Improving the preparedness against an oil spill: Evaluation of the influence of environmental parameters on the operability of unmanned vehicles

A.M. Bernabeu a,⁎, M. Plaza-Morlote a, D. Rey a, M. Almeida b, A. Dias c,d, A.P. Mucha b,e

a Centro de Investigación Marína, Universidade de Vigo, GEOMA, 36310 Vigo, Spain
b CIMAR - Interdisciplinary Centre of Marine and Environmental Research, University of Porto, Terminal de Cruezeiros do Porto de Leixões, Av. General Norton de Matos s/n, 4450-208 Matosinhos, Portugal
c INESC Technology and Science, Porto, Portugal
d ISEP - School of Engineering of Porto Polytechnic Institute, Porto, Portugal
e FCUP - Faculty of Sciences, University of Porto, Rua do Campo Alegre, s/n, 4169-007 Porto, Portugal

ARTICLE INFO

Keywords:
Unmanned and autonomous vehicles
Oil spills
Operational conditions
Wind speed
Wave height
Wave period
SpilLess

ABSTRACT

When an oil spill occurs, a prompt response reduces significantly the impact. The preparedness and contingency plans are essential to identify the most appropriate technologies. Unmanned and autonomous vehicles (UAVs) is emerging as a powerful tool of strategic potential in the observation, oil tracking and damage assessment of an oil spill.

The SpilLess project explored the suitability of these devices to be the first-line response to an oil spill. This work analyses the operational requirements related to environmental parameters following a two steps approach: 1) Environmental characterization from long wind and waves time series and modelling; 2) Definition of the optimal periods for operating each UAVs.

We have defined the periods in which each of these facilities acts best, confirming that the operational limits of UAVs are not significantly more restrictive than the traditional operations. UAVs should be included in contingency plans as available tools to fight against oil spills.

1. Introduction

Oil spills frequently coincide with storm events that lead to shipping accidents. Under these conditions, the spilled oil quickly spread, emulsify and form tar balls. A prompt response is necessary to reduce the environmental impact (Chen et al., 2019). Therefore, the development of preparedness and contingency plans is essential. Those plans must ensure a timely and effective response (Burns et al., 2002; Carson et al., 2004; Eide et al., 2007; Turner et al., 2010).

One of the important aspects that are developed in a preparedness and contingency plan is the identification of the most appropriate technologies according to the situation. The mechanical clean-up methods in open sea as suck and skim, are useful where the oil volume is high and visible but lose efficiency when the oil is presented as dispersed patches or is partially sunken, travelling at mid-water. Gradually, the oil is transported to the coast by wind, waves and currents, reaching coastal stretches that are difficult to be accessed or areas such as beaches where the oil removal is arduous, increasing the damage and delaying the beach recovery. In this sense, Schulhof and Grifman (2019) highlighted the need for technology advancements and one of the most thriving areas identified was the use of unmanned and autonomous vehicles (UAVs).

UAVs have been used regularly for ecological research and ecosystem monitoring, underwater 3D modelling, mapping of marine litter in the coastal zone, coastline erosion monitoring, coastal management, among others (Doukari et al., 2019). In the lastest years, the use of UAVs in the observation, oil tracking and damage assessment of an oil spill is emerging as a new and strategic tool (Hernan et al., 2005; Castanedo et al., 2006; Fingas, 2012; Covic et al., 2013; Dean, 2014; Dooly et al., 2016; Fingas and Brown, 2018; Nelson and Grubesic, 2019). In the case of subsurface devices (ROVs), they have even been used in the recovery of oil from the wrecks themselves (Ariza, 2004; Corbetta et al., 2005; Ewen et al., 2005). However, the role of UAVs in maritime incidents is not completely explored yet.

The SpilLess EU project was focused on the advance of knowledge about bioremediation (Argawal and Liu, 2015; Pontes et al., 2013;...
Baniasadi and Mousavi, 2019, among others). One of the most innovative contributions of the project was the adaptation of UAVs for in-situ release of produced microbial consortia and nutrients. As part of this objective, one of the limiting factors related to the operational conditions of these devices was evaluated (Det Norske Veritas, 2011; Acero et al., 2016).

The main goal of this work was to evaluate the operational periods for each UAV, defining the suitability of these devices to help on clean-up operations after an oil spill. These results could be integrated on contingency plans as new technological options that support the decision-making in the oil spill management.

