ISblue The interdisciplinary graduate school for the blue planet

# Application file 2019

# Flagship projects – Phase 2

## Summary Sheet

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|---|---|
| Project name | **SeaLex - The SEA as a Long term socio-ecological EXperiment** |
| Acronym : | **SeaLex** |
| Name of the coordinator : | STEPHAN Pierre |
| Research unit of the coordinator : | laboratory LETG, IUEM |
| ISblue research units concerned (with the names of the participants[1]): | LETG (P. Stéphan, S. Suanez, Y. Pailler)<br>LGO (A. Penaud, M. Vidal, B. Le Gall)<br>LOPS (G. Charria)<br>LEMAR (Y.-M. Paulet, J. Thebault, C. Paillard)<br>CERV -ENIB (R. Querrec, F. Devillers) |
| External collaborations : | Institut National de Recherches en Archéologie Préventive (INRAP)<br>Centre de Recherche Bretonne et Celtique (CRBC)<br>Parc Naturel Marin d'Iroise (PNMI)<br>Memorial University (Canada)<br>Société Jersiaise, UK<br>London University, UK<br>UQAR (Université du Québec à Rimousky - Canada)<br>ULAVAL (Université Laval - Canada)<br>Creaah laboratory (Rennes, France) / IRN PreCOAST (CNRS) |
| Total tentative budget : | 536.244 € |
| Request for funding from ISblue : | 400.244 € |
| ISblue Theme(s) | Theme 3-Sustainable coastal system<br>Because it concerns social adaptability and resilience to environmental coastal changes, the SEALEX project is relevant with the theme 3. |

This application form shall be used for the second stage of the Flagship call. The project description excluding the Summary Sheet is limited to 10 pages. Please respect this limit to avoid biases in the evaluation.

The summary will be used to look for external evaluators (about 1/2 page).

https://www.labexmer.eu/fr/appel-a-projets/Emblematique/++add++iuem.proposal.candidate

[1] Indicate only the participants who contribute for 15% of their time or more

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## Summary Sheet

The impact of rapid climate changes on contemporary coastal human populations is of global concern. To contextualize our understanding of human responses to Holocene and Anthropocene climate changes, it is necessary to examine in parallel (i) the historical and archeological records and (ii) the nature and the timing of past environmental changes. The SeaLex project aims at contributing significantly to the contemporary societal debate about the impacts of climate changes on coastal human populations through a retrospective view of the **long-term trajectories of socio-ecosystems**, especially in terms of **social adaptability** and **resilience**, from the start of the Holocene to present-day along the land-sea continuum in several relevant North Atlantic Ocean coastal areas.

SeaLex project will build and consolidate an original **interdisciplinary** consortium of scientists working within the Isblue research teams and beyond, by a real integration of Natural sciences, Humanities and engineering skills existing at the University of Brest. In addition to the International Research Network "PrehCOAST" for "Coast-inland dynamics in prehistoric hunter-gatherer societies" (IRN from the CNRS, coord. Grégor Marchand, stated in 2019) in which Brest is involved, numerous collaborations considered in the SeaLex project will soon become currently effective, especially with Canadian teams from Québec (ULAVAL, UQAR) around St Pierre and Miquelon future works (detailed thereafter in this project). So far, only a few initiatives combining paleoenvironmental and archaeological approaches stayed limited to the LTSER Zone Atelier Brest-Iroise, and restricted to the Neolithic/Bronze Age periods of the Molène Archipelago territory. Also, supported from 2020 by the ARMERIE program (funded by the UBO, coord. Yvan Pailler), the SeaLex project wants to integrate historians, linguists, and archaeologists working on cultural changes over a long time span to explore a large range of cultural archives.

This interdisciplinary approach of the long-term human-environmental interactions need to transcend the traditional boundaries between disciplines by producing new concepts and paradigms. Only few research teams in Europe currently work on the long-term human-environmental interactions. We plan to create strong research links with the universities of Kiel and Cadiz (identified as leaders in Europe). The use of virtual reality tools (CERV) to propose realistic reconstructions of past environmental and cultural changes is a very innovative point of the project with exciting perspectives in terms of economic and cultural development (enhancement of cultural heritage, scientific mediation, creation of video games). Finally, the SeaLex project will strengthen the ISblue training strategy by the creation of new courses for Licence, Master and PhD students.

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## 1 - Context and objectives

### 1.1. Scientific objectives[2]

The impact of rapid climate changes on contemporary coastal human populations is of global concern. the impact of human activities on landscapes and, by extension, on near-continent sea-surface water characteristics having increased over the last thousand years and more intensively for 4 ka in western France (e.g., Fernane *et al.*, 2014, 2015; Penaud et al., 2020). To contextualize our understanding of human responses to Holocene and Anthropocene climate environmental natural or anthropogenic changes (Ruddiman *et al.*, 2016), it is necessary to examine in parallel: (i) the historical and archeological records and (ii) the nature and the timing of past coastal changes. Paleosciences are able to contribute significantly to the contemporary societal debate about the impacts of climate changes on coastal human populations through a retrospective view of the long-term trajectories of socio-ecosystems, especially in terms of social adaptability and resilience. Moreover, it is crucial to document and understand the impact of past human activities on natural landscapes, erosion processes, coastal resources, geomorphological changes, as well as the respective part of environmental changes (paleogeographical changes: Stephan *et al.*, 2019; sea level rise: e.g., Garcia-Artola *et al.*, 2018; storm events: e.g., Pouzet *et al.*, 2018; water quality: e.g., Lambert et al., 2017, 2018; means of subsistence: e.g., Pailler and Nicolas, 2019) on the development or decline of coastal societies since the Neolithic (starting point of the human permanent occupation along the European coasts).

The SeaLex project aims at understanding the links between climate - environment - societies from the start of the Holocene to present-day along the land-sea continuum in several relevant coastal areas of the North Atlantic Ocean by : **i) consolidating and improving recent promising approaches in the temperate NE Atlantic Ocean (cf. Penaud et al., 2020 for the northern Bay of Biscay) and ii) emerging new studies in the western Atlantic Ocean through new international collaborations and works planned around the St Pierre et Miquelon archipelago (ULAVAL, UQAR).** This requires to gather specialists of coastal archaeology and history, geomorphological and sea-level changes, paleoclimatology and paleoecology, bio-geochemistry, as well as physicians able to simulate past environments taking into account all sources of information that sediment archives can provide behind the pluri-decadal coverage provided by instrumental data, in order to provide robust projections for the future. This project is thus obviously interdisciplinary with multiple units from ISBLUE (LETG, LGO, LOPS, CERV-ENIB) and non-ISBLUE French partners (CRBC, INRAP) as well as international partners already structured in the International Research Network IRN "PrehCOAST" and Canadian partners already contacted for the western Atlantic side.

