactions appear to be mainly from ground to sea, especially in the case of intensive agriculture, urban development, and industry. The nature of these exchanges is chemical, biological, or sediments, with sometimes huge quantities of pollutants sent to the sea (nitrates, nitrites, phosphates, or biological). These exchanges are in fact bi-directional, ocean activity producing, in turn, sediments and biological effluents that are spread back to the coast. A first classification inside this system can distinguish a set of behaviors: ground circulation (1) depending on the nature of ground pollutants (2), ocean circulation (3), and the nature of spreading (4). The introduction will review this system, and explicit quantities published for an intense agriculture region, with a strong influence of marine currents. Then, we will focus on sea spreading, to demonstrate basic circularity due to tide currents. A predicted schedule of tide directions and strength will allow for simulation spreading revealing places with a harmful sea-to-ground accumulation, after periodic effects of tides.

Ground circulation: Pollution spreading on land can be approximated by elevation analysis or observed by sensors. During rainfall events, water runoff picks up pollutants from the land and carries them into water bodies. This runoff contains sediments, nutrients, pesticides, and other chemicals. The river system is the main connection for sending ground impacts to the oceans. Another connection is drainage basins propagating pollutants within the soil. Heavy rainwater propagation can be simulated by geographic segmentation according to a grid, augmented by elevation. Truong *et al.* [1] presented the real case of a heavy rain event with a flooding effect on the ground, computed over regular tiles. Monitoring ground pollution can be achieved by dedicated sensors and data collection. The observation results are produced and published following geographic boundaries. The core segmentation is geographic divisions also used to collect or observe human activities associated with pollution sources. Fig. 1 displays a map of infected beaches in Brittany, France.

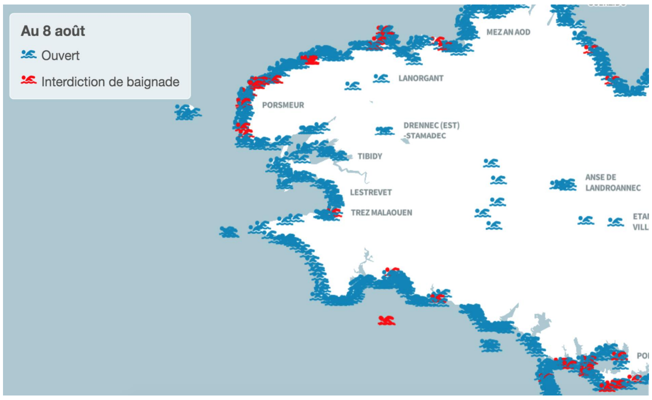

Fig. 1. Periodic map of beaches infected by bacteria (Escherichia coli) in Brittany, France. It is changing with rain, temperature, and tourism activities (Le Telegramme: 08/08/2023).

Nature and quantity of ground pollutants: Pesticides, chemical waste, cleaning products, petroleum products, mining waste, rubbish, and sewage are examples of marine pollutants of land-based origin [2]. Nitrogen-based fertilizers in agricultural activities flow to rivers and estuaries before ending up in the sea, where they encourage the growth of destructive algae, deplete the ocean's oxygen supply, and create several dead zones in which marine life cannot survive. Furthermore, in 2000, the population in coastal provinces in China reached 529 million (whole nation population: 1.29 billion), uncounted seasonal tourism, and temporary inhabitants engaged in construction work and other short-term employment. Sewage discharges into the ocean of more than 10 billion tones with dominating pollutants of

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inorganic nitrogen, phosphate, and heavy metals [3]. The contamination from land runoff caused red tide events to occur 28 times involving an area of 10,000 km^2 in 2000 and 77 times in 2001 affecting an area of 15,000 km^2.

Ocean circulation: The oceanic model is made of currents carrying objects. SHOM is the French's Naval Hydrographic and Oceanographic Service [4] that operates for reference maritime and coastal geographic information. One of the products provided by SHOM is the tidal current prediction [5] including the components of surface tidal currents hour by hour and for two characteristic tidal coefficients (45 and 95). The data come from calculations of finite element models as also developed using TELEMAC-2D. It is a computational system that calculates free surface flows in two dimensions of horizontal space.

TELEMAC-2D is an open-source system, which is helpful in developing a model suitable for different situations. The system is of general application to hydraulic problems as it is able to take into account various phenomena. Awad and Darwich [6] used the TELEMAC-2D model to simulate the quality of seawater affected by wind and local currents. The aim was to determine how much the pollutants outlet into the sea with the sea current intensity and direction. Three scenarios were taken into consideration with the average daily spill of sewage produced by the inhabitants living in the river basin. Li *et al*. [7] studied the impact of building representations on urban flooding using the TELEMAC-2D model. By physical experiments and numerical modeling, the results showed that it is largely applicable to the simulation of urban flooding although there are some differences exist in the simulation results. The model was used in [8] to simulate the dynamics of the rivers during a flood period in Brazil. The results were validated using the city flood map provided by the government.