2. Studied area

The study area comprises the Northern coast of Portugal and the Galician coast (NW Spain). While Portugal coast is a straight, sandy coast, opened to deep-water waves; the Galician coast is intricate, alternating pocket beaches with cliffs and exposed and protected areas named Rías (Fig. 1).

Just in front of this coast, the International Maritime Organisation (IMO) defined the Finisterre shipping lane in order to enhance maritime safety, since approximately 40,000 ships pass through this tempestuous sea annually. More than 12,000 of these ships carry dangerous goods in bulk, mostly fuel, regularly producing the oil spills disasters that severely affect the Galician coast. The most serious accidents are represented on Fig. 1.

The last important incident was the Prestige oil spill (2002) and affected more than 1000 km of coast from Northern Portugal to South-western France. Oil spreaded on inaccessible areas or accumulated in the bottom of subtidal zone reoiled the Galician coast for more than ten years (Fernández-Fernández et al., 2011; Bernabeu et al., 2013). This area was the focus of large studies (Bernabeu et al., 2006, 2009, 2010, 2013) and the wide knowledge related to this oil spill inspired the pilot program of SpilLess project, centred on Galician coast and Northern Portugal.

3. Unmanned and autonomous vehicles operational limits

The present study explores a new methodology for clean-up operations of the oil spills, using three different types of UAVs (Fig. 2):

a) Autonomous Surface Vehicle (ASV ROAZ II), developed by INESC TEC (Portugal) and designed for ocean operations, namely oceanographic, bathymetry, security, and search and rescue support operations. It was adapted to spread the microbial consortia at water surface as a response mechanism to oil spills within the framework of the SpilLess project.

b) Remote Operated Vehicles (ROVs) adapted by ACSM (Spain), was to spread the microbial consortia in deep (through the water column) as a response mechanism to oil spills.

c) Unmanned Aerial Vehicle (UAV STORK) was also developed by INESC TEC. The main applications are search and rescue operations, environmental monitoring, 3D mapping, inspection, surveillance and patrol. Its function within the framework of the SpilLess project was to spread the microbial consortia aerially in an oiled area.

These adapted devices were tested under controlled environmental conditions (https://www.youtube.com/watch?v=1cRwR7tj2C8), showing a good performance in the release of the microbial consortia and nutrients. However, in real scenarios, they have operational limits depending on the wind and wave conditions that will determine the feasibility of these equipment (Table 1).

4. Wind and wave analysis in the study area

Cut-off thresholds of the wind and wave conditions were used to define the autonomous and remote vehicles non-operativeness conditions to respond to an oil spill. In a first step, the wind and wave analysis
of the studied area was done. This analysis was based on the SIMAR database (from Organismo Público Puertos del Estado of Spain). The time series of wind and wave parameters have a wide spatial coverage in the study area, variable spatial resolution and a cadence of 1 h. This dataset combines two different datasets to provide long time series and wide spatial coverage. These are (a) the SIMAR-44 subset, obtained from high-resolution numerical analyses of atmosphere, sea level and waves for the 1958-2005 interval; and b) the WANA subset, based on the analysis of the sea state prediction system.

The region has been divided into 5 sub-zones (Fig. 3). Sub-zone 1 to 3 correspond to open waters to the north west (1 and 2) and north (3) off the north-western Iberian Peninsula coast. Zone 4 corresponds to the northernmost coast of Galicia (Spain) and Zone 5 comprises the western coast of Spain and northern Portugal. The ninety-seven nodes were selected from the numerical model which covers the entire study area (Fig. 3). The information was divided into 525,600 data points lasting one hour (60 years of data). For wind, the average speed and direction at 10 m above sea level were used. For waves, the significant wave height (Hs) and peak period (Tp) were considered.

We calculated the mean scalar regimes of the maritime climate (wind and waves) at each SIMAR point. The extreme regimes were discarded because the operational limit conditions from the ASV ROAZ II, ROV, and UAV STORK were framed within average regimes, as discussed further in this section.

A representative node of each area was selected for wind and wave characterization (Table 2). The data were categorized into sectors of 22.5° for the mean directional determination and statistics of the wind and wave speed.