Despite the strong expertise of the research teams involved regarding the reconstruction of past environmental coastal changes, it is still impossible to thoroughly discuss the impact of climate changes on coastal societies, and vice versa. This is due to (i) the lack of structured and harmonized dataset on ancient human occupations (cf. **WP1**), (ii) the low degrees of interaction between humanities, environmental and engineering sciences (**WP1 to WP4**), and (iii) the lack of data on the nature of changes (in terms of landscape transformation, dynamics of vegetation, marine floods) and their low chronological accuracy (cf. **WP2 and WP3**). Although paleosciences have never accumulated so much data on the Holocene, the interdisciplinary approach advocated by the SeaLex project is rarely conducted in such an integrative way. The SeaLex project has then the ambition to create real interactions within researchers in order to produce intelligible results that will also be transferred to the society by using virtual reality tools (**WP4**). These tools are envisaged as a means of visualizing palaeogeographic and cultural changes over time and of enhancing coastal cultural heritage.

### 1.2. Originality of the project and of its positioning in the international context

The SeaLex project will build and consolidate an original interdisciplinary consortium of scientists working within the Isblue research teams and beyond, by a real integration of Natural sciences, Humanities and engineering skills available at the University of Brest. So far, only a few initiatives to cross paleoenvironmental and archaeological approaches stayed limited to the LTSER Zone Atelier Brest-Iroise, and restricted to the Neolithic/Bronze Age

[2] Note that all references listed in the project are accessible through hypertext links.

periods of the Molène Archipelago territory (Pailler and Nicolas, 2019). Here, we want to integrate historians, linguists, and archaeologists working on cultural changes over a large timespan to explore a large range of cultural archives. This interdisciplinary approach of the long-term human-environmental interactions need to transcend the traditional boundaries between disciplines by producing new concepts and paradigms. The use of virtual reality tools to propose realistic reconstructions of past environmental and cultural changes is another very innovative point of the project with exciting perspectives in terms of economic and cultural development (enhancement of cultural heritage, scientific mediation, creation of video games). Only few research teams in Europe currently work on the long-term human-environmental interactions. In a position of leader, we can cite the University of Kiel which gathers about 75 people (including professors, engineers, PhDs) within the laboratory CRC1268 “Scales of Transformation: Human-Environmental Interaction in Prehistoric and Archaic Societies”. We can also note the initiative of the University of Cádiz which has recently created a priority line for training and research in nautical and underwater archeology, in collaboration with the Campus of International Excellence of the Sea (CEI.Mar). During last years, other similar initiatives are being launched with less ambition in Europe's coastal universities.

### 1.3. Lessons from the past

Coastal zones, densely populated today with more and more exposed infrastructures to natural hazards, and especially sandy shorelines, are increasingly subject to erosion. The growing risk of marine submersion in low-lying areas has for many years led to the societal question of the processes responsible for coastal mobility as well as for terrestrial and marine ecosystem changes. Main factors responsible for landscape coastal changes include rising sea-level, storminess regimes, natural modes of atmospheric and oceanic oscillations, and also direct human impacts on watersheds and coastal environments (deforestation, exploitation of natural resources, dwelling and traffic routes, agro-pastoral activities, heating and living comfort…). This knowledge can be greatly increased by going back to the recent past (the last centuries and millennia) to look for situations comparable to the present. For example, sea level rise is a global concern. Over the past two decades, the Brest tide gauge has recorded elevation rates not seen since its installation three centuries ago. Geological data indicate that it is necessary to go back 6,000 years BP to encounter rates similar to the current situation. How can we estimate the impact of the future sea-level rise on the coastal zones in terms of erosion and sedimentation, shoreline changes, transformation of landscapes and environments? Predictive modelling tools are often the preferred approach despite the many limitations related to the complexity of coastal hydrosedimentary processes and the numerous feedbacks and the non-linearity of changes limiting the predictive capabilities of model outputs. In the SeaLex project, we propose an alternative approached based on the retro-observation.

The diversity of methods and tools used, as well as the very time-consuming aspects of the techniques employed in paleosciences, has often limited their societal reach and limited the ability to transfer some results to society. Few decision-makers plan their actions taking into account information from the past. Yet we are convinced that this approach is very effective in informing both the regional causes and local effects of coastal change on different time scales. These results can therefore be very useful in spatial planning policies in the face of coastal change.

We believe that two limitations must be overpassed so that the lessons of the past can be used to build future solutions. The first concerns scientific mediation tools to make the results of this fundamental research accessible. The SeaLex project aims to explore the solutions proposed by digital virtual reality and augmented reality tools. These approaches can facilitate the interpretation of the results by the general public and decision-makers and raise the awareness of the populations concerned about past and future transformations of coastal zones. The second limitation concerns the taking into account of Man in these past changes, as both responsible and potential victim of these transformations. By integrating archaeology, history and linguistics in an interdisciplinary approach, the SeaLex project aims to strengthen the societal impact of the results by placing coastal populations at the heart of the issues, thus retracing the evolution of lifestyles, daily practices and constraints inherent to the coastal environments. Anthropologists and ethnologists have long shown that the further back in time one goes, the more blurred the frontier between Man and Nature becomes. Consequently, it becomes easier to reconstruct a kind of "narrative of origins" that reconciles natural and cultural heritage and sheds new light on the identity of coastal societies.

# 2 - Project description

## 2.1 Methods and workpackages

### WP1- Past coastal societies: distribution, chronology and lifestyles

WP1 will develop a structured georeferenced database of archaeological sites (Pre- Proto- Historical periods) distributed along the coasts of the Western Brittany and St Pierre and Miquelon archipelago using the GIS tool. In Brittany, the archaeological data from the Mesolithic to the present day are plethoric and scattered among different sources and published inventories. The database will be established from: archives, bibliography, site detection via Lidar coastal data, aerial or satellite photos and geophysical field investigations (GPR) on sites of major interest. Faced with such a mass of information, experience has shown that only collective work, with cross-examination, makes it possible to master all the sources and to disentangle them critically. This work will be coordinated by Yvan Pailler, research engineer in archaeology at the University of Brest. The data collected in this way must be structured according to their nature and prioritized according to the quality of the information from the field. **They will be made available to the SeaLex research team using the INDIGEO geographic data infrastructure.**

