4D COASTAL FLOOD ANALYSIS AND VISUALISATION FOR URBAN AREAS

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Abstract
Without adaptation, 0.2 to 4.6% of the global population may be flooded annually in 2100 with scenarios of 0.25 till 1.23 m global mean sea level rise. Therefore, it is necessary that local governments engage and educate the local community in order to adapt to the impacts of sea level rise. To this point, we developed a comprehensive four-dimensional (4D, i.e. 3D and time) flood visualisation WebGIS (Web-based Geographic Information System), as it quickly conveys strong messages, condenses complex information, engages people in issues of environmental change, and motivates personal actions. This paper describes the developed landscape visualisation of a flood model simulation for the coastal town of Ostend (West Flanders, Belgium) and presents practical considerations for future studies. This research proposes an adaptation plan with a series of practical measures to be introduced by 2050, for example, inserting gates where needed, sluices to prevent ingress of water into drains, raising floor levels in vulnerable town centre properties, and installing breakwaters. This local-scale assessment is a step towards helping the community to understand coastal flood events and how they might change with sea level rise and storm surge events.

Keywords: *Coastal flooding, sea level rise, storm surge events, landscape visualisation, flooding analysis, evacuation analysis*

INTRODUCTION

Several studies have reported increased flood risk in coastal areas worldwide [1][2][3]. A recent study published by R. M. Deconto et al., (2015) in the journal *Nature* asserts that sea levels will rise much faster than expected in the coming decades because the Antarctic ice sheet is less stable than had been assumed until now [4]. Due to the effects of sea level rise and an increased frequency and severity of storm events due to climate change [5], it is generally assumed that flood risks will increase significantly in the 21st century. All future climate models predict that the frequency and intensity of extreme weather phenomena (e.g., wetter winters, drier summers) will increase in the future. Approximately 8.7% of the world's population lives in low elevation coastal areas below 10 m [1,2], and these zones are vulnerable to the destructive power of coastal flood events. Extensive damage to energy and transportation infrastructure and disruptions to the delivery of services will temporarily disrupt the society. Immense damage to buildings, a devastating toll on the public's health, and even significant loss of life are the possible risks of coastal flood hazards. This paper describes the developed WebGIS (Web-based Geographic Information System) landscape visualisation of a flood model simulation for the coastal town of Ostend (West Flanders, Belgium) and presents practical considerations for future studies.

BACKGROUND

Approximately 234.540 people live in the low-elevation coastal area polders at the Belgian coastline. The Belgian coastline is 67 km long and consists mostly of sandy beaches with sea walls in front of the cities and dunes in between. It is situated at the southern part of the North Sea between the Netherlands and France. Next to the Netherlands, Belgium is the most vulnerable country to flooding in Europe due to rising sea levels. Moreover, the Belgian coast proves to be the most built-up region of Europe [8]. Ostend is a major tourist and economic midpoint in the Belgian province of West Flanders, which is located approximately in the centre of the Belgian coastline and has a population of 70.460 inhabitants [9].