### Table 1
**Operational limits of these devices.**

<table>
<thead>
<tr>
<th>Action</th>
<th>ASV ROAZ II</th>
<th>ROV</th>
<th>UAV STORK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea surface</td>
<td>20 knots (10.29 m/s)</td>
<td>25 knots (12.86 m/s)</td>
<td>19.44 knots (10 m/s)</td>
</tr>
<tr>
<td>Subsea</td>
<td>2.5 m</td>
<td>2 m</td>
<td>–</td>
</tr>
<tr>
<td>Aerial</td>
<td>5 s</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

### Table 2
**Geographical location of the representative nodes of each sub-zone.**

<table>
<thead>
<tr>
<th>Sub-zone</th>
<th>Node Code</th>
<th>Latitude (° N)</th>
<th>Longitude (° W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SIMAR-1032076</td>
<td>44.000</td>
<td>12.000</td>
</tr>
<tr>
<td>2</td>
<td>SIMAR-1032072</td>
<td>43.000</td>
<td>12.000</td>
</tr>
<tr>
<td>3</td>
<td>SIMAR-1044078</td>
<td>44.500</td>
<td>9.000</td>
</tr>
<tr>
<td>4</td>
<td>SIMAR-1049076</td>
<td>44.000</td>
<td>7.750</td>
</tr>
<tr>
<td>5</td>
<td>SIMAR-3014004</td>
<td>42.167</td>
<td>8.917</td>
</tr>
</tbody>
</table>

Fig. 2. ASV ROAZ II (left), ROV (centre), UAV STORK (right).

Fig. 3. Study area and location of the ninety-seven nodes from the SIMAR database and zonal subdivision of the study area.
4.1. Wind regime characterization in the NW Iberian Margin

The zones 1 and 2 show prevailing and dominant winds from the NNE and NE, followed by the winds from the SW, WSW and W (Table 3). Their maximum average wind speeds are 8.6 m/s associated to SSW in zone 1 and 8.9 m/s associated to NE in zone 2. The highest wind speeds exceeded 1% of the time (not shown in the table) are around 19 m/s and 18.6 m/s in zone 1 and 2, respectively, associated to S.

The prevailing winds in zone 4 come from the ENE and E, followed by the winds of the SW and WSW. Their highest average wind speeds ranged between 6.8 and 8.3 m/s. The highest wind speeds exceeding 1% of the time are associated with WSW winds and 17.6 m/s.

At zone 5, the prevailing and dominant winds come from the N, NNW, and NNE, followed by the winds of the S, which presents highest average wind speed, between 4.3 and 5.4 m/s. The dominant S direction presents the largest magnitudes wind speeds exceeded 1% of times of 15.1 m/s.

The scalar annual mean regime of the wind speed was obtained in the representative node of each zone. In order to obtain this regime, wind speed data were fitted by the Weibull distribution:

\[ F(\text{wind velocity}) = 1 - \exp\left( -\left(\frac{\text{wind velocity} - \delta}{\lambda}\right)^{\beta} \right) \] (1)

where \( \beta \) is the shape parameter, \( \lambda \) is scale parameter and \( \delta \) is the location parameter. The obtained parameters \( \lambda, \delta \) and \( \beta \) and the correlation index R² are presented on Table 4. The values of these parameters are very similar between zones 1, 2 and 3 and between zones 4 and 5, highlighting the different wind regimes between coastal and offshore areas.

Fig. 4a shows the annual wind speed (m/s) that exceeded 50% of the time in all the reanalysis nodes used in this study. The range of wind speeds spans between 3.2 and 7.7 m/s, being clear the occurrence of higher speeds (around 7.5 m/s) in zones 1, 2 and 3, than in zones 4 and 5 where the average values are around 3.5-5.5 m/s. This zonal characterization is maintained for the annual wind speed exceeded the 10% of the time (Fig. 4b). In this case, the speed range goes from 7 to 13.1 m/s in zones 1, 2 and 3 and from 7 to 10.5 m/s in zones 4 and 5.

4.2. Wave regime characterization in NW Spain

The prevailing and dominant waves in the 5 zones come from the WNW, NW and W (Table 5). The highest waves decrease gradually between the open sea areas (zones 1, 2, 3) but distinct from coastal areas (zones 4 and 5). At zone 5, the prevailing and dominant waves come from the N, NW and NNW, followed by the winds from the S, which presents highest average wind speed, between 4.3 and 5.4 m/s. The dominant S direction presents the largest magnitudes wind speeds exceeded 1% of times of 15.1 m/s.