- **WP1.1 Georeferenced archeological database.** This database will be used to study **coastal human spatial occupation over time using geospatial analysis tools.** It will give a more precise idea of the nature of coastal occupations, the population density along the coastline according to periods and the dynamics of these populations (continuities and breaks). Particular attention will be paid to **archaeological sites providing information on past lifestyles** (shell middens) and in particular the **exploitation of marine resources**.
- **WP1.2. Sclerochronology.** Among shell middens, shellfish and in particular species such as *Patella vulgata*, *Ruditapes sp.* and *Pecten Maximus* will be the subject of sclerochronological analyses in order to better estimate the fishing seasons and the climate during the periods concerned. The signals revealed by the analysis of shellfish from anthropogenic accumulations will be interpreted at their highest level of resolution (daily for the scallop), in order to approach human behaviour and the environments in which societies developed. This approach will be based on the analytical skills of the Ocean Spectrometry Pole (UBO, Ifremer, CNRS, IRD), which focus on stable isotopes and trace elements within carbonates. **Thanks to SeaLex, twenty years of expertise at IUEM in the calibration of carbonate proxies will be reinvested for the first time on a large scale to question past coastal societies.** The results will be cross-referenced with past climate and environmental changes reconstructed with sediment cores and fossilized bio-indicators in WP2.
- **WP1.3. Ancient DNA approach.** Sclerochronological and isotopic analyses will be coupled with **analyses of ancient DNA (aDNA) from shells sampled in shell middens.** These new metagenomic approaches have demonstrated the existence of aDNA within shell matrices and identified mollusc species (clams, mussels, scallops, abalone and oysters), their microbiotes and their pathogens (Der Sarkissian et al. 2017). Other marine species among molluscs, crustaceans, cephalopods, fishes, marine or terrestrial mammals, could also be consumed by humans, but because of their less good conservation, are found less frequently in archaeological sites. Thus, we wish to develop an innovative technique of capture probes or enrichment (Slon et al. 2017) by **pointing out target groups according to the archaeological sites studied.** These data, complementary to the archaeozoological data, will document the composition of the communities of organisms making up the shell middens and will thus allow us to **deepen our knowledge of the lifestyles and livelihoods of coastal societies** (hunting, fishing, gathering practices; plant and animal exploitation; resource storage and management).
- **WP1.4. Ethno-linguistic approach.** The ALCAM project (*Atlas Linguistique des Côtes de l'Atlantique et de la Manche*) conducts an interdisciplinary and innovative study of the concordances between linguistic and cultural areas along the Atlantic coast from Gibraltar to Scotland where it encompasses more than 500 survey points. It shows facts of continuity or deep cultural affinities which remained until then unnoticed and some of which can be traced back to Prehistory. In the SeaLex project, it will explore maritime place-names as markers of the relationships between human populations and their coastal environment in the long term. For example, Breton toponymic occurrences of gored/kored 'weir, dam, fishgarth' along the Armorican shore crossed with a new topographic and bathymetric method (Litto3D project) may detect or confirm ancient archaeological structures

dating back to Mesolithic / Neolithic. **The Celtic equivalents Gaelic cora and Welsh cored authorize to continue this kind of study along the Atlantic coast.**

## WP2 - Environmental coastal changes and forcing: reconstructions from sediment archives

Coastal environments were affected by major changes during the Holocene. WP2 proposes to reconstruct these environmental changes in time and space and to understand the responsible forcings (e.g. relative sea-level, storminess, shoreline, landscape and climate changes) through sedimentological and geochemical proxies, as well as marine and continental bio-indicators. We will seek to identify past climate extremes, reconstruct their geomorphological impact, assess their potential consequence on past human societies (link to WP1) and understand the role of ocean circulation in these extremes (link to WP3). WP2 thus proposes to reconstruct these spatio-temporal environmental changes through two main approach: coastal geomorphology/geoarchaeology and palynology/sedimentology.

- **WP2.1. Geomorphology.** Coastal geomorphological transformations will be reconstructed from sediment cores taken from estuaries and tidal marshes located in two geographical windows: (i) **Western France** and (ii) the **archipelago of Saint-Pierre-et-Miquelon**.

i) In western France, these cores have already been carried out and have been partially studied (PhD Aneta Gorczynska, in progress, supervised by B. Le Gall, P. Stéphan and Y. Pailler). More than 60 radiocarbon dates have been obtained on several coastal sedimentary sequences cover the last 8 000 years. We propose to further study these cores to reconstruct the relative sea-level (RSL) rise through the production of **new Sea-Level Index Points (SLIPs)**. We will use **benthic foraminifera** as bioindicators to improve the accuracy of the reconstructions **(**Stéphan et al. 2015). **Recent advances in statistical modelling tools** will be used to propose a **revision of the RSL rise curves for western France**. On some of the reference cores, detailed grain size analyses will be performed to reconstruct the **storminess signal**. Finally, the **periods of coastal dune formation** will be reconstructed for the first time on the scale of western France. While well-constrained chronologies of Holocene dune accretion were reconstructed in Portugal, Spain and Ireland, the data available for the French Atlantic coast are limited to the Aquitaine dune complex (SW France; Stéphan et al., 2019). This lack of data is mainly due to the absence of well-developed palaeosoils interbedded into the aeolian sand deposits, especially in Brittany where only thin humic layers are preserved into the coastal dune sediment records. In this WP2, we propose an alternative approach based on the use of archaeological information available in the coastal dunes of Brittany where a high density of well-conserved archaeological sites were excavated from the end of the 19th century. These widely available archaeological data will be inventoried in WP1 and used in WP2 as chronological indicators to reconstruct the coastal dunes evolution during the last 8 Ka BP at a regional scale.

ii) In the Saint-Pierre-et-Miquelon archipelago, the only data available on Holocene coastal environments are limited to the dune barriers connecting the islands of Langlade and Miquelon (Billy et al., 2014; 2015; 2018). This lack of paleoenvironmental data severely limits our understanding of main human settlement dynamics in the archipelago over the last few millennia. However, an archaeological program has just begun in 2019 in this area, where many sites are currently destroyed by coastal erosion. A geoarchaeological investigation is therefore essential. We therefore plan to conduct a sediment coring campaign in several salt-marshes of the archipelago in order to study: (i) relative sea level variations, (ii) glacio-isostatic readjustment due to the retreat of the Laurentide ice-sheet, (iii) the chronology of storm events. A first coring campaign is already planned for the summer of 2020. **This work will be conducted in collaboration with Canadian geomorphologists and archaeologists from the University of Laval (ULAVAL) and the University of Rimousky (UQAR). This work will be carried out in the framework of a PhD required in the SeaLex project, and co-supervised by Guillaume Marie (UQAR).**