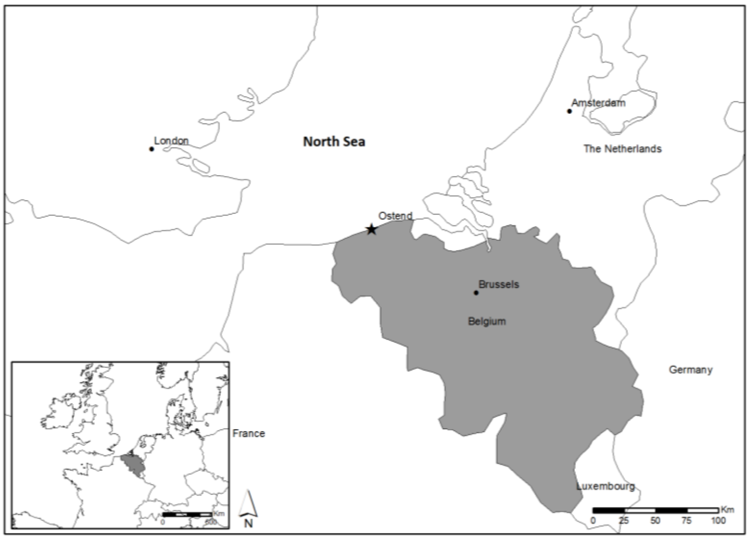

Figure 28. Location of coastal city Ostend, Belgium

Due to its high level of urbanization (population density of 1862 inhabitants/km²) and its position nearby the relative open harbour, Ostend is fairly sensitive to flood hazards. The storm surge of 1 February 1953 resulted in an extensive flood in Ostend and the loss of several citizens. Among other coastal towns, Ostend suffered immense damage to their sea walls. In response to that, sea walls were heightened and reinforced, yet insufficiently enough to protect against a more severe storm surge than the one from 1953. Statistical analysis of measured sea level at the Belgian coast shows that the annual average sea level in 2013 was significantly higher than at the beginning of the time series in 1951. The sea level rose 115mm in Ostend from 1951 to 2013 [8].

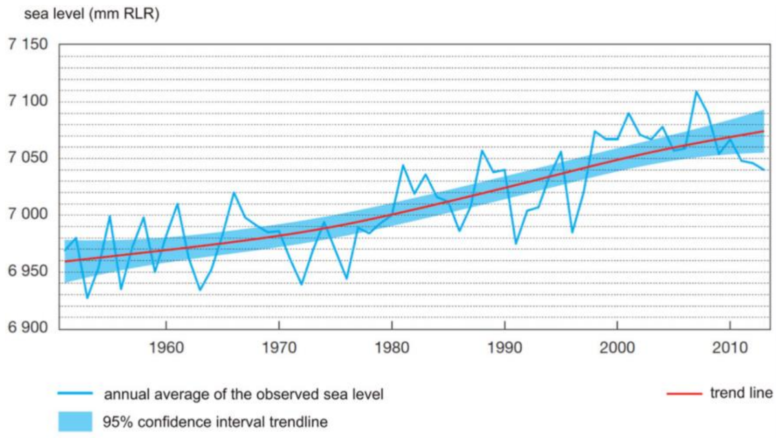

Figure 29: Evolution of sea level on the Belgian coast (Ostend, 1951-2013)[8]

Due to sea level rise and the high economic activity in Ostend (or Oostende in Dutch), Ostend suffers a high economic vulnerability for coastal flooding (see Figure 30: Indication of areas with a high economic vulnerability on the Belgian coast [10]Figure 30) [10].

