Dear Editor and Reviewers,

We are grateful for the opportunity to submit a revised version of our manuscript which is now entitled "Integrating regional protocols for post-event assessments with local GPS and UAV-based quick response surveys: a pilot case from the Emilia-Romagna (Italy) coast", following the new cut of the work. The authors' order also changed and is now "Enrico Duo, Arthur C. Trembanis, Stephanie Dohner, Edoardo Grottoli, and Paolo Ciavola".

In the following you will find a summary of the changes applied to the manuscript and the Authors' answers to the Reviewers. In that part, we copy-paste the referees' comments and add the authors' answers (in bold) with the initial label A.#.§, where # is the referee (1 or 2) and § is a sequential integer indicating the ID of the answer.

The new structure and changes were applied to comply with the requests made by the Reviewers and the Editor, following the proposal of the Authors summarized in "nhess-2017-337-SC1" and explained in more details in the supplement material of "nhess-2017-337-AC2/3".

We thank again the Reviewers, for their useful comments and suggestions, and the Editor for the opportunity to improve our work. We are looking forward to receiving your reviews and decisions.

Best regards,

Enrico Duo, on behalf of the authors

Summary of applied changes

Major changes were applied to comply with the requests of the Reviewers and the Editor. The changes allowed to:

- better contextualize the local survey implemented at Lido degli Estensi within the regional protocol implemented by the regional authorities;
- address the lack of information about the local interviews and the collected qualitative information.

The main changes implemented are as follows:

a. the title changed in "Integrating regional protocols for post-event assessments with local GPS and UAV-based quick response surveys: a pilot case from the Emilia-Romagna (Italy) coast" and the authors' order changed in "Enrico Duo, Arthur C. Trembanis, Stephanie Dohner, Edoardo Grottoli, and Paolo Ciavola";
b. the "Abstract" was completely revisited;
c. the "Introduction" was revisited and specific paragraphs were added focusing (i) on the existing regional protocol for emergency and post-event assessment and (ii) on the importance to involve local stakeholders for coastal studies;
d. the section "Study Area" was renamed as "Case study" and was revised; the new section includes (i) the regional setting and the description of the local case study (Section 2.1), revised on the basis of the reviews; (ii) a review of the protocol for coastal alert and monitoring of the Emilia-Romagna Region (Section 2.2) with focus on the importance of the regional early warning system and the methods for post-event assessments; (iii) a thorough description of the February 2015 event (Section 2.3), including the regional implementation of the protocol for coastal alert and monitoring undertaken during the event and described in the paper (in italian) by Perini et al. (2015b);
e. the "Methods" section was revised: the local protocol description was revised and additional information on the performed interviews were added (Section 3.3); the description of the photogrammetric process was reviewed and the requested information added; minor changes occurred in the other subsections, addressing the specific comments;
f. the "Results" section was improved adding the qualitative information collected through the local community (Section 4.1) and minor changes were applied in the other subsections;
g. the "Discussion" (Section 5) was consistently enriched by adding: (i) a discussion of the outcomes of the interviews including references to standard protocols for stakeholder involvements that can improve the quality and reliability of the collected information; (ii) a discussion of the outcomes of the local survey was added, supported by a new figure (Figure 9), focusing on how the local assessment could be integrated in the regional scale assessment. Additionally, the existing text was revisited;
h. The former section "Practical and general recommendations" was reviewed, better contextualized and merged in a separate section (Section 6) named "Suggestions for possible improvements";
i. "Conclusions" (Section 7) was reviewed accordingly with the new structure of the manuscript;

j. Logic flaws and writing were improved, as suggested, and all the other specific comments were addressed.

The new structure is as follows:

1. Introduction
2. Case study
   2.1. Regional settings and study site
   2.2. Coastal alerts and monitoring in Emilia-Romagna
   2.3. Storm event
3. Methods
   3.1. Quick Response Protocol
   3.2. Pre-storm conditions
   3.3. RTK GPS survey
   3.4. UAV survey and photogrammetric process
4. Results
   4.1. Summary of the interviews
   4.2. Elevation data
   4.3. Erosion and sedimentation patterns
   4.4. Coastal flooding
5. Discussion
6. Suggestions for possible improvements
7. Conclusions

Other minor changes were applied where necessary. Some figures were modified, adding additional information, and the order slightly changed. Some references, a new figure and a new table were added.