• **WP2.2. Palynology.** Previous work on the Brittany coasts and in particular Southern Brittany (Fernane et al., 2015; Delaine et al., 2015), the Bay of Brest (Lambert et al., 2017, 2018) and the Bay of Douarnenez (Lambert et al. 2019), and further offshore in the mid-shelf mudflat called *Grande Vasière* (Baltzer et al., 2015; Mojtahid et al., 2019; Penaud et al, 2020), highlight a certain number of common climatic, environmental and anthropogenic episodes during the Holocene, with however specificities of sites in coastal environments and in particular gaps (absence of deposition or erosion) leaving certain intervals uninformed (as in the Bay of Brest for example around the Bronze Age). Furthermore, current studies suggest a probable diachronism between South and North Brittany for human occupations (thesis Aneta Gorczynska, in progress). Thus, in the framework of a PhD project in palynology that will start in October 2020 (supervision: E. Goubert, M. Vidal, A. Penaud), some coastal sites are already planned to be studied so as to complete missing environmental information. The synthesis at the Brittany scale requires a sufficient number of sedimentary sequences, as continuous as possible, from land to sea. In marine environments (marine cores MD04-2835 and MD95-2002), sedimentation rates are lower than in estuarine environments, but Holocene sedimentation is continuous through time, with no sediment hiatus. Regarding pollen grains, the marine hemipelagic sedimentation averages the regional landscape history (Brittany) by collecting sedimentary inputs from peripheric watersheds. However, continental anthropogenic signals such as crop pollen grains (*Cerealia*-type) are poorly represented/detected in the ocean far from their local source emissions. Regarding marine bio-indicators, the study of dinocyst assemblages (same palynological slides than for pollen grain analyses) will allow discussing palaeohydrological changes through time and quantifying past sea-surface temperatures and salinities (seasonal, annual) as well as primary productivity conditions through a transfer function (Modern Analogue Technique) applied to dinocyst assemblages (de Vernal et al., 2019).

## WP3- Numerical models of past coastal hydrological processes

In WP2, combining coastal sites with high exposure of these coastal sites to storms, changes in relative sea-level and human practices (SeaLex PhD in geomorphology, PhD in palynology) to marine (required SeaLex Post-doctoral position for 1 year) environments will allow to have the most exhaustive possible idea of environmental changes that took place during the Holocene from the local scale (marshes, estuaries) to **macro-regional forcings (offshore hemipelagic sequences in open marine environments) for which paleohydrological and paleoclimate changes will be confronted to model simulations of WP3.**

A recent study showed that we can reconstruct the evolution of major drivers in the coastal circulation in the Bay of Biscay thanks to paleoenvironmental information extracted from sediment cores (Penaud et al., 2020). Palynological data allowed describing a possible Bay of Biscay ocean circulation patterns for the last 7 ka BP. Using those data and associated analyses, collected information on the potential drivers of the circulation (i.e. sea level, atmospheric oscillations and impact on precipitation and river runoffs, large scale ocean circulation – gyres) can be used to run complex realistic simulations based on available configurations for the Bay of Biscay. The circulation in the Bay of Biscay will be simulated using the Coastal and Regional COmmunity CROCO model (Shchepetkin and McWilliams 2005, Debreu et al. 2012, Petton et al. 2020). Such model configurations can be implemented for interannual simulations and can give a detailed view of the Interannual variability or differences between contrasted past periods (Charria et al., 2017; Akpinar et al., 2020). Limitations of such numerical model are related with the external forcings and constraints (bathymetry, river runoff, atmospheric forcings, large-scale ocean boundary conditions).

In the SeaLex project, based on collected data (e.g. sea level, atmospheric regimes) and some additional argued assumptions (sensitivity of river runoffs intensity, large scale current intensity) like for the Iberian Poleward Current), we aim to simulate specific years during the Holocene related with different scenario (for example, Holocene thermal optimum (9-6 ka BP) versus Neoglacial (from 4.2 ka BP), Bond events). Those simulations will be performed firstly in the Bay of Biscay as available data already allow first experiments. Following other data analysed in WP2, other scenario for the Bay of Biscay can be designed and other geographical regions can be considered for similar approaches (Saint-Pierre-et-Miquelon archipelagos for example – existing modelling experience, needs drivers data to simulate Holocene scenarios). **Related with the uncertainties in the different drivers, such realistic numerical simulations is an unusual approach as it will need a previous knowledge of the different forcings. The inter-disciplinary framework of the SeaLex project allows aggregating this information necessary to design those numerical experiments.**

**Holocene modelling exercises will be discussed in parallel with paleo-reconstructions acquired in WP2 across Brittany's coasts (and other regions), as well as human occupation of WP1. This will help to better understand underlying forcing behind coastal dynamics (environment and humans) at the Holocene time scale.**

### WP4- The development of virtual reality tools

Virtual reality and augmented reality will be used as a natural means of communication of the data collected during WP1 and the results of WP2 and WP3. Virtual reality makes it possible to combine first-person perspectives that allow the user to be involved in simulated environments with third-person perspectives that allow the user to step back from space and time for a better understanding. In this WP4, we will be able to directly use the data of the scans made in WP1 and we will be able to connect to the GIS proposed in WP1 to position them. Based on the scans, product schematics and archive photos, we will be able to propose some simple 3D models to illustrate the principle and for specific important models we will work with 3D modeler to have detailed models and use those already realized with our partners from WP1. We will use the same information to place them in an augmented reality situation (on site). The idea is to give the user the possibility to integrate WP1, WP2 and WP3 data in the same scene. To integrate the results of the WP2 and WP3 simulations, we will use the automatic generation of 3D models according to the type of information (e.g. generation of specific plants according to the coring results) and 3D metaphors (e.g. transparent and dynamic arrows to represent the current).

Beyond the inherent interest of virtual reality and in order to ensure that the researchers' message is well integrated into the virtual environment, we propose new methods to automatically integrate the knowledge generated by WP1 to WP3 in the environment. Those virtual environments integrating domain knowledge are called Intelligent Virtual Environment. In this project, we will work in collaboration with all WPs to define an ontology of the different domain knowledge and the database structure to store that information. This allow to create generic methods to create the Intelligent Virtual Environment. As the domain knowledge is consider as data in the virtual environment it allows autonomous agents in the virtual environment to manipulate it in real time. This principle permits, on the one hand, to design mediation or pedagogical scenarios in order to ensure that an objective is achieved (Saunier et al., 2016). On the other hand, it also allows researchers to reason about these data, in collaboration and in situation.

