USING LAGRANGIAN ELEMENTS TO SIMULATE ALONGSHORE TRANSPORT OF HARMFUL ALGAL BLOOMS

M. Mateus • A. Silva • H. de Pablo • M. T. Moita • T. Quental • L. Pinto

CHAPTER SYNOPSIS

Background
Harmful Algal Blooms (HABs) therefore poses serious restrictions to the sustainable development of coastal areas and raises serious challenges to their management. From a management perspective, a major concern regarding HABs is the ability to predict where a bloom is likely to initiate, to be transported from its last known location and for how long it will persist. The assessment of potential impacted areas is crucial when there is a serious risk of contamination of marine resources, posing a threat to human health.

Results
The work described in this chapter focus on the transport and dispersion of HAB (post-bloom detection), and represents a critical step towards the development of an alarm system of impending HAB formation. Simulations described here start with a possible location for bloom initiation and describe its transport determined by surface currents, and the extent and location of the bloom. Model predictions are compared with field data from selected HAB events along the Portuguese coast.

Conclusions
The model simulations contained in this chapter illustrate the capability of the model to predict the bloom transport and dispersion. Also, the results showed here help to interpret field data and to test hypothesis regarding the epicentre of the blooms and the possible pathways of its transport along the coast.

1 HARMFUL ALGAL BLOOMS AND THEIR IMPLICATIONS

The base of aquatic food chains is composed by around 4000 species of phytoplankton. Some of these species are considered to be harmful because they have a potential negative impact on human health through the production of a range of potent natural biotoxins. As an example, the presence of Diarrhetic Shellfish Poisoning (DSP) toxins from *Dinophysis* spp. or Paralytic Shellfish Poisoning (PSP) in the case of *Gymnodinium catenatum* leads to prolonged shellfish closures for periods that can last for several weeks in Portugal, Spain, France and Ireland [1, 2]. This also means that these episodes have a detrimental effect on the economy through their negative impact on fish or shellfish farming or other human use of ecosystem services.

Harmful Algal Blooms (HABs) therefore poses serious restrictions to the sustainable development of coastal areas and raises serious challenges to their management. It is difficult to forecast HAB initiation. Nevertheless, predicting and monitoring HABs is a fundamental step to develop proactive strategies to ameliorate their impact on human health and the economics of coastal communities. From a management perspective, a major concern regarding HABs is the ability to predict where a bloom is likely to initiate, to be transported from its last known location and for how long it will persist. The assessment of potentially impacted areas is crucial when there is a serious risk of contamination of marine resources, posing a threat to human health.

Current blooms locations, future bloom locations, and areas of impacts are critical components of a forecast system. The work described in this chapter focus on the transport and dispersion of HAB (post-bloom detection), and represents a critical step towards the development of an alarm system of impending HAB occurrences. Simulations described here start with a possible location for bloom initiation and describe its transport determined by surface currents, and the extent and location of the bloom. Model predictions are compared with field data from selected HAB events along the Portuguese coast.

2 KEY EVENTS AND OBSERVATIONS

The in-situ data are from the National Monitoring Program of HABs, held by the phytoplankton laboratory of IPMA - IPIMAR. Several nearshore stations along the Portuguese coast are weekly sampled throughout the year. A number of HAB events that occurred along the west and south coasts of Portugal have been selected for the model simulations based on 2 main criteria: (1) Availability of field data (raw data, processed data, published data, etc.) to allow a proper synoptic description of the bloom, and relevance of the blooms (magnitude, impact or other relevant aspects); (2) Availability of data for model forcing.

Despite the significant number of HAB episodes that could be used in the modelling exercises, the availability of data to force the regional model imposed restrictions on the time window. Simulations were made in hindcast mode of the PCOMS model [3], and given that the model runs since the beginning of 2009, all simulations correspond to events from 2009 onwards. Four HAB episodes in the Portuguese coast have been selected for the modelling simulations, two on the west coast and two on the south coast (Figure 1).

- A bloom of *Gymnodinium catenatum* that occurred in summer 2009 in the northwest coast;
- A bloom of *Dinophysis acuminata* that took place in the northwest coast during spring 2011;
- A bloom of *Ostreopsis ovata* that occurred in the south coast in late summer 2011;
- A bloom of *Pseudo-nitzschia* spp. that occurred in the south coast in spring 2012.

A summary of these events, along with the dates and probable location of their origin is presented in Table 1, and the main geographic location of the study areas is found in Figure 1.

2.1 *Gymnodinium catenatum* blooms

Inshore concentration on *G. catenatum* blooms depends on the cross shelf transport by upwelling and the transport velocity of the blooms seems to be lower than the driving currents. Bloom initiation and development apparently depends on a minimal concentration of cells ($> 10^3$ cells L^{-1}). Temporal fluctuations in *G. catenatum* concentration follow the upwelling-downwelling events.

Gymnodinium catenatum blooms were absent from the Portuguese coast for a decade (1996-2004) being the last major blooms recorded between 1985 and 1994, from August to November. In early September 2005, in Lisbon Bay, a bloom of this species initiated. There was a progressive increase in the concentrations northward, reaching the Galician rias in November [4]. The northward shift of the population was related to the northward surface flow that develops at the end of the upwelling season [5]. In late November/early December, *G. catenatum* reached a maximum concentration (43×10^3 cells L^{-1}) on the Aveiro coast and lasted in northern Portuguese waters until January 2006.