The scalar annual mean regime of the wave speed was obtained in the representative node of each zone. In order to obtain this regime, wave height was fitted by the Gumbel distribution:

\[ F(H_s) = \exp\left( -\exp\left( -\left(\frac{H_s - \lambda}{\delta}\right)^{\beta} \right) \right) \] (2)

where \( \lambda \) is location parameter (distribution mode) and \( \delta \) the scale parameter. Table 6 shows the fitting parameters and the correlation coefficient (R²) for the studied zones. As occurred with the wind distribution, the parameters \( \lambda \) and \( \delta \) are very similar in open waters (zones 1, 2, 3) but distinct from coastal areas (zones 4 and 5).

Fig. 4a shows the annual Hs (m) exceeded 50% of the time in all the reanalysis nodes used in this study. The range of Hs goes from 0.7 to 2.4 m, being clear the occurrence of higher wave heights (around 2-2.4 m) in zones 1, 2, 3, while in zones 4 and 5, the average values are around 0.8-1.9 m. This zonal distribution remains the same for the annual Hs exceeding 90% of the time analyses (Fig. 5). In this case, the Hs range goes from 2.2 to 4.7 m.

The annual distribution of peak wave period (Tp, period for which the spectral function of density reaches its highest value) and significant height (Hs, the mean of the one third of the highest waves in the record) are shown in Fig. 6. The most frequent wave conditions in zone 1 and 2 are the same (Hs = 1.5 m; Tp = 8.3 s). In the zone 3, the most frequent significant wave height is slightly lower (1 m), with the peak period of 8.5 s. In the coastal areas, zone 4 presents a Hs = 1.3 m and Tp = 9.2 s, and zone 5 the lowest wave height, Hs = 0.7 m with a Tp = 8.3 m.

5. The study of operational conditions of unmanned vehicles

It should be noticed that the use of the UAVs is mainly limited by the environmental conditions in the oiled area. The weather conditions can restrict the operational capacity of these devices. Based on the maritime climate characterization on the NW coast of Spain, the time of suitable weather conditions for UAVs operations is evaluated as hours per year.

Table 3

<table>
<thead>
<tr>
<th>Directions</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed</td>
<td>Direction probability</td>
<td>Wind speed</td>
<td>Direction probability</td>
<td>Wind speed</td>
<td>Direction probability</td>
</tr>
<tr>
<td>N</td>
<td>0.0667</td>
<td>6.5</td>
<td>0.081</td>
<td>6.7</td>
<td>0.0511</td>
</tr>
<tr>
<td>NNE</td>
<td>0.0830</td>
<td>7.3</td>
<td>0.1095</td>
<td>7.9</td>
<td>0.628</td>
</tr>
<tr>
<td>NE</td>
<td>0.0931</td>
<td>8.1</td>
<td>0.1047</td>
<td>8.9</td>
<td>0.9937</td>
</tr>
<tr>
<td>ENE</td>
<td>0.0697</td>
<td>8.4</td>
<td>0.0680</td>
<td>8.1</td>
<td>0.9956</td>
</tr>
<tr>
<td>E</td>
<td>0.0406</td>
<td>7.2</td>
<td>0.0256</td>
<td>5.8</td>
<td>0.0723</td>
</tr>
<tr>
<td>ESE</td>
<td>0.0210</td>
<td>5.5</td>
<td>0.0174</td>
<td>5.1</td>
<td>0.0316</td>
</tr>
<tr>
<td>SE</td>
<td>0.0208</td>
<td>5.5</td>
<td>0.0195</td>
<td>5.5</td>
<td>0.0215</td>
</tr>
<tr>
<td>SSE</td>
<td>0.0273</td>
<td>6.7</td>
<td>0.0269</td>
<td>6.6</td>
<td>0.0213</td>
</tr>
<tr>
<td>S</td>
<td>0.0472</td>
<td>7.9</td>
<td>0.0462</td>
<td>8.0</td>
<td>0.0294</td>
</tr>
<tr>
<td>SSW</td>
<td>0.0684</td>
<td>8.6</td>
<td>0.039</td>
<td>8.4</td>
<td>0.0761</td>
</tr>
<tr>
<td>SW</td>
<td>0.054</td>
<td>8.3</td>
<td>0.0809</td>
<td>8.1</td>
<td>0.0991</td>
</tr>
<tr>
<td>WSW</td>
<td>0.0835</td>
<td>8.1</td>
<td>0.0784</td>
<td>7.7</td>
<td>0.0873</td>
</tr>
<tr>
<td>W</td>
<td>0.0837</td>
<td>7.9</td>
<td>0.0773</td>
<td>7.4</td>
<td>0.0804</td>
</tr>
<tr>
<td>WNW</td>
<td>0.0769</td>
<td>7.5</td>
<td>0.0720</td>
<td>7.2</td>
<td>0.0654</td>
</tr>
<tr>
<td>NW</td>
<td>0.0712</td>
<td>6.9</td>
<td>0.0709</td>
<td>6.5</td>
<td>0.0557</td>
</tr>
<tr>
<td>NNW</td>
<td>0.0614</td>
<td>6.5</td>
<td>0.0686</td>
<td>6.3</td>
<td>0.0467</td>
</tr>
</tbody>
</table>
5.1. Annual non-operativeness