However, in order to ensure the usability of the virtual environment, **we will propose and evaluate innovative ways of interaction.** Navigating in space in virtual reality or augmented reality is quite natural. However, the interest of this project also lies in the ability to navigate in time. The challenge is therefore to propose **virtual or augmented reality interaction modes that allow to combine spatial and temporal navigation while preserving the ability to carry out "business" interactions.** We will rely on work in progress on temporal navigation in a virtual environment applied to heritage. This work proposes to use tangible devices to complement the classical interaction modes in virtual reality.

## 2.2 Teams Involved

### WP1 - Past coastal societies: distribution, chronology and lifestyles

The WP1 will be coordinate by **Yvan Pailler**, archaeologist working at the INRAP (the French National Institute for Preventive Archaeological Research). He is employed for two years (2020-2022) as research engineer at the University of Western Brittany. Its task will be to build and structure the geocultural database. **Daniel Le Bris** is assistant professor specialized in geolinguistic at the University of Western Brittany (laboratory CRBC) and coordinator of the ALCALM project. **Yves-Marie Paulet** and **Julien Thebault** are professor and assistant professor in marine biology (laboratory LEMAR, IUEM) at the University of Western Brittany, respectively. They are specialists of the sclerochronological approaches on marine shells and they will co-supervise the post-doc asked in WP1. **Christine Paillard** is a senior researcher at the CNRS (French National Center for Scientific Research). She is a marine biologist (laboratory LEMAR, IUEM) and her work is based on the analysis of DNA on marine shells. She will co-supervise the post-doc on these aspects. The post-doctoral student recruited will also benefit from co-supervision with **Meghan Burchell**, associate professor at the Memorial University (Canada) whose research in archaeology, biology and geochemistry is aimed at understanding long-term human-environmental interactions. More specifically, she studies the micro-structure and geochemistry of hard tissues such as shell, bone, teeth and coral to derive information on past climate, human settlement patterns and diet. The majority of her work focuses

on coastal landscapes and the development of new techniques to improve seasonality and paleoclimate reconstructions using high-resolution stable isotope sclerochronology. This totally new international collaboration will encourage the emergence of research projects between the SeaLex team and researchers at Memorial University.

### WP2 - Environmental coastal changes and forcing: reconstructions from sediment archives

The workpackage 2 will be coordinate by **Aurélie Penaud**, assistant professor in marine paleontology and paleoclimate at the University of Western Brittany (laboratory LGO, IUEM). She will supervise a PhD student who will work on the pollen analysis of coastal sedimentary sequences distributed in northern and southern Brittany. She will also supervise the post-doctoral fellow working on the micro-paleontological analysis of marine sedimentary sequences (cores MD04-2835 and MD95-2002). **Muriel Vidal** is assistant professor in Geology and Palynology at the University of Western Brittany (laboratory LGO). She will also supervise the post-doctoral student who will be recruited and participate in the analysis of the results. **Bernard Le Gall** is a senior researcher in geology at the CNRS (laboratory LGO). He supervise the Aneta Gorzcinska's PhD work which focuses on the study of coastal sedimentary sequences in Brittany. **Pierre Stéphan** is researcher in coastal geomorphology and geoarchaeology at the CNRS (laboratory LETG, IUEM). He will work on the detailed analysis of the coastal sediment cores available for the coasts of Brittany in order to reconstruct the Sea-Level Index Points, the storminess signal, and the palaeogeographic changes in several geographic windows. He will supervise the PhD student who will be recruited as part of the SeaLex project. Pierre Stéphan will participate in the various field missions planned in Saint-Pierre-et-Miquelon. **Serge Suanez** is professor of geomorphology at the University of Brest (LETG laboratory). He will be the director of the thesis that will be carried out in the SeaLex project and will provide expertise on the analysis of coastal geomorphological processes. The PhD work will be carried out in the framework of a new collaboration with archaeologists and geomorphologists from the Canadian universities UQAR and ULAVAL. **Guillaume Marie** is professor in Coastal Geomorphology at the UQAR (Rimouski, Québec) and will co-supervise the PhD work at Saint-Pierre and Miquelon.

### WP3 - Numerical models of past coastal hydrological processes

The workpackage 3 will be coordinate by **Guillaume Charria**, researcher in Ocean Physic and modelling at the IFREMER institute (laboratory LOPS). His research is focused on continental shelf and slope dynamics in the Bay of Biscay with a specific focus on (sub)mesoscales and fronts and their interannual variability in the frame of the climate change. He will supervise the recruited post-doctorant in charge of numerical simulations of the Bay of Biscay for several past considered scenarios. Prior to the numerical simulation work, **Aurélie Penaud** will also contribute to this WP3 by helping to define the most significant chronological windows and to parameterize the major climatic forcing. In the final phase of WP3, Aurélie Penaud will be involved in the validation of the model outputs based on micropaleontological analyses carried out on sediment cores at different points in the Bay of Biscay. **Pierre Stéphan** and **Yvan Pailler** will be also involved to cross the WP3 results with the major coastal morphological changes (WP2) and the past human occupations (WP1), respectively. This collaboration between physicists, geologists, geomorphologists and archaeologists is completely new.

### WP4- The development of virtual reality tools

The WP4 will be coordinate by **Ronan Querrec**, professor at the University of Brest and director of the European Center for Virtual Reality (CERV, Brest National School of Engineering-ENIB). The CERV's research focuses on virtual reality, autonomous behaviours, intelligent environments, Human-Machine interaction, and the modeling and simulation of complex systems. Ronan Querrec's research is focused on Technology Enhanced Learning and Cultural Heritage. He will supervise the two post-doctorants in digital humanity and computer science. **Frederic Devillers** is a research engineer, working at the CERV. He will contribute to the technical supervision of the post-doctorant who will be recruited in computer science. **All researchers of the SeaLex project** will be also involved to provide environmental and archaeological data and to contribute to the development of mediation and pedagogical scenarios. Again, this collaboration between computer scientists and geoarchaeologists is completely new at the scale of the University of Western Brittany.

# 3 - Expected outcomes

## 3.1 Expected follow-up of the project

### A project strengthening research/training interactions

We note that in the current IsBlue training programs, paleoenvironmental sciences do not sufficiently study the anthropogenic component of the socio-ecosystems. At the University of Brest, we also note that Humanities (history/archaeology) do not pay enough attention to the environmental aspects of past societies. The interdisciplinary SeaLex project aims to decompartmentalize the environmental sciences, humanities and engineering sciences by offering new courses and teaching contents common to these three fields of science. We aim to introduce and develop different forms of research activity and to create conditions that motivate students' participation in this specific research works. **In licence degree**, we will propose to all UBO students a **new course (*UE libre*) for an introduction to complex environmental issues and interdisciplinary approaches**, based on research carried out on the territory of the LTSER-France site ZABrI. We also offer **new courses for PhD and Master 2 students** to deepen the different concepts, methods and research tools used in the SeaLex project. We will be also concerned about the real job opportunities for students in the academic research and in other sectors of the economy interested by the project (tourism, natural and cultural heritage institutions).