The northward propagation of the bloom, based on densities of cells above 10^3 cells L^{-1} observed along time on the NW coast monitoring stations, was calculated to be ~ 0.06 m s^{-1}, about one order of magnitude lower than velocities (0.2 - 0.6 m s^{-1}) from a northward coastal current observed at the same time off the Galician rias and obtained from a lagrangian drifter (NOAA/Coast Watch) [6]. In subsequent years these events initiate elsewhere and expanded further south.

2.2 *Dinophysis acuminata* blooms

Dinophysis acuminata blooms are normally associated with buoyant plumes of lower salinity. A major bloom occurred in 2011 from mid-June to the end of July at the NW coast of Portugal, with an epicentre in Galicia (SP), and progressing towards south until Aveiro (PT). Maximum values observed at Espinho (PT) from 11 - 17 July.

2.3 *Ostreopsis ovata* blooms

Ostreopsis spp. is a subtropical epibenthic genus that bloomed at the south coast of Portugal (Algarve) for the first time in September 2011 [7]. The bloom was spotted in the shallow waters of D. Ana beach (Lagos coast) due to the presence of mucilaginous filaments at the surface. Cells normally proliferate forming a thin pellicle that covers the substrate and cell aggregates are normally released in the water column after events of increasing hydrodynamic regime (waves, currents). The bloom progressed towards W along the coast.

2.4 *Pseudo-nitzschia* spp. blooms

The ubiquitous pennate diatom genus *Pseudo-nitzschia* was associated with a major outbreak in the south coast of Portugal, in May 2012 with two possible origin scenarios (Lagos or Olhão coasts). The genus is composed of roughly 20 species [8], a number of which are responsible for the production of the neurotoxin, domoic acid (DA) and the associated Amnesic Shellfish Poisoning (ASP). These events give to the genus worldwide environmental, economic and human health importance. This particular event in 2012 persisted for 3 weeks and was responsible for shellfish closures for DA contamination during one week before cells decreased in the water.

On the Portuguese coast, blooms of *Pseudo-nitzschia* are recurrent events during spring-summer upwelling episodes, but only after 1995, ASP episodes were associated with the presence of the DA producer *Pseudo-nitzschia australis* [9]. A statistical model developed to connect the physical variables UI and Sea Surface Temperature (SST) with *Pseudo-nitzschia* concentration in Lisbon Bay [10], showed for the west coast an upwelling index limited to be less than 1000 $m^3\ s^{-1}\ km^{-1}$ (north winds <8 m s^{-1}) for bloom maintenance and development. Stronger upwelling events did not contribute to increase phytoplankton concentrations since high turbulence conditions seem to promote the dispersion of cells. The model placed *Pseudo-nitzschia* in the second step of the phytoplankton succession, after 4 - 6 days of the intensification of the upwelling event.

3 MODELLING APPROACH

3.1 Model characteristics, implementation and validation

The model used in this operational platform for west Iberia is the MOHID model (see http://www.mendeley.com/profiles/mohid-water-modelling-system for a long list of references), which is an open-source geophysical regional circulation model anchored at MARETEC, a research group in Instituto Superior Técnico, Portugal. A full description of model characteristics, setup of the model implementation and validation is presented elsewhere [3] and will be avoided here.

3.2 Particle tracking model

The methodology followed in this study to model HAB dispersion and transport is similar to the methodology presented in [11]. The modelling approach requires the input of one or several polygons in the form of a series of points called Lagrangian Elements (LE) to be moved through time and space. The LE particles have passive transport and are moved around in two dimensions (x and y) according to local current fields pre-calculated by the hydrodynamic model. The LE is used in an offline coupling in which the hydrodynamic simulation output is first saved and then used (by reading in) to drive the particles kinetics. A major benefit of the offline linkage approach is the ability to utilize previously computed hydrodynamic solutions.

Surface currents from the hydrodynamic model are used to estimate the likely trajectory of the LE in two dimensions without any additional input from the wind. Biotic factors were not considered in the particle-tracking simulations.

3.3 Simulated scenarios

The modelled scenarios were selected based on available information, as described previously. Also, as already mentioned, the scenarios try to simulate the transport and extent of the HAB based on an origin that is assumed to be known, or define hypothetical locations as the bloom origin. Regardless of the origin (known or hypothetical), model predictions are used to test it.

Table 1 provides information on the origin of the bloom for the simulations, as well as the starting date for all tested scenarios. Simulations are arranged in a way to be grouped by species, and the results from the hindcast will be presented according to this arrangement. The location of each site along the Portuguese coast can be seen in Figure 1.

Scenarios GC–N1 and GC–N2 address the same bloom event and aim at identifying a possible origin for a *G. catenatum* bloom. For *D. acuminata* the same applies to scenarios DA–N1 and DA–N2 that simulate a bloom of this species with the same origin in the NW coast of Iberia, but with different starting dates. For the *Ostreopsis ovata* bloom only one scenario is presented (O–S1) corresponding to the geographic location and time when the bloom was first spotted in routine monitoring analysis of HABs. Finally, *Pseudo-nitzschia* spp. bloom in the south coast of Portugal presented two possible origins for the event, PN–S1 and PN–S2.