Authors' answers to the Reviewers

In this part, we copy-paste the referees' comments and add the authors' answers (in bold) with the initial label A.#.§, where # is the referee (1 or 2) and § is a sequential integer indicating the ID of the answer.

REFEREE #1 (nhess-2017-337-RC1 and nhess-2017-337-RC1-supplement)

The manuscript entitled Quick Response Assessment of the Impact of an Extreme Storm Combining Aerial Drone and RTK GPS by Trembanis et al. illustrates a rapid deployment of RTK GPS and UAV survey after a storm that produced floods in the nearby communities. The study explores the potential application of UAVs as a rapid response to evaluate the extent of an event.

The main limitation of this manuscript is the structure of the text, which does not flow well and is complicated by logical flaws. For instance, the introduction does not have a leading thread, and all points do not support well the general direction of the manuscript. Similarly, Section 2 presents various aspects in a random order, and does not support a solid understanding of the background of the study area. Additionally, logical problems also occur within sentences, some of which are unnecessarily long, use very imprecise words and non-scientific wording (e.g. "The authors present"). The manuscript would therefore highly benefit from a complete reworking of the structure and, in some instances, re-writing.

Conceptually, the manuscript presents a few important flaws. Firstly, in few instances the authors present this study as a potential basis for a Quick Response Protocol (QRP), but the study itself mostly illustrates one application of such a deployment. Although it is mentioned that this study took place in the context of a EU project, no background is given and the reader is left to wonder what is the broader context and about the nature of the relationship with the Early Warning System as well as the local policy makers. I recommend removing any mention of a "protocol" and focus on the application at one case study. Second, the title of the manuscript contains impact assessment, which implies a quantification of the impact due to the storm either on the built or natural environments. No quantification as such is presented in the manuscript, and only parts of the changes of the morphology of the beach is qualitatively investigated. Thirdly, it is mentioned in the method and in the discussion that interview with residents were performed. However, no detail is given on the procedure or the purpose, and at no point any attempt is made to include (or even mention) the results of such interviews in the more global result. Why? Finally, the authors present the result as a potential benchmark to assess the discrepancies between RTK GPS, UAV and LiDAR-derived topographic products, which is not the case. A global comparison should include statistically robust tests and the transparency of the data. The present manuscript lacks critical information such as the quality report obtained from Pix4D, the error on the GCPs (amongst other) required for a comprehensive comparison. Additionally, i) only in the last section are the flaws on the GCPs presented, which have a first-order control on the accuracy of UAV-derived DSMs and ii) no benchmark area was identified to estimate the error between the three datasets where no change has occurred.

Scientifically, my main is related to the application of the UAV survey, which lacks important steps to assess and reduce the uncertainty. First and foremost, considerations regarding GCPs made in Section 6.2 are typically made before the deployment, any many options for designing and placing efficient GCPs exist, most of them being thoroughly presented in the user manuals of the most common SfM softwares. As a result, limitations presented in Section 6.2 should be presented in the methodology section along with a quality report of the error on the GCPs, as this step has a first order importance in the accuracy of the results. Second, it is difficult to understand why a manual flight plan was preferred over an automatized one, which provides consistency on the overlap of images. Thirdly, the workflow presented in Fig. 5 only shows the automatic workflow implemented in Pix4D, but an important step, namely the manual cleaning of the point cloud, has been ignored. This step is critical to reduce the noise of the densified point cloud, which greatly influences the accuracy of the resulting DSM. Fourthly, the error of all UAV-derived products, particularly when it comes to change detection, should be critically assessed and reported based on such outputs as distortion or point density maps. The authors could use supplementary material to provide this information. Finally, no real scientific results are presented on the impacts, and only some qualitative descriptions of the changes on the beach morphology are reported.