### A project strengthening science/society interactions

Coastal areas, particularly in Brittany, have an exceptionally rich and diverse natural and cultural heritage that is a factor in attracting tourists and promoting economic development. In Brittany, tourist activity represents 8.1% of GDP (2.300 million euros in economic spin-offs) and around 1.3 million people have visited historical and archaeological sites in 2018. Surveys carried out among tourists indicate that the two criteria for choosing Brittany are (i) coastal landscapes (70% of respondents) and (ii) cultural heritage (38% of respondents). The SeaLex project aims to respond to a strong social demand to better understand the human-environmental interactions, through the enhancement of cultural and natural sites with high potential, through the development of innovative tools using virtual reality. Concrete actions in this direction began in 2019 as part of an INTERREG project to develop "Bio-Cultural Heritage Tourism" in several natural protected areas in France and England. In the Molène archipelago, the natural parks have involved several researchers of the SeaLex research team to create mediation tools to visualize past landscape changes and discover ancient archaeological sites in virtual reality. These tools are currently being developed and will be exhibited in various museums in the region and in tourist offices. The virtual tools will be used to raise awareness of environmental issues, coastal changes and the enhancement of cultural heritage, with the aim of providing a narrative of coastal societies' occupation over time. In order to raise awareness of these aspects among young audiences, the development of a video game such as escape game appears as a perfectly adapted response in the future. The dissemination of the results to public institutions such as the Marinarium of Brest (Oceanopolis) and the national education system is also considered in the next years.

### A project strengthening science/innovation interactions

The SeaLex project will implement various innovative tools and approaches that will open up new research perspectives. The analysis of ancient DNA preserved in shells is still experimental, but the expected results are likely to open up great opportunities to study past marine biodiversity and the impact of human fishing and collecting activities on ecosystems. Virtual reality and augmented reality tools are expanding and offer many opportunities to build new methods for communicating scientific results, in order to make research results easily accessible. Finally, the interactive digital poster system (*Evol'Iroise*) that we wish to develop within the framework of SeaLex reinvents the scientific poster and opens up many perspectives for the valorization of research data, creating new ways of communicating and transmitting knowledge.

## 3.2. A first step toward more ambitious projects with new international partners

### Strengthening collaboration with Canada

The SeaLex project will consolidate newly established collaborations with different international teams involved on common field works. In the Saint-Pierre-et-Miquelon archipelago, a Franco-Canadian geoarchaeological research program began in 2019 with scientific members from Isblue (P. Stéphan) and Canadian geomorphologists and archaeologists from ULAVAL and UQAR. The objectives of this project are to (i) retrace prehistoric human occupations and (ii) reconstruct environmental changes over the past millennia. Until now, almost nothing was known about archaeology in this archipelago. In September 2019, the first archaeological prospecting mission identified 4 shell middens that offer interesting opportunities to study some aspects of past societies (material culture, resources consumed, fishing practices, periods of use, etc.), and to study marine paleo-biodiversity and temperature variations in coastal waters. In the next years, these shell middens will be sounded by archaeologists and the possible discovery of black clam (*Arctica Islandica*) into these deposits could offer great opportunities for paleoclimate reconstructions from sclerochronological skills developed by the International laboratory BeBest. In August 2020, a sediment coring mission will be carried out by a Master 2 SML student co-supervised by G. Marie (UQAR) to study the relative sea-level variations and the Holocene glacio-isostatic adjustment in the archipelago.

### Use the European's Universities Network SEA-EU

At an international scale, we plan to create strong research links with the universities of Kiel and Cadiz (identified as leaders in Europe) through the hosting of guest researchers (we are thinking of Johannes Müller from Kiel and Salvador Domínguez-Bella from Cadiz) and international post-docs.

### Strengthening collaboration into the European Research Network PrehCOAST (CNRS)

At the European level, the SeaLex project will strengthen the collaborations initiated in the International Research Network PreCOAST (Coast-inland dynamics in prehistoric hunter-gatherer societies) supported by the CNRS from 2019 to 2023. The initial phase of the PRECOAST research group involves researchers from Spain (Santander), France (Bordeaux, Brest, La Rochelle, Paris, Rennes, Toulouse), Latvia (Riga) and Norway (Oslo). It integrates archaeologists and palaeo-environmentalists involved in the exploration of coastal societies of Prehistoric hunter-gatherers (Paleolithic, Mesolithic, Neolithic). It aims to overcome certain national divisions in the assessment of cultural or environmental processes on a continental scale, but also to help develop archaeology adapted to similar parameters and constraints. This concerns the very nature of these prehistoric societies whose subsistence is based on maritime resources, but also the concepts necessary to renew their study. Working in both marine and continental environments implies the use of geophysical prospecting methods or very particular excavations. The IRN PreCOAST takes a great interest in the historical role of coastlines as a privileged means of circulation, whether for exchanges or migrations, in order to write a connected European prehistory. The researchers involved in the SeaLex project have already planned to organise an international workshop in May 2020 in Brest bringing together the scientists involved in IRN PreCOAST. This workshop is untitled "Investigate the shore, sounding the past: new methods and practices of maritime prehistory" and will be an opportunity to define common fieldworks and to build common programs at national and international levels.

### Promote SeaLex at major scientific events

We also want to propose sessions on the theme of "human-coastal environmental interactions during the Holocene" in the next international congresses (Congress of the Association de Sédimentologie Française scheduled to take place in Brest in 2021 / session dedicated to the EGU in 2021).

### To be represented in international organizations

We also plan to integrate the Advisory Body of the Underwater Cultural Heritage of the UNESCO program. This follows the UNESCO International Conference held in the city of Brest in June 2019 and will provide broad visibility for ISBLUE in international organizations and opportunities to integrate international programs.

## 3.3 Impact of the project on ISblue training

### New interdisciplinary free course in licence degree

During their first three years at the University of Brest, students must choose 2 free courses (corresponding to 2 or 3 ECTS) which offer activities complementary to their initial discipline and provide the opportunity to acquire new knowledge. We plan to propose a new free course (*UE libre*) based on the interdisciplinary approach (Archaeology, Biology, Geomorphology, Geology, Palynology, History) developed in the SeaLex project.