Table 1. *Modelled scenarios for HAB events hindcast runs.*

Year	Species	Scenario	Box # (Fig. 1)	Origin	Date
2009	*Gymnodinium catenatum*	GC – N1	2	Aguda/Porto	6 Sep2009
		GC – N2	2	Vagueira	6 Sep 2009
2011	*Dinophysis acuminata*	DA – N1	1	Galicia	29 Jun 2011
		DA – N2	1	Galicia	6 Jul 2011
	Ostreopsis ovata	O – S1	3	Praia D. Ana (Lagos)	20 Sep 2011
2012	*Pseudo-nitzschia* spp.	PN – S1	3	Lagos	23 May 2012
		PN – S2	3	Olhão	23 May 2012

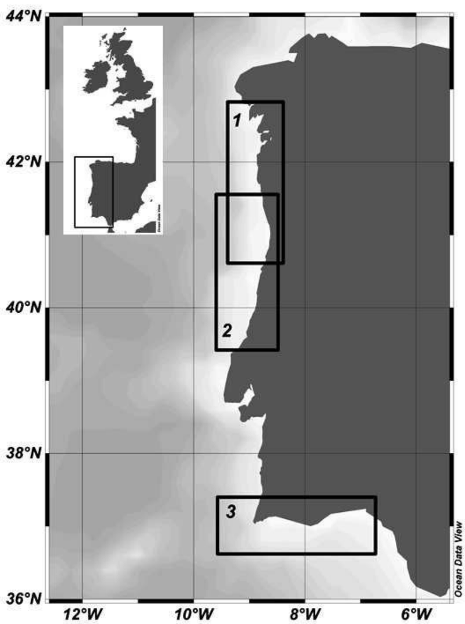

Figure 1. *Model domain of the MOHID-PCOMS model used in the hindcast simulations. Specific areas of modelled HAB transport episodes comprehend the Galician coast, Spain, and the north-western Portuguese coast (1), the NW Portuguese coast (2), and the Algarve on the south coast of Portugal (3).*

4 MODEL RESULTS

4.1 *Gymnodinium catenatum* bloom simulations

Two scenarios were simulated for the NW coast bloom (GC–N1 and GC–N2), corresponding to two distinct origins and initiation date. In the first scenario (GC–N1), the bloom is assumed to start in Aguda beach, NW coast (Figure 2, Table 1).

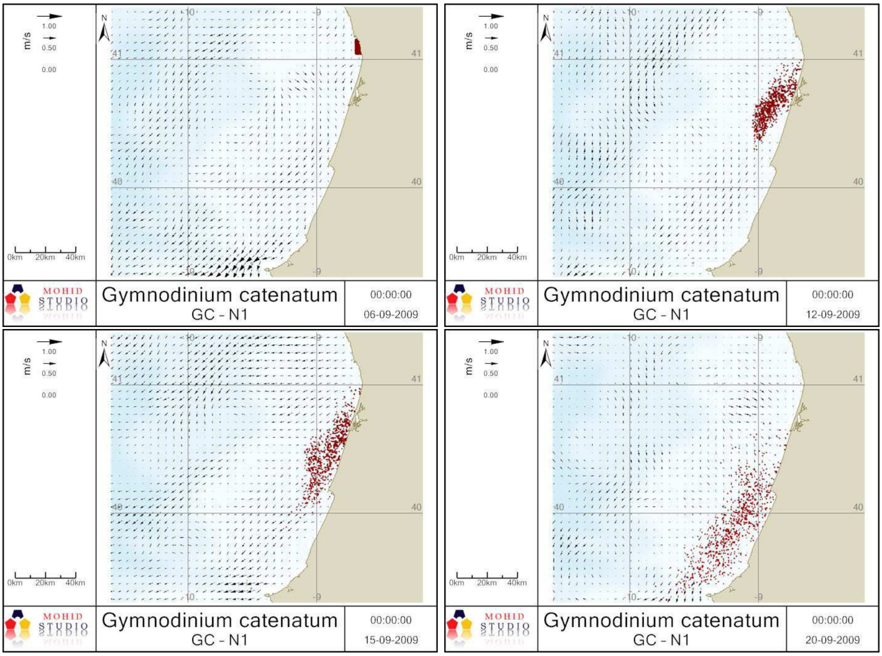

Figure 2. *Transport of the G. catenatum bloom with an origin in the Aguda area (scenario GC-N1).*

From the beginning of the simulation it is possible to see that the particles are transported south with the higher density of particles progressing off the coast. In situ data showed that the bloom seems to have started in Aguda (GC–N1) between 24-30 August (1500 cells L^{-1}). An increased in cell concentrations begin to be observed nearshore Aveiro between 31/08 and 06/09 to reach maxima of 54 - 63×10^3 cells L^{-1} one-two weeks later (14-20/09) as also seen in the model image of 19/09 (Figure 4). The presence of the species was still observed further south in the subsequent days, as visible through the small amount of particles in the Vagueira beach and South from there.

In this event the model was able to reproduce the timing of the bloom transport along the coast, after its start in the Aguda/Oporto area. The results supported the idea of an epicenter located in this area, from which the blooms was transported south.