Nature of spreading: The nature of spreading in sea areas is different with different kinds of pollutants. As an example, oils tend to spread out on top of the water for hundreds of nautical miles. Plastic trash can be transported around the world with ocean currents. Waves produce sprays carrying back marine pollution to the ground. Aerosolized toxins from harmful algae blooms are transported on land with wind effects and subsequent exposure and inhalation of the generated aerosols can induce adverse human health effects [9].

The rest of the paper is as follows. Section II presents a brief discussion of marine current estimation methods. Section III shows the tidal currents modeling based on 2D vectors. We present illustrations of water circulation and pollution monitoring with tidal currents in Section IV and a conclusion was drawn in Section V.

II. Marine Currents

A. Physical Causes

Marine currents are complex motions of water produced locally or globally by physical forces: wind, water density differences, and tides resulting from sun and moon attraction and Coriolis effect. The wind pushes against the sea surface and drives currents in the down-wind direction, with strength decreasing following depth. Winds have a tendency to drive localized currents along coastlines, which can lead to phenomena like coastal upwelling. Differences in temperature (thermal) and salinity (haline) drive a vertical circulation that transports heat from the tropics toward the poles. Thermohaline circulation-driven currents are significantly slower moving than tidal or surface currents and can be found in both deep and shallow ocean depths. Currents driven by wind and thermohaline circulation are non-periodic currents to be predictable since they are associated with changing weather. The gravitational pull of the moon and sun causes tides. Water moves up and down over a long period of time during tides. The currents produced by tides are strongest near the shore, in bays, and in estuaries along the coast. They are referred to as "tidal currents". The currents are generally measured in knots (1 knot = 1.85 kilometers per hour) and the direction of a current is the direction it is headed for or where the current is flowing towards counted from 0° to 360° (0° being the geographic north) clockwise. Strong tidal currents can travel at speeds of eight knots or more.

B. Currents Estimation and Measurement

Current modeling is critical for people working in marine activities.

1) Measurement

Sensing observation: Current measurement is typically done with sensors, grouped as single-point current meters and current profilers. A current meter is an oceanographic device for flow measurement by mechanical, tilt, acoustical, or electrical means. It is an instrument for measuring the velocity of the flow of a fluid in a stream. A magnetic compass can be incorporated into the current meters to determine the orientation of the instrument with respect to the magnetic north. Single-point current meters will only measure the current in the exact depth where they are installed [10]. As sea currents vary significantly with depth, it's preferred to measure the current profile for the entire water column by using a dedicated tool. The Acoustic Doppler Current Profiler is extensively used to measure ocean currents [11]. The American National Oceanic and Atmospheric Administration scientists (NOAA) typically deploy Acoustic Doppler Current Profilers to measure currents throughout the water column at various locations for a period of one to four months. The device operates using reflections of the sound wave from drifting particles for the measurement. The profiler sends an acoustic signal into the water column and that sound bounces off particles in the water. The instrument calculates the speed and direction of the current by knowing the frequency of the return signal, the distance it traveled, and the time it took for the signal to travel.

Radar observation: Radio antennas and high-frequency Radio Detecting and Ranging systems are used to map surface ocean current patterns over a large area in coastal areas [12]. These shore-based instruments use the Doppler effect to determine when currents are moving toward or away from the shore or to measure the velocity of a current. The utilization of high-frequency radar systems in coastal areas has rapidly increased alongside the use of moored current meters [13]. It has been demonstrated that coastal high-frequency radar can resolve quick changes. However, their coverage remains limited although the number of high-frequency radars has been augmented.

Satellite observation: A combination of surface current measurements by satellite and high-frequency coastal radar is a promising approach to cope with both the resolution and fast dynamics characteristic of coastal areas and the medium size and slower evolution of surface currents in the open ocean regions. Satellites provide information about the ocean bathymetry, sea surface temperature, ocean color, coral reefs, and sea ice. The sea surface temperature shows patterns of water circulation characterized by cold water and warm water currents.

2) Prediction

Observation data are collected by different types of sensors (currents, salinity, temperature, oxygen, and pressure) at selected locations to track the movement of various water masses. These data are used to generate current predictions in the locations. To create accurate prediction models, it is necessary to periodically resurvey various coastal and estuarine locations [14]. Extensive numerical models have been used to study the characteristics of tidal currents based on physical and geographical parameters temperature, salinity, water depths, vertical turbulent viscosity, and diffusion [15]. These numerical models need to be assessed and calibrated using observational data, such as observation with current sensors, to produce reliable current models.