### New Master degree or course for PhD students

A Declaration of Intent was submitted to ISBLUE in March 2019 to propose a training project in coastal archaeology to be co-led by the University of Western Brittany (UBO) and the University of Southern Brittany (UBS), that will strengthen the partnership within the different universities of Brittany. This action will result in a resolutely interdisciplinary approach, with bridges between humanities, natural and engineering sciences within a common training programme.

### International collaborations into the SEA-EU universities network

Within the framework of SEA-EU, we aim to open up and establish strong links with European universities such as Kiel and Cadiz through exchanges of Master students and PhD co-supervision. This partnership with these sea-oriented universities and, moreover, with research teams dedicated to archaeological research in coastal areas is an opportunity because it should enable us to pool our skills to respond to calls for projects on a larger scale.

### A geoarchaeological project on the island of Jersey

The Island of Jersey is the second field of study on which the SeaLex project team will strengthen these international collaborations, in particular with archaeologists from London University and the Société Jersiaise. After an initial survey mission on the foreshore carried out in 2019 by one of us (YP), a larger team will go in the spring to carry out surveys with several objectives:

-mapping numerous dolerite blocks on the foreshore that could in some cases correspond to partially dismantled megalithic monuments (alignments, enclosures);

-to carry out fine prospecting work around Neolithic massive grinding stones in order to see if there are any remains of dwellings (dry stone walls, erected blocks).

-study the architecture of numerous fish traps and stone passages built to cross tidal channels. It is not excluded that some of these structures had a dual function. At the same time, carry out a micro-toponymic study to see if there are any evocative toponyms.

-reexamine the heavily sea-eroded Green Island islet where a necropolis of cists was unearthed during excavations carried out by R.G. Warton in 1913. In addition to the tombs, several shell middens are also mentioned. If at least part of these were still visible, we would try to take samples from them, as they could provide a great deal of information on the nature of these occupations and the paleoenvironments.

### Translating the theoretical into practical: summer workcamps students

A modern Master degree must promote the development of the students' creative/critical thinking, reasoning abilities and research skills. Students need to possess not only the necessary amount of basic and specialized knowledge, but also certain creative skills for solving practical problems, be able to adapt quickly to changing conditions and constantly improve his skills (Ruchinaa et al., 2015). We believe that field missions offer the unique experience of being able to develop these kinds of skills. For this reason, we are planning to set up a summer workcamps students starting in the summer of 2021. This workcamp will be supported by the ARMERIE program (*Archéologie Maritime et Recherche environnementale*), funded by the University of Brest (UBO) over the period 2020-2022 whose aim is to promote archaeological research at the UBO in strong interaction with the marine sciences developed within IsBlue. The researchers involved in the SeaLex project will participate in the scientific supervision of this camp. This workcamp will be open to Master students of the universities of the SEA-EU network. It is conceived as an annual 10-day field mission in complete immersion with the scientific staff. Situated near the city of Brest, the island of Béniguet is envisaged to host this workcamp as there are many archaeological sites dating from the Neolithic to the medieval period, very rich shell middens, a very mobile shoreline and well-

preserved sedimentary archives. We plan to conduct archaeological excavations, geophysical prospecting campaigns and core sampling with students.

**An interactive poster for scientific presentations: Evol'Iroise**

A new tool of scientific mediation named « Evol'Iroise », is planned for the next months and will be updated in the future. It is a digital and interactif poster illustrating the changes in the ecosystems of the Iroise region, the territory of the LTSER site "Zone Atelier Brest-Iroise". This tool for mediation will be used to highlight the scientific works in progress, and the results on this territory, with different approaches and disciplinaries. The first scenarii will be constructed around the geomorphology, palynology, climatology, archaeology, and sclerochronology approaches over the Holocene temporal window. Based on web technologies and requiring no knowledge of computer coding, it will be easy to modify its content in order to integrate the new data and scientific studies in the future. This project is aimed at large audiences, not only to scientific mediation but also to the training of students. It will be a good pedagogic support for the different masters within the graduate school EDSML.

# 4 - Resources and budget

## 4.1. Overview of the budget asked

| WPs | Budget items | Requested to ISblue (k€) | Obtained (k€) | Sources of fundings |
|---|---|---|---|---|
| WP1 | • M2 internship (6 months) x 6 | 0 | 21 | ARMERIE Program (UBO funding) |
| | • Field missions (Jersey, Brittany) | 0 | 10 | ARMERIE Program (UBO funding) |
| | • Congress organisation | 0 | 14 | ARMERIE Program (UBO funding) |
| | • 2-yrs Reseach Engineer (half-time job) in 2020 and 2021 | 0 | 36 | ARMERIE Program (UBO funding) |
| | • 1-yr Reseach Engineer (full-time job) in 2022 | 36 | 0 | * |
| | • 1-yr post-doc for sclerochronology-aDNA | 42 | 0 | * |
| | • Costs of sclerochronological and aDNA analysis | 15 | 5 | ARMERIE Program (UBO funding) |
| WP2 | • PhD - Geoarchaeology | 94 | 0 | * |
| | • Field missions (Saint-Pierre-et-Miquelon) | 20 | 15 | DRAC Bretagne |
| | • 1-yr post-doc for palynology | 42 | 0 | * |
| | • Costs of analysis | 15 | 15 | ARTEMIS Program for 14c datings |
| WP3 | • 1-yr post-doc for modelisation | 42 | 0 | * |
| WP4 | • 7 months post-doc in Digital Humanities | 24,5 | 0 | |
| | • 10 months post-doc in Computer Science | 35 | 0 | |
| | • External prestation | 10 | 0 | |
| SeaLex project | • Dissemiation of results (congress, papers, etc) | 20 | 10 | IRN PreCOAST (CNRS) |
| | • Evol'Iroise scientific mediation project | 5 | 10 | Marine Protected Area (PNMI) |
| | **TOTAL:** | **400,244** | **136** | |

**The total budget asked for the SeaLex project is of 400.244 euros.**

## 4.2. Justification of the costs.

**WP1- Past coastal societies: distribution, chronology and lifestyles** — **Total request: 93 K€**

**• Post-doctoral support in sclerochronology (1 year).** — **Budget request: 42 K€**

The recruited post-doctorant will develop sclerochronological and aDNA studies in the same individual shells from Iroise Midden. This combined approach has never been carried out until today, and offers very promising perspectives based on ISBLUE specific competency. Of four or five reference sites in the Iroise Sea area,

sclerochronological and aDNA investigations will be conduct on individual of the dominant species constituting the shell middens. Sclerochronological preparations will be conduct following the protocols developed at the IUEM (embedding, sectioning, and polishing) at the Lemar laboratory. Carbonate samples will be drilling at the most pertinent resolution scale along the shell using Micromill (NewWave Research MicroMill 300 µm wide drill bit), and analyze for Carbon and Oxygen stable isotopes on a KIEL IV carbonates device coupled with a Finnigan MAT-253 mass spectrometer. ICMPS study will be also be realize conducted on laser ablated carbonate sample from the same individuals for trace elements already calibrated for biological carbonates from the same coastal waters. To avoid contamination, aDNA sampling will be done preceding the sclerochronological process. aDNA will be extracted from the shell powder in a platform dedicated to ancient DNA following adequate tools and controls and under strict criteria required to authenticate the results as already described by Der Sarkissain et al. (2017). The post-doctoral, will analyse aDNA from individual shells to identify the species of molluscs, but also to potentially determine the aDNA embedded inside the shell matrix (bacteria, protists, cells from macroalgae....) (Paillard et al., 2019). The post-doc will also design capture probes targeting each group of interest to enrich extracted DNA before sequencing also the sediment matrix of the shell middens (Slon et al., 2017).