Results for the scenario GC–N2 (Figure 3, Figure 4) didn't compared well with field data, since the hypothesis tested in this simulation could not explain the in situ values. As such, the origin of the bloom in this scenario was ruled out.

4.2 *Dinophysis acuminata* bloom simulations

Two scenarios were simulated for *D. acuminata* blooms in the northwestern coast (DA–N1 and DA–N2). Both simulations assume the same bloom origin (Galicia), but with different starting dates. These simulations intended to explain the 5000 cells L^{-1} that were observed in the monitoring station of Espinho (NW coast) from 11 to 17 July 2011.

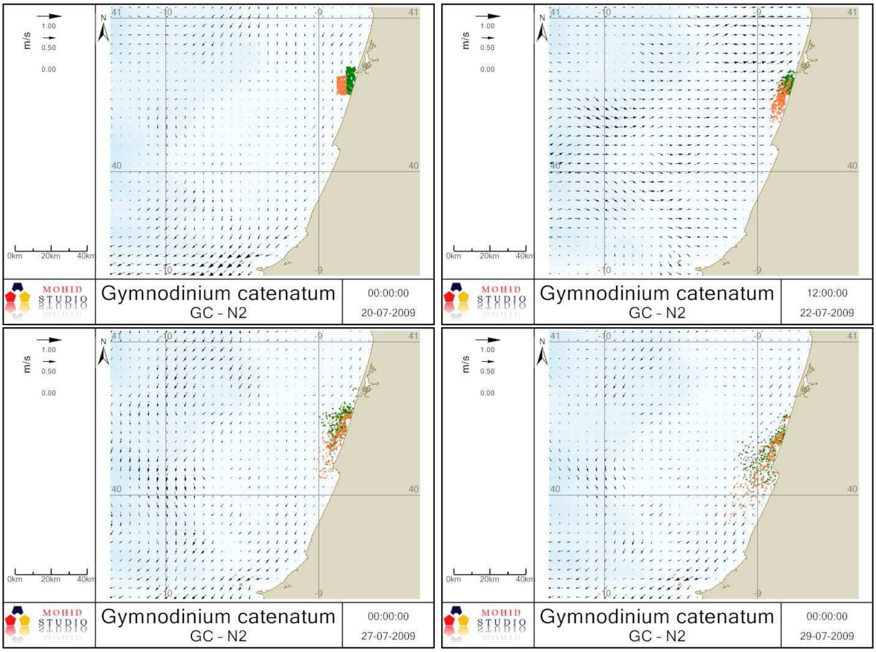

Figure 3. *Transport of the G. catenatum bloom with an origin in the Vagueira area (scenario GC-N2). Particles with distinct colors are used to differentiate the path of particles with different origins.*

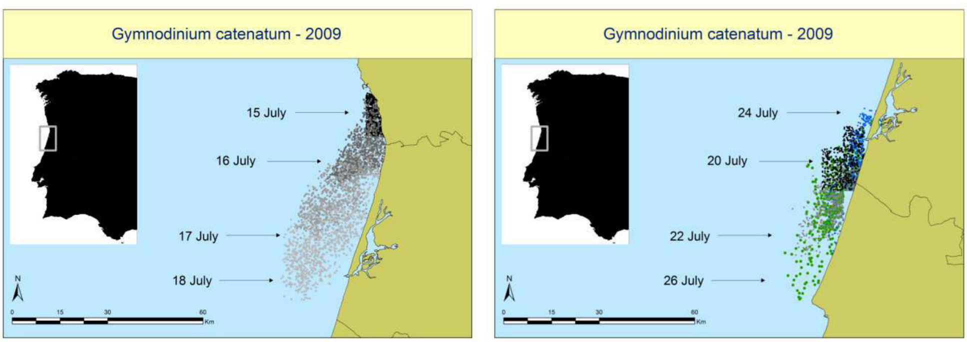

Figure 4. *Summary of model simulations (scenario GC-N1 and GC-N2) for the dispersion of a Gymnodinium catenatum bloom in 2009. Simulations differ in the timing and location of possible bloom formation.*

In both scenarios the bloom is transported southward from its origin, as a direct influence of surface currents induced by the northerly winds that predominate during this period of the year. There is, however, a significant difference between the scenarios, namely the position of the particles during the transport. As it is possible to see in Figure 5, the bloom initiated by the end of June has an initial transport to N for the first two days, and then it is transported south. The initial deflection towards N transports the bloom offshore an then south, in this scenario only a small fraction of the particles actually reach the coast. The monitoring weekly sampling could not corroborate this scenario.

In the second scenario (DA–N2) the hydrodynamic conditions traps the bloom against the coast line where it stays throughout the subsequent transport southward (Figure 6). The particles are transported along the Portuguese NW coast and reach Aveiro area by 13 July, when 260 cells L^{-1} were observed in the water. Espinho is further south and the simulation show particles in this area around 15 July, what can be confirmed by the in-situ data. This scenario seems to explain the origin of the cells hypothesized above.