As a result, the present manuscript is hard to judge. On one side, the manuscript promises global conclusions (i.e. protocol, impact assessment), but results suggest that the manuscript should rather focus on the application to one case study. On the other side, most results and conclusions focus on the method, which is not as constrained compared to photogrammetric studies published in the literature, and the true science that could be derived from the method is mostly neglected. In this context, I must mention that I understand the complications associated with UAV surveys and RTK GPS ground-truth, and the limitations of the accuracy of the method should not be a factor preventing the publication of such a study, for as long as i) limitations are thoroughly and transparently presented from the beginning and ii) the method is used to support science. Therefore, I feel that this manuscript would deserve to be published once i) objectives are toned-down to consider the application to one case study rather than pretending to serve as a basis for a protocol and ii) more quantitative science is put forward based on the result of the UAV survey. For these reasons, I recommend major revisions and a possible resubmission.

A.1.1 We thank the referee #1 for this general comment. The highlighted issues and suggestions were very useful. We restructured the manuscript based on the proposal contained in "nhess-2017-337-SC1" and the supplement material of "nhess-2017-337-AC2/3". In particular, (i) the local scale survey was contextualized within the regional protocol for post-storm assessment; (ii) the title was modified; (iii) the interviews were included; (iv) the text on the photogrammetric process and UAV-derived outcomes was reviewed and improved.

The manuscript does not aim at comparing the survey techniques, demonstrating that UAV are better than RTK GPS or LiDAR-based methodologies. The capacity of UAV for beach survey was already demonstrated by several studies (that are cited in the manuscript). The reason why we present UAV-derived data is for demonstration purposes, showing the level of detailed data (i.e. orthomosaic and Digital Surface Model) that this methodology can provide for rapid post-event surveys, damage assessment, and flooding extension. This approach aids regional managers by integrating large scale assessments with local, fine scale approaches, where necessary.

Manual flights were completed during all UAV surveys due to a lack of automated mission planning software available for the DJI Phantom Vision 2+ at the time of these surveys. Software companies released updates to include "follow me", "waypoint", and "hover" capabilities in March of 2015 but no systematic mapping option. Thus manual flights were conducted to the best of the authors' abilities with available objects on the beach as GCPs. At the time of this study, recommended GCPs per area varied wildly and was left to the discretion of the surveyors. The debris on the beach (and GCPs) was (were) not always visible in the resulting aerial images, therefore DSM error varied greatly. This caused the authors to choose a section of the study site where the available GCPs created a reasonable DSM to compare to RTK GPS data. Minor point cloud editing occurred over the selected DSM to remove major outliers but surface objects were kept. The choice to use objects on the beach as GCPs stemmed from the authors' goal to show rapid data collection following the extreme storm event where controlled GCPs such as painted boards and tarps are not always feasible

from a time, effort, or economic standpoint for local authorities. Therefore, the suggestions in Section 6 (which include former Sections 6.2 and 6.3) are aimed at readers using readily available objects as GCPs rather than systematic seeding of the study site with standardized GCPs.

Please find below some general comments. Other comments are also included in the annotated PDF file.

Introduction Too general, does not really frame the project. The introduction of UAVs mainly builds upon the limitation of RTK GPS. It needs a stronger, clearer logical workflow.

A.1.2 The introduction was reviewed and improved. We stressed on the importance of local scale assessments in support of regional ones. In order to quickly survey local hotspots and provide accurate data, minimizing the costs, UAVs are preferred for this type of studies.

Section 2 & 3 Both sections should be merged into a generic "Case study" section. I have a problem with the logic used in the presentation of the background data. For instance, Section 2 provides elements of the physical geography and morphology of the study area at various scales, the history of feedback between urbanization and response on the natural systems, previous projects, policy and management, climate and classification of storms in a random order that is hard to follow. In particular, the classification section illustrates parts of the illogical ordering of the manuscript: first, the classification scheme is barely used throughout the paper and could be summarized in a Table; second, the final sentence of the last paragraph of Section 2 classifies the studied storm, even before its presentation in Section 3.

A.1.3 The former Sections 2 and 3 were reviewed and improved as proposed. The regional setting and case study site were reviewed and lightened (Section 2.1). Additionally, the new merged section (Section 2) includes a review of the Emilia-Romagna alerting and monitoring protocol (Section 2.2). The section related to the storm event (Section 2.3) was enriched with information on the activation of the regional protocol during and after the emergency.