Based on the operative limits of each device, Fig. 7 shows the non-operating average annual hours. The results highlighted that the subsurface device (ROV) has the lowest inoperativeness hours, with values that range from 11.41 to 936.96 h per year. The surface vehicle (ASV ROAZ II) presents values significantly higher, between 13.96 and 2036 h and hours per month. UAVs are assumed operatives when all relevant parameters (wind speed, wave height and period) are simultaneously in the prescribed limits and non-operatives when the limits are exceeded.
per year. The aerial device (AUV STORK) has the most restrictive operativeness, with 177.55 to 2494 h per year exceeding the operational limits.

For the three devices, the non-operativeness times are significantly higher offshore, zones 1, 2 and 3 (surface, ~1400 to 2036 h; subsurface ~500 to 937 h and aerial devices ~1400 to 2494 h) compared to coastal areas, zones 4 and 5 (surface ~13.96 to 1000 h; subsurface ~11 to 450 h and aerial devices ~177.5 to 1900 h).

5.2. Monthly non-operativeness

In general, the aerial devices present the higher number of hours of non-operativeness in each month, follow by the surface device. Fig. 8 shows the distribution maps of number of hours of non-operativeness for the worst and best month for each device. The zonation appreciated in the annual analysis is maintained monthly, with the number of hours of non-operation in zones 1, 2 and 3 being greater than in zones 4 and 5.

6. Discussion

Several authors highlighted the importance of new technologies developments to fight against oil spills. The UAVs are one of these technologies which applicability in environmental studies is growing in the last years. In this work, we have analysed the operating conditions of these devices, providing managers with a new toolkit and establishing a methodological way to define the most appropriate periods for their use. This will allow a quick response of agencies in the pre-planning stages.
The most important limiting factor in the use of UAVs is related to their operational conditions. This study explores the environmental conditions that constraint the non-operativeness of these devices in the NW Iberian Peninsula considering both deep waters and coastal areas.

Our approach required the analysis of the wind and wave climate of the target area to assess the suitability of the intended devices. In our case, we used free data series available from Puertos del Estado from the coastal and marine buoys net of direct measurements and the grid of WANA points to model wave and wind conditions since 1958 to characterize the target area. The parameters used were wind speed, wave height and period, and wave direction. The most frequent wind directions come from NNE to E and from SW to W, except for the coastal area of the Rías Baixas (zone 5) where the direction changes from NNW to NNE probably modifying for the coastal alignment. The wind speed fits well to Weibull distribution and maximum values reach 8-9 m/s decreasing to 4,9-5,4 m/s in the protected coastal area (zone 5).

As for wave provenance, the most frequent directions are fairly similar in the different sectors for open and coastal areas. They are clearly dominated by waves from NW to W, including the WSW in the zone 5. The maximum wave height does not correlate with the most frequent directions. These values are attained with SSW to WSW waves, except for the northern coast (zone 4). These results describe the wave climate in the northern Iberian Peninsula: the most frequent direction is associated to NW quadrant, but the highest waves are associated to SW quadrant.