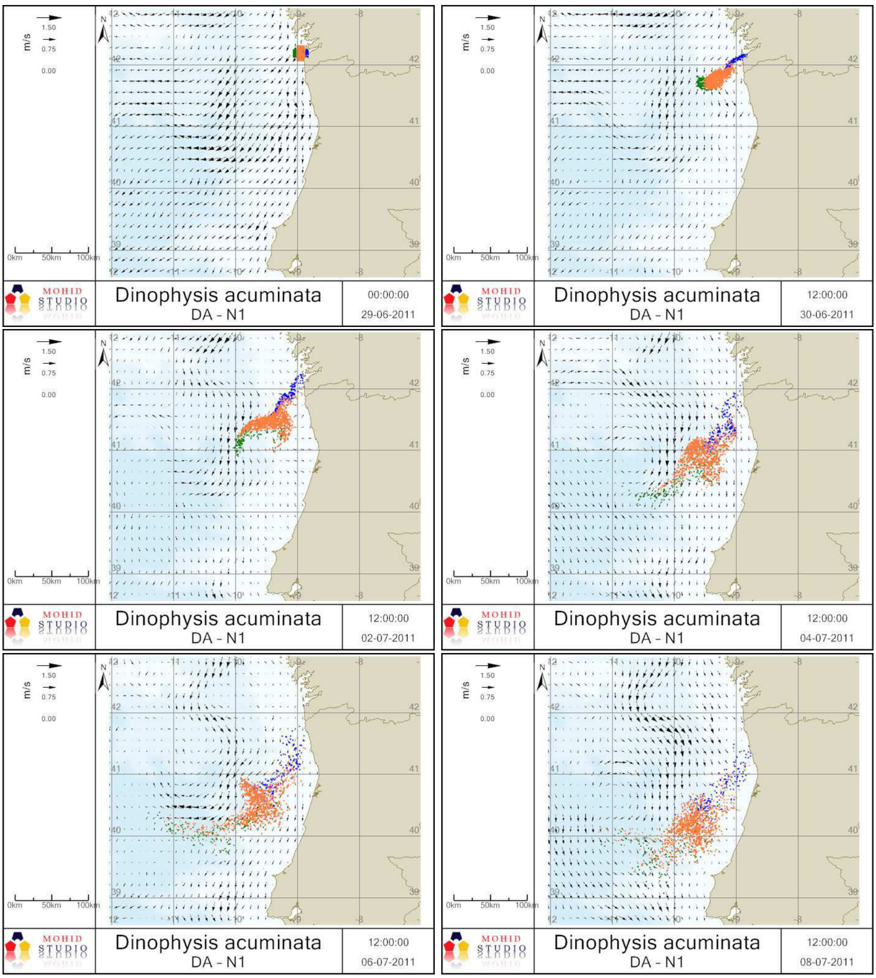

Figure 5. *Time series for the D. acuminata bloom with an origin in the Galician coast, Spain (scenario DA-N1).*

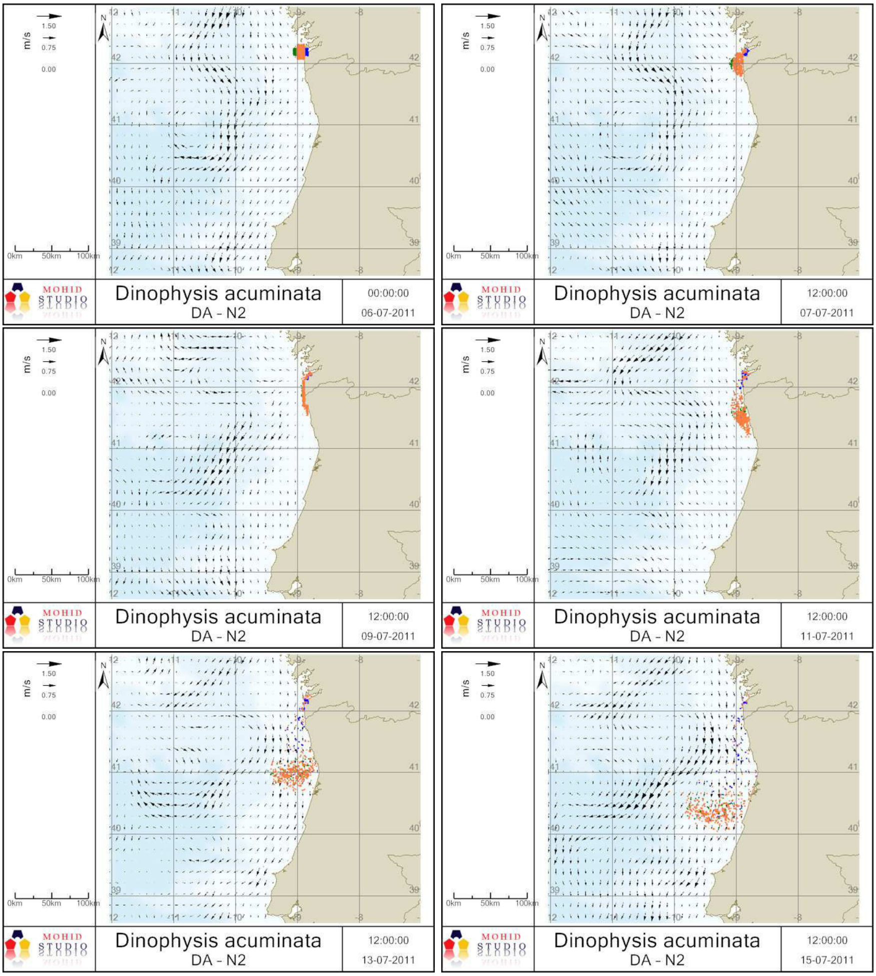

Figure 6. *Time series for the D. acuminata bloom with an origin in the Galician coast, Spain (scenario DA-N2).*