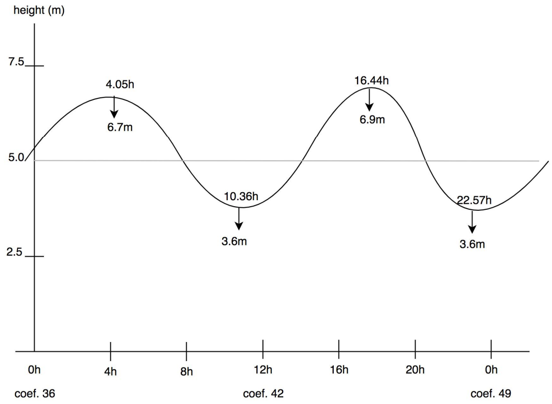
III. Tidal Current Model

In this section, we will introduce the principles of tides, tidal estimation from an oceanographic service, and a formal model of tidal currents' velocity and direction used in this study.

A. Tide Principles

Tidal currents are periodic currents making prediction for future dates possible. They embed height range and speed that affect coastal activities such as fishing, shipping, and tourism. Tidal currents can break up some pollutants or carry others back to shore and contribute to shoreline changes due to erosion.

The *tidal coefficient* represents the height of the tide in relation to its mean tide. Typically, it fluctuates between 20 for low tides and 120 for high tides. The strong tides, called spring tides, occur near the times of a new moon or full moon when the Earth, moon, and sun attraction are all lined up so that the tidal bulges caused by the moon and by the sun add to each other (mean spring tides: coefficient 95). The weak tides, called neap tides, occur near times of first quarter and third quarter the tides when the moon and the sun work against each other (mean neap tides: coefficient 45). The tidal range, or the variation in water height between high and low tide, increases with increasing tidal coefficient. In the example shown in Fig. 2, the tidal range is 3.1 m corresponding to lower coefficients (around 40) and the tidal range is 7.4 corresponding to higher coefficients (around 90). This indicates that the water level rises and retreats considerably. The mean water height is different between places. In our example of Roscoff, it is 5 m, whereas the Bay of Mont Saint-Michel has a mean water height of 7.5 m.



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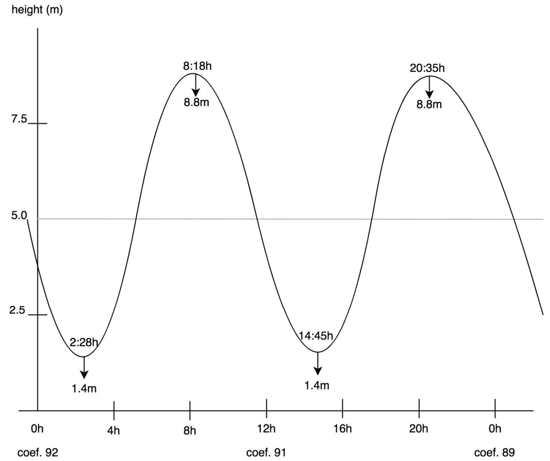


b) 08 April, 2023

Fig. 2. Water height in relation with tidal coefficients in Roscoff, France. Larger coefficients: water level will increase and decrease in a large range indicating a strong flow of water. Smaller coefficients: water level will increase and decrease in a small range indicating a weak flow of water. Increasing water level means the water move towards the English Channel (a) and decreasing water level means the water move away from the English Channel (b).

B. Tidal Estimation Following SHOM Model

While predicted tide coefficients are used by many users, prediction systems are only used by scientific departments, thanks to astronomic considerations known in advance. In France, prediction data are produced by SHOM. SHOM also provides algorithms allowing to compute strength according to discrete time and location.

Two basic measurements are needed for the estimation of the tidal current velocity [16]. The first data parameter is the spring water level H that will be needed for the evaluation of the tidal coefficient. It represents the difference between high and low tides. The second data parameter groups the spring and neap water current velocities, v_{sw} and v_{nw}, respectively. The data parameters are produced by SHOM depending on geographic locations. These data are formulated as tables communicated in CSV format. An example of the current data is shown in Fig. 3.

```
Roscoff
4843.628 -358.975
0 0 4 12 11 8 3 -6-11-11 -7 -1 0 * 0 0 0 -1 -1 -1 -1 0 0 1 -1 0 0
2 5 7 8 7 5 1 -5 -8 -7 -6 -4 -2 * 0 0 -1 -1 0 0 0 0 0 0 0 0 0
```

Fig. 3. Tidal current in one data point in Roscoff from SHOM.

Each data file includes a header for the reference shore name, followed by geographical coordinates then the surface vertical v and horizontal u components hour by hour. The first line is for spring water currents, the second line is for neap water currents. The data points are presented as colored dots in Fig. 4 grouping four overlapping systems with different grid paths. In the data, spring tides have a coefficient of 95 and neap tides have a coefficient of 45. Measures are taken hour by hour, from −6 hours to +6 hours in reference to the time in which occurs the tides in 0.1 knots. The u and v components are separated by an asterisk.