**• Costs associated with the sclerochronological and aDNA analyses.** **Budget request: 15 K€**

These costs are estimated at 20 K€. We ask 15 K€ to IsBlue.

**• Research engineer support in coastal archaeology (1 year).** **Budget request: 36 K€**

The aim of WP1 is to build a structured database of coastal archaeological sites in western Brittany and the archipelago of St-Pierre and Miquelon. This work will be coordinated by Yvan Pailler, archaeological research engineer. From 2020 to 2022, Yvan Pailler will be employed by the ARMERIE program funded by the University of Brest. During these first two years, part of Yvan Pailler's working time (30%) will be devoted to the SeaLex project. For the year 2023, a full time position of research engineer is requested in order to finalize the database and cross-check the results with the work of the other WPs.

**WP2-Environmental coastal changes and forcing: reconstructions from sediment archives**

**Total request: 171 K€**

**• PhD in Geoarcheology.** **Budget request: 94 K€**

The recruited PhD student will be supervised by Pierre Stéphan and Serge Suanez, as well as Guillaume Marie (UQAR). The objective of this thesis in geoarchaeology will be to study past and present erosion and sedimentation processes in the Saint-Pierre-et-Miquelon archipelago and to analyze their role in the distribution and conservation of archaeological remains. The PhD work will be conducted in collaboration with archaeologists and geomorphologists from Canada and France involved in the archaeological research program funded by the DRAC-Bretagne on the period 2019-2022. The relative sea-level rise and the periods of major storms will be reconstructed from several sedimentary cores extracted into the many salt-marshes distributed in the archipelago. The SLIPs method will be used to better define the Holocene relative sea-level rise and the role of glacio-isostatic adjustments. These results will be cross-referenced with an analysis of visible coastal stratigraphies, in particular the dating of raised beaches that indicate ground uplift associated with the retreat of the Laurentide Ice Sheet. Part of the PhD work will also be devoted to the detection of archaeological remains based on already available Lidar data and field observations. On the sites investigated by the archaeologists (in particular shell middens), the PhD student will carry out a detailed analysis of the stratigraphy (sedimentology, geochemistry, datings). Finally, the PhD work will focus on the coastal erosion dynamics currently affecting the archipelago's coasts. Monitoring of the coastline will be set up on endangered archaeological sites, in collaboration with the local authorities (DTAM). This work will make it possible to estimate current erosion rates and assess the priorities for intervention on eroding sites. This work will enable the issues associated with archaeological heritage to be taken into account in public strategies concerning coastal risks.

**• Field missions to Saint-Pierre-et-Miquelon.** **Budget request: 20 K€**

Costs associated with field missions include transportation, food, accommodation and shipping of scientific equipment to the field.

# Application file 2019

# Flagship projects – Phase 2

**• Post-doctoral support in palynology (1 year).** **Budget request: 42 K€**

In the WP2, the post-doctoral fellows of 1 year will perform marine palynological analyses on two hemipelagic cores (MD04-2835 and MD95-2002). She/He will conduct pollen grain and dinoflagellate cyst identifications so as to reconstruct continental (vegetation) and marine (phytoplanctonic) changes through bio-indicator assemblages. From thoses analyses, she/he will quantify climate parameters on land (temperature, precipitations) and hydrological parameters (sea-surface temperature and salinities, past regimes of primary productivity) thanks to transfer function applied to both proxies, and she/he will discuss these informations in parallel with numerical simulations of WP3 for the Bay of Biscay.

**• Costs associated with palynological and geomorphological analysis.** **Budget request: 15 K€**

These costs include the preparation of palynological slides, consumables (chemicals and coring equipment).

**WP3-Numerical models of past coastal hydrological processes** **Total request: 42 K€**

**• Post-doctoral support in numerical simulation (1 year).** **Budget request: 42 K€**

In the WP3, the post-doctoral fellows will deploy the configuration based on the information (particularly for the external forcings) from the project consortium. From the performed numerical simulations he/she will analyze results considering observations collected in the WP2. From those analyses, he/she will improve the understanding of the Bay of Biscay circulation for the considered scenarios. Results will be discussed in the European framework around Bay of Biscay dynamics including colleagues from Spanish institutes (AZTI, San Sebastian; IEO, Santander).

**WP4-The development of virtual reality tools** **Total request: 69.5 K€**

**• Post-doctoral support in digital humanity (7 months).** **Budget request: 24.5 K€**

The recruited post doctorant will carry out, first, studies on domain ontologies. Based on the analysis of the results of WP1, 2 and 3, the post-doctoral fellow will be in charge of formalizing the semantics of the models/data obtained in order to make them interpretable by a scenario engine in a virtual environment. The post-doctoral fellow will also be in charge of proposing mediation scenarios and pedagogical scenarios to effectively present the results obtained in WP1, 2 and 3.

**• Post-doctoral support in computer science (10 months).** **Budget request: 35 K€**

The recruited post doctorant will contribute to the technical realization of the interfaces between the databases used in WP1, 2, 3 and the virtual environment. It will also contribute to the creation of virtual and augmented reality scenes and the implementation of generic generation methods as well as the implementation of metaphors. Finally, it will contribute to the implementation of tangible interactions for temporal navigation in the virtual environment.

**• Subcontract with a company who is a specialist of 3D models.** **Budget request: 10 K€**

Some elements of the virtual environments cannot be reconstructed automatically (housing, graves, etc.). They will therefore require a reconstruction based on plans imagined by the WP1 researchers for example. This task is very technical, requires specialists and does not contribute directly to the scientific aspect of this project. We therefore plan to subcontract the geometrical reconstruction of certain elements.

**The file must be uploaded to the ISBLUE server, in a single PDF**