4.3 *Ostreopsis ovata* bloom simulations

The bloom was spotted for the first time in 20 of September 2011 at D. Ana beach (Lagos coast) due to the presence of mucilaginous filaments at the surface of the water. Thus, in the simulation is assumed that the origin of the bloom is the D. Ana beach (Figure 7; Figure 3, box 3). To understand the progress of the bloom, a period of 5 days of simulation, between 20 September (12.00 h) and 25 September 2011 (00.00 h), is performed (O-S1).

The analysis of the simulation results show that the bloom progress is strongly influenced by the surface currents in the area. During the period simulated the direction of the currents varied between W and SW with a maximum velocity of $\sim$1.5 m s^{-1}. During the two first days due to the relatively weak currents predominantly to W a dispersion of the bloom along the coast is observed. In two days, the bloom was transported around 10 Km W. On the third day the currents change direction to SW promoting the dispersion of the bloom offshore and to W, and the same pattern is observed until September 24th. At the end of the period simulated the bloom was dispersed along the coast to W and off the coast to a distance of about 15 km (Figure 7). Additional details on this bloom can be found in [7].

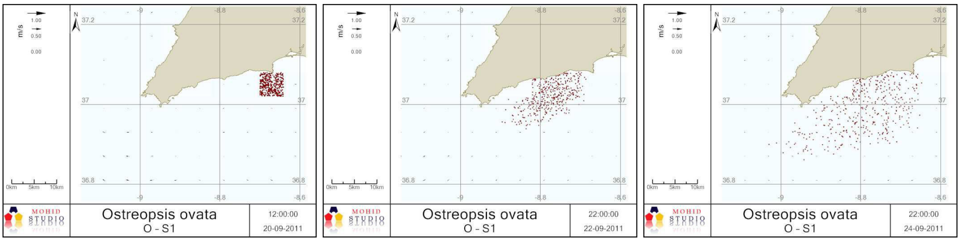

Figure 7. *Time series for the Ostreopsis ovata bloom event. Snapshots for the initial instant, t = 2 days and t = 5 days (scenario O-S1).*

4.4 ***Pseudo-nitzschia*** **spp. bloom simulations**

Two simulations were setup for the *Pseudo-nitzschia* bloom, both with the same starting date but with different origins. The hypothesis consists of 2 multi-specific blooms whose evolution in simultaneous produced different species peaking on the W and E sides of the Faro promontory. The model confirmed that the two populations did not overlap. The circulation pattern at the surface during the simulated period is dominated by an eastward flow. However, some inflections in the direction do occur in result to the shift in the wind direction. As observed in the results (Figure 8 and Figure 9), the different origins in the bloom led to a rather different scenario in the dispersion and in the potential impacted areas.

In the first scenario (PN–S1, Figure 8) the bloom disperses but stays confined to an area off Lagos (origin) between 23 and 27 May, reaching 17×10^3 cells L^{-1}. From 28 May onwards the blooms spreads and was transported to east along the coast, with a maximum concentration of 90×10^3 cells L^{-1} (30/05 in Armação de Pêra). After a 10-days period the bloom is widely spread along the southern coast and covering a large area both onshore and offshore.

The second scenario, PN–S2 shows a striking different transport and dispersion pattern of the particles, seen in Figure 9. As the simulation begins (in situ cells at 28/05/12, were 47×10^3 per liter), part of the cells remained in the area until 06/06/12, reaching 293×10^3 cells L^{-1} while according to the model, a growing number of particles are further transported away from the coast into open ocean by a jet consisting of deflection of the eastward current along because of the Ria Formosa promontory.

5 CONCLUDING REMARKS

Even a rudimentary forecast system can be useful and could be used as a baseline for future improvements [11, 12]. Once a feature or algal bloom has been identified in imagery or field data, it enables to track bloom position, thus compensating for missing imagery, and creating a nowcast and forecast for potential impacted areas. The model simulations contained in this chapter illustrate the capability of the model to predict the bloom transport and dispersion.