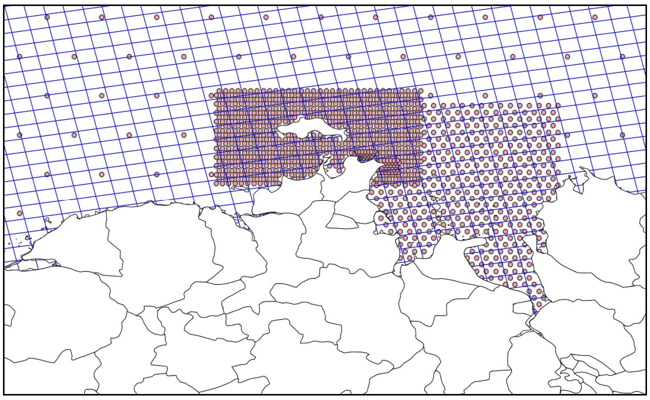


Fig. 4. Ocean tile versus ground layout: polygons on land and grid aligned on 1 km^2 in the ocean. Tidal currents are presented as data points depending on SHOM scales choice.

C. Formal Model as 2 Dimensional Vectors

The current velocity is calculated by equation 1 [4]. In which, a_0 is the tidal coefficient for neap tides (mean 45) and b_0 is the tidal coefficient for the spring tides (mean 95). The current direction is calculated by equation 2 also depending on the mean tidal coefficient of spring and neap tides.

$$v = v_{nw} + \frac{C - a_0}{b_0 - a_0}(v_{sw} - v_{nw}) \tag{1}$$

$$d = d_{nw} + \frac{C - a_0}{b_0 - a_0}(d_{sw} - d_{nw}) \tag{2}$$

where:

v: velocity in a place

$v_{nw} = \sqrt{u_{45}^2 + v_{45}^2}$: velocity in neap tides

$v_{sw} = \sqrt{u_{95}^2 + v_{95}^2}$: velocity in spring tides

C: coefficient in a time

d: current direction in a place

$d_{nw} = a\tan 2(u_{45}, v_{45}) * 180/\pi + 180$: velocity in neap tides

$d_{sw} = a\tan 2(u_{95}, v_{95}) * 180/\pi + 180$: velocity in spring tides

u_{45}, v_{45}: the horizontal and vertical components in coefficient 45 provided by SHOM

u_{95}, v_{95}: the horizontal and vertical components in coefficient 95 provided by SHOM

To model the impact of ground activities on marine pollution, we need to represent the two spaces in simulation systems. So, the sea area is segmented into regular tiles and the ground area into irregular cell spaces. Doing this way, the impact of the ground to sea can be represented by interactions between neighboring cells. The simulation systems are generated and used in experiments as described below.

IV. Tidal Current Simulation

A. System Generation

On land, geography divisions are used to query local values monitored in the territories (Fig. 5). In the ocean, the segmentation on the ocean is regular tiles with each cell having a size of 1 km^2 provided by the European Environment Agency [17]. For each country in the European Union, three types of vector polygon grid shape files for 1, 10, and 100 km^2, are available covering at least the country borders plus a 15 km buffer (not reflecting the extent of the territorial waters). As can be seen in Fig. 4, the 1 km^2 grid is different from the SHOM grid of currents. Thus, we use the nearest point interpolation method to estimate currents in the 1 km^2 grid. The ground and ocean segments are connected with channels carrying messages at an abstract level. Messages are the only way to exchange inside the neighborhood.