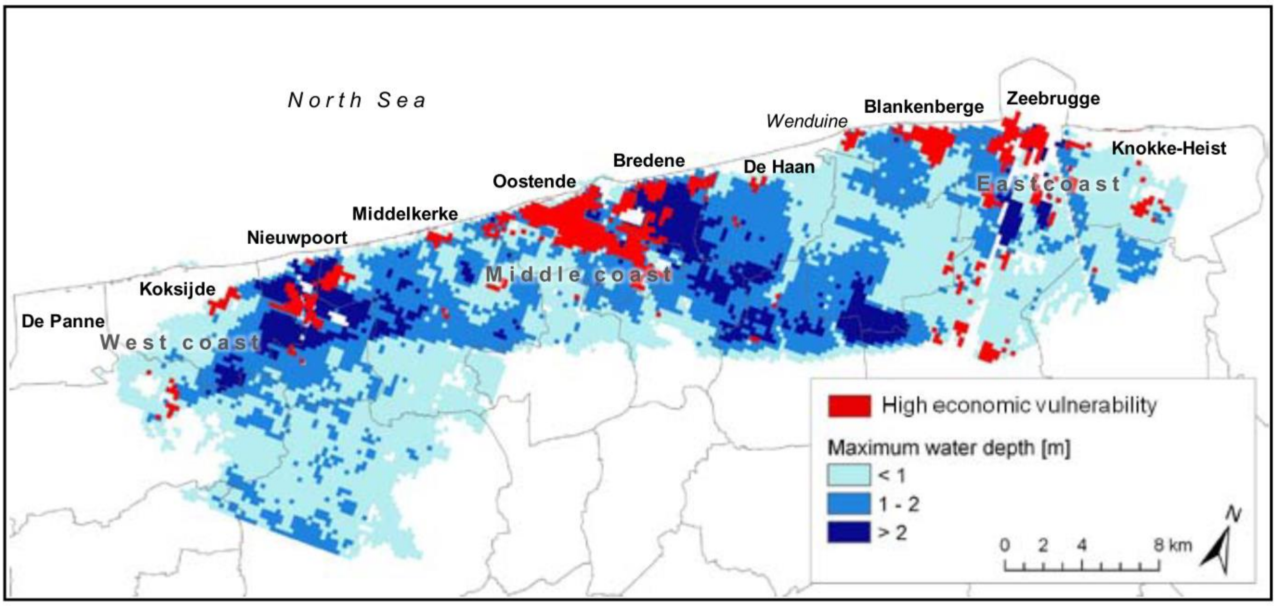

Figure 30: Indication of areas with a high economic vulnerability on the Belgian coast [10]

The flood management strategy in Flanders has taken a focal turn from a flood control approach to a risk-based approach due to the predicted growth of flood hazards [12]. This yielded an important change from focusing on protection against a certain water level to protection against the consequences of a flood surge while considering its probability. This risk-based approach computes the probability a flood will occur within a certain time period (e.g., 50 years) [13].

The 2011 study "Masterplan Coastal Safety" [14] assesses that more than one third of the coastal cities were not sufficiently protected against a super storm. Consequently, the flood risk calculation output was not acceptable.

Table 7: An overview of the flood risks (for conditions in 2006) in the Belgian coastal area[15]

FLOOD RISKS IN THE BELGIAN COASTAL ZONE			
Storm surge level	Return Period	Deaths	Direct economic damage
+ 6.5 m TAW	~ 100 year	41	0.67 billion euro
+ 7 m TAW	~ 1000 year	251	2.1 billion euro
+ 7.5 m TAW	~ 4000 year	885	3.9 billion euro
+ 8 m TAW	~ 17000 year	3297	6.5 billion euro

In this flood risk calculation, the number of casualties and economic damage has been assessed for a range of storm surge levels. Since these results were published, there has been an increasing trend in yearly volumes of sand for beach and foreshore nourishments (supplied by dredgers).

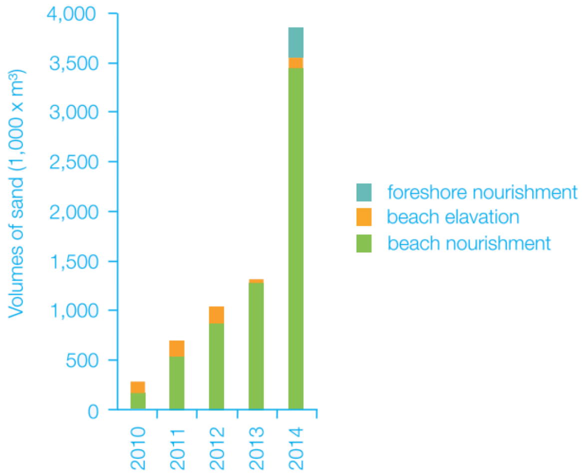

Figure 31: Yearly volumes of sand for beach nourishments[15]

Since 2010, work has clearly been done to improve coastal safety at the Belgian coast. Despite the attempts to improve coastal safety, however, many people remain unaware of coastal and environmental affairs. Mayors of coastal cities, aldermen, and other policy makers are in general fearful to instill anxiety in the local population who are at risk at times of coastal flood hazards. Unfortunately, authorities work from the principle “let sleeping dogs lie” and do not inform inhabitants about the risk related to flood hazards. Consequently, public awareness lags behind. Afraid to be criticized in media and afraid of creating panic and commotion among the public, authorities are careful with spreading information. Yet lack of public awareness equals lack of motivation among people to support changes in coastal landscape or to even protest necessary measures to improve coastal safety. Although these changes are made with good intentions, such modifications and transformations are criticised by environmental organizations, research centres, the population, etc.

COMMUNITY AWARENESS

This paper is written in the framework of the research project CREST (Climate REsilient coaST) [16]. This project aims to increase resilience in areas of coastal flooding caused by extreme weather events and intends to create wider community awareness of flooding and promote adaptation actions. For example, urban green vegetated roofs and permeable paving and gardens could ease flooding woes. Satellites and warning systems would save lives in flood-prone coastal areas when a 1000-year storm arrives. Since extensive temporarily damage to energy infrastructure would disrupt society, vital agencies (e.g., traffic centres, hospitals, etc.) could install emergency energy facilities (e.g., batteries). Vital infrastructures located at the coast (e.g., airports) would have an immense economic impact if affected. Although it comes at a staggering cost to protect these vital infrastructures, the benefits far outweigh the risks.