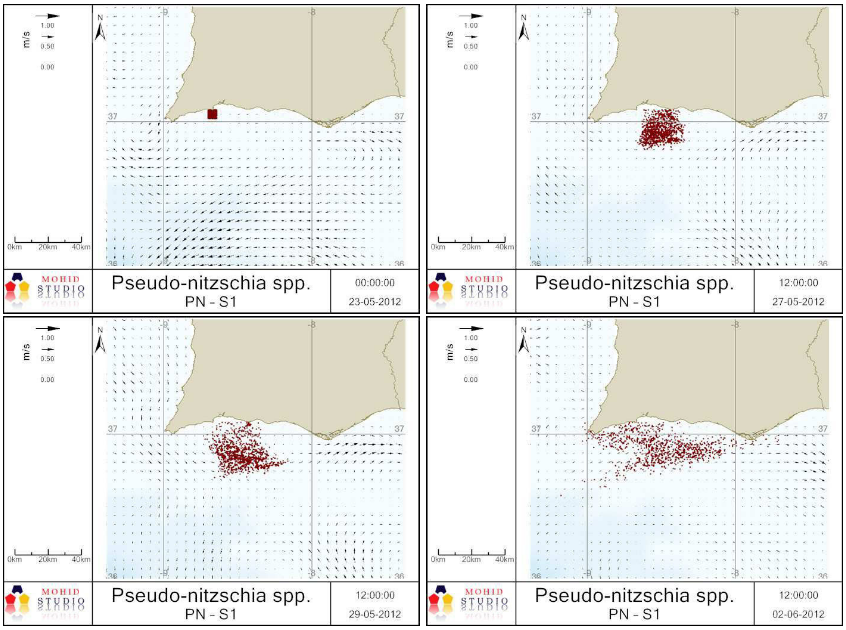

Figure 8. *Time series for the Pseudo-nitzschia spp. bloom with an origin in Lagos (scenario PN-S1).*

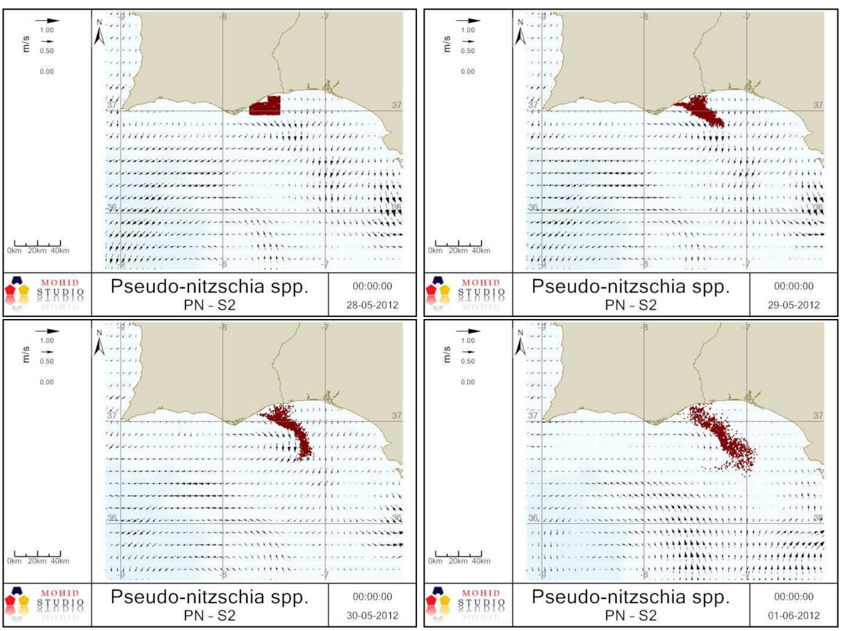

Figure 9. *Time series for Pseudo-nitzschia spp. bloom with an origin in Olhão (scenario PN-S2).*

Also, the results showed here help to interpret field data and to test hypothesis regarding the epicentre of the blooms and the possible pathways of its transport along the coast. While relaying only in physical transport simulations, the use of LE provides significant information on the fate of a specific bloom. In most cases, given the limitation of data, this modelling approach can offer the only way to track the dispersion pathways of a bloom after being spotted by in situ data. This might be the case of blooms occurring in thin-layers such as *Dinophysis* and *Pseudo-nitzschia* which are frequently associated with the pycnocline or nutricline [13, 14], thus impossible to track by remote sensing.

Model validation is a fundamental step in any modelling exercise and vital to determine model behaviour and to identify needed improvements. The skill assessment of the operational forecasts depends on the ability of the model to forecast conditions at an appropriate time and space resolution. As far as the work presented here goes, the only undertaken validation of the modelling forcing data was by comparing the skin temperature of the model with remote sensing data, and by a qualitative evaluation of the surface current fields. In this study there is a limitation imposed by the lack of field physical data and its coarse resolution near shore, not allowing further simulations of small scale features such as the presence of counter-currents or the patchy distribution of phytoplankton.

Although the present results can simulate major surface current patterns adequately, the 6 km resolution may impose serious limitations to simulate the dispersion and transport in the proximity of land. This limitation points to the need of having high-resolution subdomains nested in the actual solution, especially in areas where HAB have, historically, a relevant impact. However, after being tested with weekly HAB monitoring data, the model was able to simulate events with larger space scales helping to understand the dispersion processes in some HAB episodes that occurred in the Portuguese coast, and to test some hypothesis regarding their epicenter and transport (e.g., alongshore transport of *Dinophysis acuminata* at the Algarve coast in 2011). The model helped in real time decisions at smaller scales, when simulations were performed in a forecast mode to predict the impact areas during the first *Ostreopsis ovata* event in the south coast of Portugal (September 2011).

6 FUTURE DEVELOPMENTS OF THE MODEL

Current blooms locations, future bloom locations, and areas of impacts are critical components of a forecast system. The modelling approach presented in this study shows that models are essential tools to predict bloom transport and help in the identification of potentially impacted areas along the coast.

Validation and skill assessment are vital to forecasting, not only to determine model behaviour, but also to identify needed improvements. Similar studies point that systematic sampling is decisive for model validation, even when using qualitative descriptors [15].