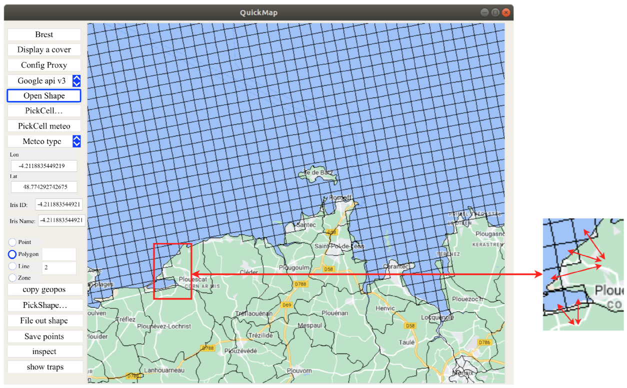


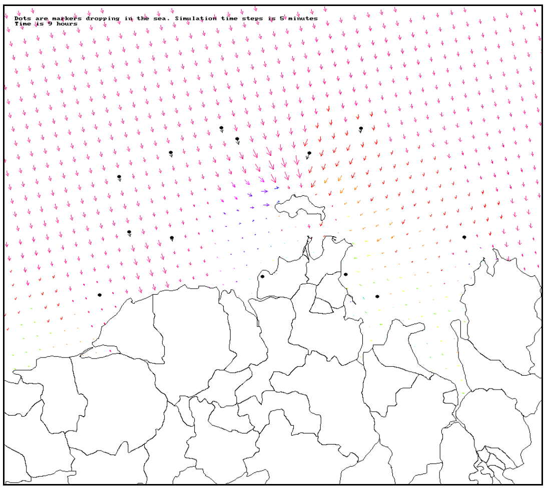
Fig. 5. Segmentation on ground and sea area. Irregular segments on ground as the administrative divisions by government and regular tiles on the ocean. UBO tools allow zooming and panning for zone selection and generating process systems in the selected zone.

Process systems are generated as the cooperation between irregular polygons in land and ocean tiles. This cooperation provides a new approach to environmental simulation, especially pollution on shores related to chemicals released from land. It produces a process system similar to Cellular Automata including polygons and a grid of 1 km^2. Each process interacts with other processes within the adjacent neighborhood. The simulation in coastal areas strongly depends on tidal currents. The initial conditions are tidal currents in tiles and local data collected on land. UBO tools allow to zoom and pan to select specific locations and generate cell systems with adjacent neighborhoods in the location depending on input shapefiles.

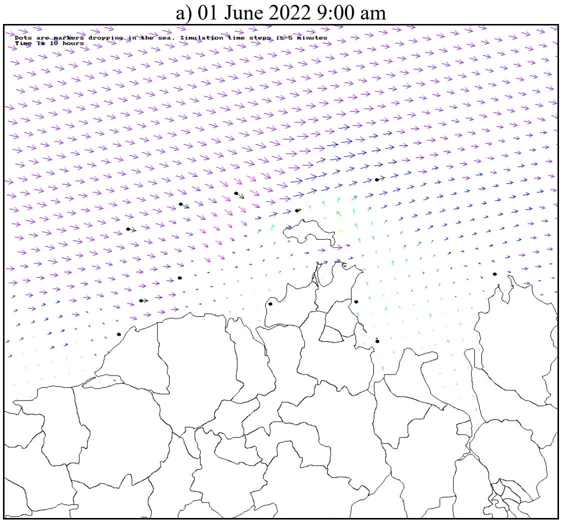
B. Water Circulation with Currents

Experiments are presented with a system consisting of 891 cells (with 854 grid cells). In Fig. 6, current directions are represented by arrows and current strengths are the length of arrows. The current direction and strength will be changed hourly with different tidal coefficients. In this case, we use tidal coefficients provided by SHOM in Roscoff harbor [18] in a period of 2 months, June and July 2022.

Water circulation is described by currents in a sea area. This is useful in monitoring marine pollution since water flow transports and spreads pollution in aquatic environments. In areas with limited water circulation, pollutants tend to accumulate and persist, leading to serious environmental and ecological consequences. Lack of water circulation promotes the accumulation of pollution, such as the growth of harmful algal blooms.



a) 01 June 2022 9:00 am



b) 01 June 2022 10:00 am

Fig. 6. Marker movement by currents. Current direction is represented by arrows and current strengths is the length of arrows. Notice the decreased current strength and the direction, reflecting orientation of the sea entering the English channel. Also notice the influence of Ils-de-batz on current direction.

As shown in Fig. 6(a), the global direction of the currents is southeast with flood currents (water moves toward the shore). After an hour, in Fig. 6(b), the global direction is changed along with the current strength. The figures reveal three retention zones with a lack of water circulation that can concentrate and retain pollution without being advected offshore by currents. These places show the need for regular monitoring to identify the potential sources of contamination. This is crucial to prevent the development of high pollutant concentrations in marine coastal waters.

C. *Monitoring Virtual Markers*

We monitor virtual markers moving in sea areas with currents. Following the cellular automata approach, the simulation is based on synchronous processes communicating over channels. These processes execute a single program operating on local data and messages representing neighbor interactions. Data are tidal currents considering geographical locations. A simulator fires all the cells in parallel, taking care of transports, cell to cell, whatever the nature of the transport. Simulation steps follow the physical application rate, and the necessity to cover large time periods.