If coastal cities want to prepare themselves at every scale and at every opportunity, the local community has to be involved in this matter. Informing people why decisions have been made in spatial planning and demonstrating the consequences of said choices allows the community to discuss and debate whether to protect areas by raising buildings or, on the contrary, retreat from the coastline to allow the migration of important natural systems, such as wetlands. By involving and informing the community, people are more prepared to adapt to climate change. To create this wider community awareness, there is a need to educate the local inhabitants of the potential danger of coastal flood events.

By visualising the consequences of all possible practical adaptations (e.g. inserting gates where needed, sluices to prevent ingress of water into drains, raising floor levels in vulnerable town centre properties, installing breakwaters, etc.), people are more informed and will support decisions if they have the feeling they are involved and their opinion is valued. This local-scale assessment is a step towards helping the community to understand coastal flood events and how they might change with sea level rise and storm surge events.

USER FRIENDLY INTERACTIVE WEBGIS TOOL

Lack of public awareness can be remedied with the use of better understandable and user-friendly interactive WebGIS mapping tools. Because WebGIS maps quickly convey strong messages, condense complex information, engage people in issues of environmental change, and motivate personal actions, the CREST project focuses on searching the ideal flood assessment WebGIS method to encourage people to mitigate and adapt to climate change. It is clear that it takes more effort to create a useful WebGIS tool for flood hazard visualisation than just visualising static 2D layers.

For instance, to make it easier to imagine the consequences of flooding and to make a map more realistic and detailed, an additional 3D visualisation of the landscape (for example, in the form of a split screen) is needed. Surveys showed that 3D visualisations have an enormous added value because 3D visualisations are more vivid and therefore more understandable and make it easier to imagine the consequences of the flood then 2D visualisations. The open question about the added value of the 3D visualisation in respect to the 2D visualisation is answered with the following statements:

- It makes it simpler to imagine the consequences of the flood.
- It enhances prediction of what a flood means for an area and helps people to better empathize with the situation.
- It is more realistic and detailed. It is easier to interpret various outcomes.
- It is more vivid and therefore more comprehensible.
- Less interpretation is required to estimate the consequences of the flood.
- It helps the user to better understand how serious the flood is.
- It better shows the consequences for the environment. [17]

Nevertheless, it is easier to assess on a 2D map where the maximal contour of the flood occurs in comparison with the estimation of the position of the maximal flood contour on a 3D map. Therefore, 2D visualization is not replaceable by a 3D visualization, because 3D maps cannot take over all functionalities and perfect representations inherent to 2D maps. The addition of a 2D visualisation together with a 3D visualisation (for example by using a split screen) is therefore recommended.

Because we are dealing with visualising changing events (e.g., approaching hurricanes, altering wind velocity, moving flood situations, etc.), we can use time-enabled WMS layers since they have the advantages of visualising, altering, and shifting events [18]. Thus, it is possible to visualise the intensity or velocity of a flood or the rising velocity of the water in a specific location. Furthermore, it is possible to assess how long it takes before a specific area is flooded. This information is desperately needed for evacuation and transport possibility assessment and damage to infrastructure estimation. With this time-enabled WMS layer, it is possible to embed the output of flood modeling software such as TUFLOW, Flood Modeller, MIKE FLOOD, TELEMAC, OpenFoam, etc., in a WebGIS environment.

COASTAL FLOOD VISUALISATION WEBGIS TOOL FOR URBAN AREAS

For the coastal city Ostend, a realistic and comprehensive four-dimensional (4D, i.e. 3D and time) flood visualisation tool is created by using Ol3-Cesium Openlayers [37] [38]. Ol3-Cesium uses WebGL and is written in Javascript, which is an open standard that visualises 3D-computer graphics in a webpage without using special plug-ins for web browsers. Ol3-Cesium automatically creates a virtual globe side-by-side the existing OpenLayers3 map by adding a 3D web library. The globe camera and the map view (centre, resolution, rotation) are bidirectionally synchronized, interacting on one updating the other. Thus, the Ol3-Cesium virtual globe follows synchronous when the OpenLayers3 map is manipulated (zooming, panning, etc.).