Considering the UAVs operational limits, the wind and sea state

<table>
<thead>
<tr>
<th>Surface device</th>
<th>Subsurface device</th>
<th>Aerial device</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASV ROAZ II</td>
<td>ROV</td>
<td>UAV STORK</td>
</tr>
<tr>
<td>January</td>
<td>266</td>
<td>161</td>
</tr>
<tr>
<td>February</td>
<td>257</td>
<td>160</td>
</tr>
<tr>
<td>March</td>
<td>263</td>
<td>141,5</td>
</tr>
<tr>
<td>April</td>
<td>124</td>
<td>63</td>
</tr>
<tr>
<td>May</td>
<td>111</td>
<td>36</td>
</tr>
<tr>
<td>June</td>
<td>174</td>
<td>101</td>
</tr>
<tr>
<td>July</td>
<td>45</td>
<td>54</td>
</tr>
<tr>
<td>August</td>
<td>146</td>
<td>100</td>
</tr>
<tr>
<td>September</td>
<td>206</td>
<td>115</td>
</tr>
<tr>
<td>October</td>
<td>152</td>
<td>48</td>
</tr>
<tr>
<td>November</td>
<td>115</td>
<td>67</td>
</tr>
<tr>
<td>December</td>
<td>369</td>
<td>250</td>
</tr>
<tr>
<td>Annual hours</td>
<td>2082</td>
<td>1296,5</td>
</tr>
<tr>
<td>Annual percentage of time</td>
<td>23.8%</td>
<td>14.8%</td>
</tr>
</tbody>
</table>

Bold highlights the maximum and minimum monthly values.
conditions in the NW Iberian Margin define a broad operative window that span between 70 and 85% of average annual time. These results confirm the suitability of these emerging tools not only for tracking an oil spill, but as a part of the clean-up method themselves. As expected, the open sea presented harder operative conditions than the coastal areas, inclining the preferential use of the UAVs as a defence barrier in areas close to the coastline.

The aerial device presented the most restrictive conditions of operation, with 67% of the annual hours being operational; whilst the subsurface device was the least restrictive, with 85% of the annual hours being operational. This indicates that the subsea response to oil spills should be preferred during adverse weather.

The worst operative periods present in winter, mainly in December, and during the season transitions (March and September) for all the UAVs. In general, in this stretch of coast, the winter period is difficult for any maritime operations, and it is expected that other clean-up methodologies have similar weather conditions limitations. The most favourable months for marine operations are July and November.

7. Conclusions

NW Spain coast is affected for recurrent oil spills, but these are not isolated incidents. The recurrence of spill events supports the necessity of continuing to develop innovative and environmentally compatible technologies to remove oil contamination from the environment.

The UAVs technologies are emerging tools in the fight against an oil spill. The SpillLess project explored their use as clean-up tools in a first line response in affected areas. The results of the present work show that the operational limits of these UAVs are not significantly more restrictive than the traditional marine operations. UAVs can be significantly cheaper, reaching easily some areas affected by oil spills, and being environmentally friendly.

The three studied UAVs (aerial, surface and subsurface devices) present broad operative windows related to wind and sea state conditions in the NW Iberian Margin. The ROV has wider windows of operativeness since its operational limits are less restrictive. The subsea response to oil spills is easier compared to both the surficial and aerial response during adverse weather conditions. The aerial response revealed much more difficult.

The presented work establishes the suitability of these new technologies as an oil spill response method and define the periods during an immediate spatial and temporal window. Responders must analyse the conditions of the acting zone during adverse weather conditions of the oil spill. The SpillLess project explored their use as clean-up tools in a first line response in affected areas. The results of the present work show that the operational limits of these UAVs are not significantly more restrictive than the traditional marine operations. UAVs can be significantly cheaper, reaching easily some areas affected by oil spills, and being environmentally friendly.

The three studied UAVs (aerial, surface and subsurface devices) present broad operative windows related to wind and sea state conditions in the NW Iberian Margin. The ROV has wider windows of operativeness since its operational limits are less restrictive. The subsea response to oil spills is easier compared to both the surficial and aerial response during adverse weather conditions. The aerial response revealed much more difficult.

The presented work establishes the suitability of these new technologies as an oil spill response method and define the periods during an immediate spatial and temporal window. Responders must analyse the conditions of the acting zone during the day of operation to ensure the viability of this in situ clean-up means.

CRediT authorship contribution statement

A.M. Bernabeu: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. M. Plaza-Morlote: Conceptualization, Methodology, Formal analysis, Writing – original draft. D. Rey: Formal analysis, Writing – review & editing, Project administration. A. Dias: Conceptualization, Formal analysis. A.P. Mucha: Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This work has been funded by the EU SpilLess project: First-line response to oil spills based on native microorganism cooperation, through Blue Labs: innovative solutions for maritime challenges program. (EASME/EMFF/2016/1.2.1/4.02/SI2.749374 - SpilLess). N. García-Valiente for her counsel in the script’s development. M. Plaza-Morlote was awarded a Postdoctoral fellowship by the Xunta de Galicia (Department of Culture, Education and University Planning) supported by the European Social Fund 2014/2020 (ED481B-2018-058).

References