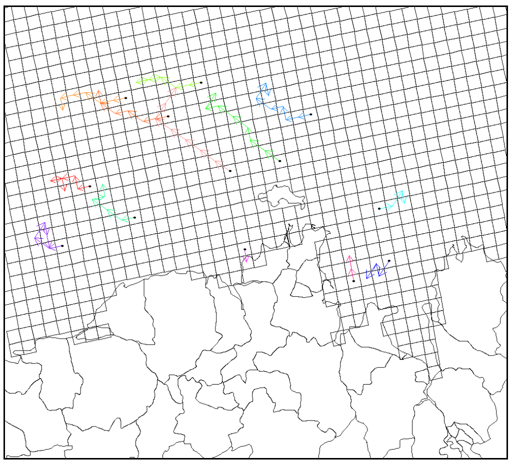
The maximum current strength reaches 7 knots (12.95 km/h) on Brittany shores, France. Thus, to catch the movement between cells in 1 km^2 (move 1 cell at most by each iteration), the simulation time step is 5 min. We drop virtual markers in the ocean area and monitor the movement of markers as shown in Fig. 6, where 13 markers are represented by black dots. The marker movement in grid cells is calculated by current speed and direction as shown in Algorithm 1.

Algorithm 1: Marker movement in grid cells

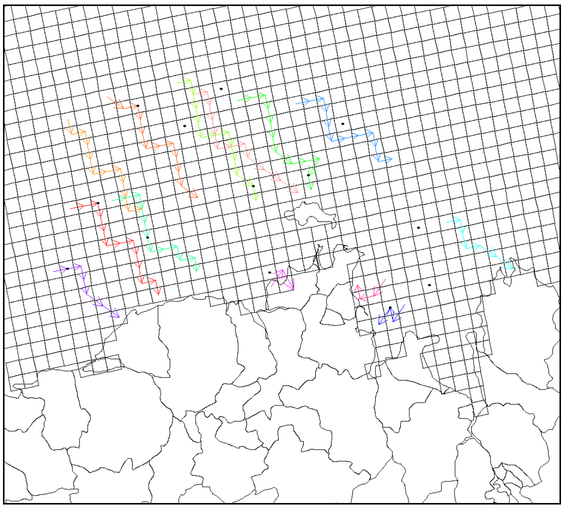
Initialize n markers in n random grid cells
if *This cell has a marker* **then**
    Calculate current speed;
    Calculate the marker position in this cell;
    if *marker position > 1 km* **then**
        Move marker to my neighbor;
    foreach *n: neighbors* **do**
        if *n move a marker to its neighbor* **then**
            Calculate n current direction;
            Calculate n current speed;
            //check moving by current direction
            if *n move a marker to this cell* **then**
                Update marker position in this cell; *//by current speed*
                Update marker identity for tracking;
end

It is possible to keep a history of visited places of each marker to track biological or physical alterations (Fig. 7). Fig. 7(c) shows the positions of markers after 4 days. It can be seen that there are loops in the direction of the markers. Some markers close to the coastal line cannot escape to the sea affected by flood and ebb currents. A clearer view is provided in Fig. 7(a) and 7(b). These figures show the marker movement in different places in the first 6 hours and the second 6 hours.

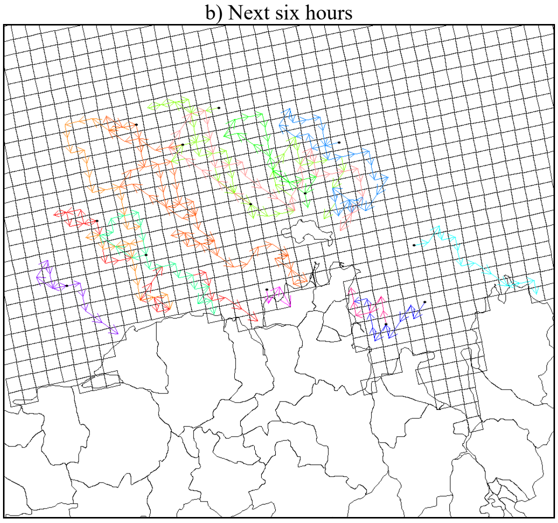
A subsystem in the simulation is that cells will have pipelines to slow down transfer objects internally. Transfers are achieved upon the agreement of the neighbors. Management of virtual markers in studied zones is similar to pollution accumulation on shore: with counting bags storing objects in excess. The local count represents the density of objects (pollution). This gives a potential way of monitoring the spatial and temporal distribution of marine buoyant plastics by providing the dynamics and pathways of how plastic waste moves in the sea area and enters the shores.



a) First six hours



b) Next six hours



c) Four days

Fig. 7. Marker positions after simulation with tidal currents showing loops in direction.

D. Monitoring Pollution Coverage Area

In the same space, green algae development can be monitored with the effect of currents. Ground information is coming from administrative data collection, with known timed samples of activities producing pollution. Colored polygons represented the area with nitrate concentration [19] on land as shown in Fig. 8. These polygons contain sources of pollution that propagate nutrients to coastal areas.