3D visualization of buildings are embedded in the WebGIS Ol3-Cesium tool. Features such as vulnerability, maximal damage, dimensions of a building, time to evacuate safely from a specific location when a storm surge appears, potential improvements to a property or area, the maximal height of the storm surge for a certain building, etc., can be obtained by the user by clicking on the objects. By adding a timeline to the WebGIS tool, it is possible for the user to choose for which situation (1953-2016) the flood event ought to be visualised. Hereby, it is possible to request the features for a certain building for a specific period. By adding the time feature to the WebGIS tool, a four-dimensional (4D, i.e. 3D and time) flood visualisation tool is created. This makes it possible for the user to see what steps have already been taken and the positive result such actions have had on the surroundings. This tool will reassure inhabitants that coastal safety has been taken care of and which improvements will be tackled in the future.

Layers will be embedded in the WebGIS tool to visualise potential 1000-year storm surge events for situations over the years 1953 to 2016. With this tool, it will be possible to visualise the situation for a storm surge in February 1953, exactly as it happened in 1953, while also projecting data onto a situation in 2016. Therefore, positive progress of coastal protection is emphasized, meanwhile creating a positive impact on people. Presenting immediate and wider perspective on storm surge events over the years will dissuade protest and encourage discussion and positive constructive criticism among the community.

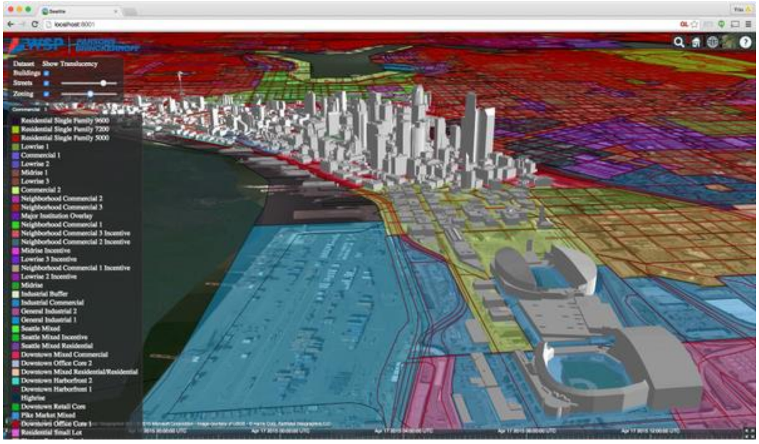

Figure 32: Screenshot of Ol3-Cesium web-based map [19]

CONCLUSION

More than 634 million people, or approximately 8.7% of the world's population, live in low elevation coastal areas below 10 m. Several studies have reported increased flood risk in coastal areas worldwide. Although scientists widely stress the compelling need to mitigate and adapt to climate change, public awareness lags behind. Mayors of coastal cities, aldermen, and other policy makers are in general fearful to instill anxiety in the local population who are at risk at times of coastal flood hazards. Therefore, authorities work from the principle “let sleeping dogs lie” and do not inform inhabitants about the risk related to flood hazards. Lack of public awareness equals lack of motivation among people to support changes in coastal landscape or to even protest necessary measures to improve coastal safety.

To this point, we developed a comprehensive four-dimensional (4D, i.e. 3D and time) WebGIS visualisation tool, as it quickly conveys strong messages, condenses complex information, engages people in issues of environmental change, and motivates personal actions. This paper describes the developed WebGIS of flood simulations for the coastal town of Ostend (West Flanders, Belgium) and presents practical considerations for future studies.

3D visualization of buildings are embedded in the WebGIS Ol3-Cesium tool, whereby data can be obtained by the user by clicking on the objects (maximal flood height, maximal economic damage, etc.). By adding a timeline to the WebGIS tool, it is possible for the user to choose for which situation (1953-2016) the flood event ought to be visualised. It is thus possible to request the features for a certain building for a specific period. Layers will be embedded in the WebGIS tool to visualise potential 1000-year storm surge events for situations over the years 1953 to 2016. With the tool, it will be possible to visualise the situation for a storm surge in February 1953, exactly as it happened in 1953, while also projecting data onto a situation in 2016.