The next steps in the modelling efforts towards a HAB forecast capability will be:

- Devise a validation scheme for the LE simulations;
- Assess the need for higher spatial resolution on some areas of the Portuguese coast, in particular neashore by incorporating small scale features in order to accurately simulate patchy type distributions and alongshore transport;

- Include ecological processes in the model simulations. Chlorophyll fields from remote sending data will then be used to identify transport and intensification of particular blooms, and to validate the model;
- Focus on a particular species and try to reproduce the main ecological features in an attempt to determine the conditions for bloom initiation and growth.

ACKNOWLEDGEMENTS

This work was developed in the research project ASIMUTH – Applied Simulations and Integrated Modelling for the Understanding of Toxic and Harmful Algal Blooms, supported by the EC FP7 Programme, Space Theme (Grant Agreement No. 261860). The first author of this work is supported by the Portuguese Science Foundation program Ciência2008. The second author of this work is supported by an FCT grant SFRH/BPD/63106/2009. We are thankful to all colleagues that have been contributing to the phytoplankton analysis of the National Monitoring Plan of HABs.

REFERENCES

1. Escalera, L., B. Reguera, Y. Pazos, A. Morono, and J.M. Cabanas, Are different species of Dinophysis selected by climatological conditions? African Journal of Marine Science, 2006. 28(2): p. 283-288.
2. Trainer, V.L., G.C. Pitcher, B. Reguera, and T.J. Smayda, The distribution and impacts of harmful algal bloom species in eastern boundary upwelling systems. Progress in Oceanography, 2010. 85(1-2): p. 33-52.
3. Mateus, M., G. Riflet, P. Chambel, L. Fernandes, R. Fernandes, M. Juliano, F. Campuzano, H. de Pablo, and R. Neves, An operational model for the West Iberian coast: products and services. Ocean Science, 2012. 8(4): p. 713-732.
4. Pitcher, G.C., F.G. Figueiras, B.M. Hickey, and M.T. Moita, The physical oceanography of upwelling systems and the development of harmful algal blooms. Progress in Oceanography, 2010. 85(1-2): p. 5-32.
5. Moita, M.T., S. Palma, P.B. Oliveira, T. Vidal, S. A., and G. Vilarinho, The return of Gymnodinium catenatum after 10 years: bloom initiation and transport off the Portuguese coast, in Poster nº PO.06-14 on XII International conference on HABs2006.
6. Pazos, Y., Á. Moroño, J. Triñanes, M. Doval, P. Montero, and M.G. Vilarinho, Early detection and intensive monitoring during an unusual toxic bloom of Gymnodinium catenatum advected into the Galician Rías (NW, Spain), in Painel nº PO.13-53, 12th International Conference on HABs2006: Copenhagen.
7. David, H., A. Laza-Martínez, E. Orive, A. Silva, M.T. Moita, M. Mateus, and H. de Pablo, First bloom of Ostreopsis cf. ovata in the continental Portuguese coast. Harmful Algae News, 2012. 45: p. 12-13.
8. Lundholm, N., N. Daugbjerg, and Ø. Moestrup, Phylogeny of the Bacillariaceae with emphasis on the genus Pseudo-nitzschia (Bacillariophyceae) based on partial LSU rDNA. European Journal of Phycology, 2002. 37(1): p. 115-134.
9. Vale, P. and M.A.M. Sampayo, Domoic acid in Portuguese shellfish and fish. Toxicon, 2001. 39(6): p. 893-904.
10. Palma, S., H. Mouriño, A. Silva, M.I. Barão, and M.T. Moita, Can Pseudo-nitzschia blooms be modeled by coastal upwelling in Lisbon Bay? Harmful Algae, 2010. 9(3): p. 294-303.
11. Wynne, T.T., R.P. Stumpf, M.C. Tomlinson, D.J. Schwab, G.Y. Watabayashi, and J.D. Christensen, Estimating cyanobacterial bloom transport by coupling remotely sensed imagery and a hydrodynamic model. Ecological Applications, 2011. 21(7): p. 2709-2721.
12. Velo-Suárez, L., B. Reguera, S. González-Gil, M. Lunven, P. Lazure, E. Nézan, and P. Gentien, Application of a 3D Lagrangian model to explain the decline of a Dinophysis acuminata bloom in the Bay of Biscay. Journal of Marine Systems, 2010. 83: p. 242-252.

13. Moita, M.T., L. Sobrinho-Goncalves, P.B. Oliveira, S. Palma, and M. Falcao, A bloom of Dinophysis acuta in a thin layer off north-west Portugal. African Journal of Marine Science, 2006. 28(2): p. 265-269.
14. Suárez, V., S. González-Gil, P. Gentien, M. Lunven, C. Bechemin, L. Fernand, R. Raine, and B. Reguera, Thin layers of Pseudo-nitzschia spp. and the fate of Dinophysis acuminata during an upwelling-downwelling cycle in a Galician Ría. Limnology and Oceanography, 2008. 53(5): p. 1816-1834.
15. Stumpf, R.P., M.C. Tomlinson, J.A. Calkins, B. Kirkpatrick, K. Fisher, K. Nierenberg, R. Currier, and T.T. Wynne, Skill assessment for an operational algal bloom forecast system. J Mar Syst, 2009. 76(1-2): p. 151-161.