Nitrate is monitored in Brittany, France since 1995 as a parameter of water condition. In 2020, 718 stations were taken to evaluate nitrate concentrations (c) based on five classes: bad (c > 50 mg/L), poor (25 < c ≤ 50 mg/L), medium (0 < c ≤ 25 mg/L), good (2 < c ≤ 10 mg/L), and very good (c ≥ 2 mg/L). The limitation value is 50 mg/l used as an indication of bad water condition. The Brittany region is classified as a "vulnerable zone" with high nitrate concentration reported. Action programs have been initiated in these territories concerning balanced fertilization and good agricultural practices that must be respected. In agriculture, nitrates are essential plant nutrients, but in excess amounts, they have a negative impact on the water's quality. Together with phosphorus, nitrates in excess amounts can accelerate eutrophication causing a dramatic rise in aquatic plant growth as well as changes in the types of plants and animals that inhabit the stream.

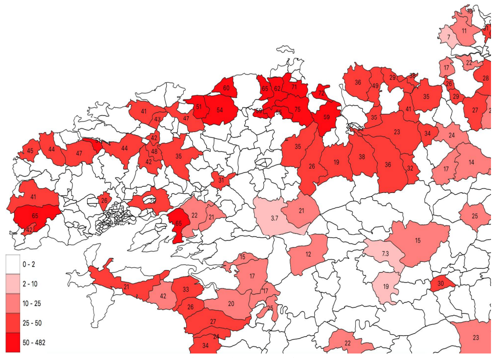
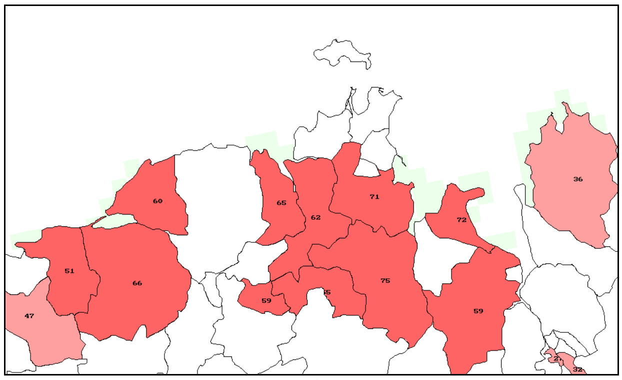
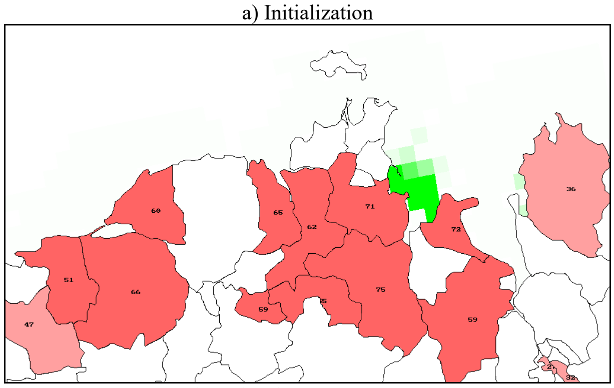


Fig. 8. Nitrate concentration values in North West Brittany, France in 2020. The values are presented inside polygons in mg/L units.

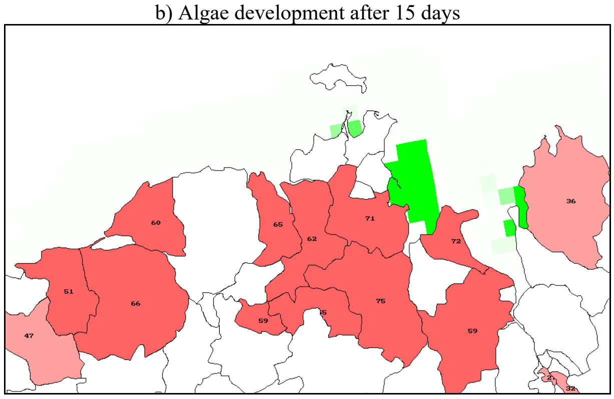
Fig. 9 shows the simulation of green algae development affected by currents. We initialize grid cells in the sea area with algae density (green color) in places close to colored polygons (Fig. 9 (a)). The interaction between grid cells is followed by a Moore neighborhood with a simple transition rule defined as in equation 3. The algae density is the growth rate and the density sending/receiving to/from its neighbors. Density transmission between cells is affected by current strength and current direction.