This 4D WebGIS tool makes it possible for the user to see what steps have already been taken and the positive result such actions have had on the surroundings. Presenting immediate and wider perspective on storm surge events over the years will dissuade protest and encourage discussion and positive constructive criticism among the community. This tool will reassure inhabitants that coastal safety has been taken care of and which improvements will be tackled in the future. Therefore, positive progress of coastal protection is emphasized, meanwhile creating a positive impact on people and communities.

ACKNOWLEDGEMENTS

This paper is written in the framework of the research project CREST (Climate REsilient coaST) [16]. This project aims to increase resilience in areas of coastal flooding caused by extreme weather events.

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BIOGRAPHY

Samuel Van Ackere

Samuel Van Ackere is a PhD student of Geography at Ghent University as of 2015. His research focuses on the risk of coastal flooding and the impact of wave overtopping during extreme storms on structures, buildings, and people. Low-elevation coastal areas are vulnerable to the effects of sea level rise and an increased frequency and severity of storm surge events due to climate change. Therefore, his project aims at finding adaptive solutions that increase the resilience of these zones. His project focuses on creating a socio-economic impact assessment tool which models and estimates risk and provides evacuation maps.

Hanne Glas

Hanne graduated in 2013 with a Master of Science in Geomatics and Surveying at HoGent-Ugent. She is currently working as an assistant in the Ghent University Industrial Engineering–Surveying program as of May 2014. She is also researching flood risk assessment in the SIDS (small island developing states) for her PhD.

Annelies Vandenbulcke

Annelies Vandenbulcke started working at the Department of Geography at Ghent University in 2014. Within the framework of her PhD, she researches to optimize the integration of a laser scanner, a global navigation satellite system (GNSS), and an inertial navigation system (INS) to be used for hydrographic applications. As an academic assistant, she supervises several courses in which students acquire practical training on the general principles of 3D data-acquisition techniques, more specifically laser scanning, photo modeling, and survey engineering.

Cornelis Stal

Dr. Cornelis Stal is a post-doctoral researcher with experience in the field of the combination, processing, and quality analysis of airborne and terrestrial laser scanning for 3D city modeling. His special interest is in the (automatic) generation of geometric, radiometric, and semantic-rich 3D models, derived from irregular point sets and other spatial data sets. This means that both laser scanning as a discipline in the land survey and geo-IT (GI-systems, GI-programming, GI-management) are important pillars of his research. Recent research opportunities have allowed him to add an additional focus on geomatics applications for bathymetric modeling. He is currently working on the analysis and processing of GNSS data acquired from tidal buoys.

Michiel Decock

Since October 2015, ir. Michiel Decock has beena scientific researcher at the Department of Geography at Ghent University. His focus is primarily set on the development of efficient algorithms in the treatment of point cloud data.

Greet Deruyter

MSc in Civil Engineering Technology (1984), MSC in Land Survey Engineering Technology (1995), Doctor of Science: Geography (2005). From 1984 until 1992, Greetwas employed at Volo Cars Europe, consecutively as production planner, applications analyst, and system manager. From 1993 until 2013, she was part of the academic staff of University College Ghent. Since 2007, she has beenaffiliated withUGent as a visiting professor and later as an assistant professor (2013) and associate professor (2015). Her research is situated in the broad domain of geomatics and land surveying.

Alain De Wulf

Prof. dr. ir. Alain De Wulf is a full-time professor at Ghent University (Belgium), researching and lecturing on the general principles of 3D data-acquisition techniques in the domains of land and hydrographic surveying and quality aspects of geodesy in particular. He is involved with his scientific research team in different projects, ranging from topographic campaigns for archaeological projects (Malta, Altai (Russia), Thorikos, Titani (Greece), etc.) and till bathymetric projects involving vertical reference surfaces and GNSS buoy tide measurements.

Philippe De Maeyer

Philippe De Maeyer is a senior full professor in cartography and GIS. He is also the chair of the Department of Geography. His research topics cover cartography (esp. historical) and applications of GIS in different domains (such as archaeology, risk calculation, and hydrography). He is a full member of the Royal Academy of Overseas Sciences and chair of the National Committee of Geography.