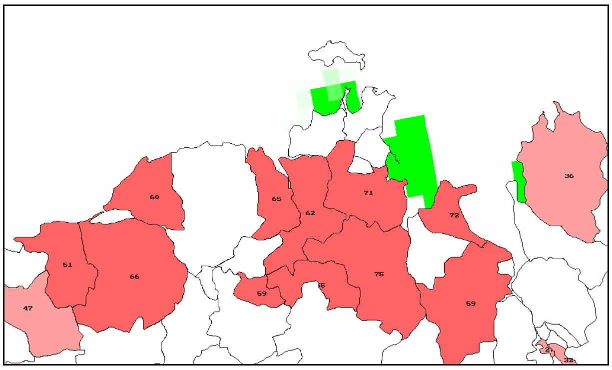
a) Initialization



b) Algae development after 15 days



c) Algae development after 40 days



d) Algae development after 55 days

Fig. 9. Green algae development affected by currents. Algae density is represented in green color. Initialize grid cells in sea area with algae density in places close to colored polygons, which are sources of pollution that propagate nutrients to coastal areas.

$$D_{t+1} = D_t + D_t * r - sum_{send} + sum_{receive} \tag{3}$$

where:

D_t: algae density in a cell at time step t

r: growth rate per day, in this simulation, it is 75% meaning 0.0026% per iteration of 5 minutes

sum_{send}: algae density sending to its neighbors calculated by Eq. 4

$sum_{receive}$: algae density receiving from its neighbors calculated by Eq. 5

$$sum_{send} = \frac{D_t * \sqrt{u_C^2 + v_C^2}}{100} \tag{4}$$

where:

u_C and v_C: tidal current of coefficient C represented by west-east and south-north components

Sending a part of its density depending on its current strength

$$sum_{receive} += D_i * {}^{v_i}\!/_{100} * \alpha \tag{5}$$

where:

D_i: algae density in cell neighbor i at time step t

v_i: current strength of cell neighbor i

α: a fraction receiving from neighbor i depending on its current direction with west-east and south-north components

As shown in Fig. 9(b), after 15 days, the algae density develops in the area near Saint-Pol-de-Leon whereas other beaches show less chance of growing green tides due to water circulation. The sea currents spread progressively algae to neighbor cells, especially in retention zones. A cell will send its algae density to its neighbors with a percentage depending on its current strength. It can send to at most three neighbors depending on its current direction with west-east and south-north components. After 40 days (Fig. 9(c)) and after 55 days (Fig. 9(d)), the algae density develops in the area near Roscoff.

The eutrophication phenomena are generally confined to large enclosed water systems. The nutrients are entrapped by tidal currents causing eutrophication phenomena. In open areas with suitable dilution factors and widespread dispersal, they would not give rise to eutrophication phenomena. The simulation results show three places with the possibility of algae development problems. Especially, the polygons in Roscoff do not contain sources of pollution that propagate nutrients to the sea area. Thus, it is important to simulate the pollution propagation with water flow to examine the pollution sources to have the correct and appropriate solutions.

V. Conclusion

Based on the cooperation between regular and irregular cell spaces, we show how to model a variety of pollution on shores. The green tides are discussed as the major reason for eutrophication accelerating by excess amounts of nitrates from agricultural runoff. Modeling ground activities can be done in two ways, simulation propagation of pollution sources on a 2D ground with elevation differences or querying observation data within administrative boundaries. Modeling ocean behaviors is done based on tidal currents in a regular grid of 1 km^2. An illustration of tidal currents is provided with marker movements in the coastal area near Roscoff, France. We also provide a simple model of green algae development in the effect of tidal currents with nitrate input sources in the same place. The simulation mechanism reveals risk from ground activities, with spatial and time characteristics. It can be used for a wide variety of accidental or systematic activities. This provides a general approach to model pollution on shores with currents showing water circulation in places suspected of pollution, which can be employed as a quick assessment tool for studying marine pollution issues. It is possible to test different scenarios by modifying the initial conditions and the transition function. One could track the pollution propagation over time given a source of pollution. Additionally, making the simulation accessible to policymakers will help support them in making decisions related to marine pollution prevention. Specifically, the marine areas vulnerable to pollution will need to be monitored more closely. Different coastal localities may have different safety indicators for pollutants due to differences in water circulation. Overall, it is important to manage ground activities in a way that reduces the inputs of nutrients and other pollutants into coastal waters and promotes the health and resilience of coastal ecosystems. The limitation side is that tidal currents need to be re-computed in different places with respect to the geographical locations and bathymetry. In addition, tidal currents showing water circulation are important in monitoring the shores however it is also important to take into account the effects of other parameters such as wind, waves, and water surface temperature. The random behavior of spreading pollutants on the surface of the sea is highly affected by wind and wave.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization and methodology were formulated by Bernard Pottier and Vincent Rodin. Trieu Thanh Ngoan conducted the research, analyzed the data, and wrote the drafted manuscript. Bernard Pottier designed two compatible systems for sensor networks (NetGen), then physical simulation (PickCell). These developments have supported international research initiatives funded by French foreign office. In the present work, he also shared a marine knowledge coming from his favorite recreative activity cruising and racing sailboats. Vincent Rodin, Bernard Pottier, and Hiep Xuan Huynh supervised the research, revised, and finalized the manuscript. All authors had approved the final version.

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