Section 5.1 Please describe the results of the SfM algorithm in a table (i.e. number of images used, number of images validated, overlap, errors on GCPs etc: i.e. Pix4D report). Additionally, point clouds are usually manually cleaned before generating the DSM in order to reduce the noise. Subjective steps, such as outlier removal and curve smoothing, are mentioned in the text, which probably wouldn't be required if the dense point cloud had been cleaned.

A.1.4 The requested results from the SfM processing were provided. With respect to the point clouds, major outliers were removed before surface processing however, the authors preferred to maintain as much data as possible and then chose to delete outliers via MATLAB processing, when analysing the extracted profiles.

Section 5.2 This section is weak as it only presents a 2D validation of the UAV-derived orthomosaic (which is usually more reliable than the 3D geo-referencing), whereas other potential research questions are ignored. What is the maximum water height required to inundate the farthest point observed? How does such an estimated height compare to observed floodmarks? Additionally, Fig 7 suggests that the so-called "secondary inundations" all occur in private properties. Were these observations validated by interviews? Have potential mitigation measures been identified in the field?

A.1.5 We will answer to these questions in the text. We included information collected through the interviews (see also A.2.5). Regarding the maximum elevation reached by the water, the requested information was added in Section 4.4 and discussed in Section 5. About the "secondary inundations", the observations were validated by the team that documented with on-the-ground pictures. This was better explained in the text. Potential mitigation measures were identified in the framework of the EU FP7 RISCKIT project, through specific

interviews performed months before the event and the survey here reported. However, it is beyond the aim of this manuscript to include that analysis.

Section 5.3 There is a confusion between DSM, DTM and DEM. If the UAV-derived product has not been treated and contains elements on the beach, then it is indeed a DSM (as is the output of Pix4D). Please clarify. Additionally, it would be useful to identify zones unaltered by the storm in order to compare the alignment of the LiDAR and UAV datasets.

A.1.6 The UAV product is the DSM and the authors updated to the correct terms through the manuscript. The pre-storm conditions where represented by a LiDAR-derived DTM from October 2014. We also agree that the manuscript would benefit from adding the proposed comparison on unaltered areas. However, the UAV survey was performed on the beach while the unaltered areas belongs to the inland edge of the domain which is not close enough to the GCPs and presents major alignment errors. The authors tested this approach without positive improvements.

Section 6.2 The points listed in Section 6.2 are important limitations to the presented approach and subsequent results and should be presented in the methodology section. Figure 9 demonstrates that many GCPs are potentially misleading, i.e. too small, round features, or objects that are easy to move (Fig. 9B). It is therefore difficult to trust the result of the UAV-derived DSM when such considerations are made after rather than before the field deployment. It is therefore necessary to assess the quality of all GCPs in the target area and show it on Figure 1 (i.e. colormap showing the quality of the GCPs). Additionally, these aspects make it even more important to report the error on the GCPs in a table.

A.1.7 GCP limitations from this study were included in the methods section. However, GCPs associated with high error, or difficult to detect from the images were discarded in point cloud processing and therefore have no influence upon outputted surfaces. These choices were discussed within the methods sections so readers are more aware of the authors' reasoning behind processing choices and resulting data. The suggestions for choosing GCPs is a valuable section for readers wishing to utilize in-situ objects as GCPs and thus the authors feel this is a valuable contribution to the paper and the readers. The requested information was added in Figure 1.

Other - The manuscript contains many long sentences - There is often poor logic in the construction of sections, paragraphs and sentences. Adverbs such as "however" or "notably" are often misused and complicate the understanding of the sentences - The use of "the authors" should be... should not be! Caesar died more than 2000 years ago, time to move on! Use an impersonal form if possible - There should be consistency in the way you refer to drones. UAV is the most frequently used denomination - There is a frequent use of very general and unconstrained terms namely "data" or "wide". Be as specific as possible - Always add a space between values and units - Please double check any reference to DSM vs DEM. I think there is confusion there. Unless filtered, the point cloud of Pix4D produces a DSM.

A.1.8 We addressed all these comments.

Please also note the supplement to this comment: https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-337/nhess-2017-337-RC1-supplement.pdf

A.1.9 We thank the referee #1 for the valuable comments in the supplement material. We addressed them in the new version of the manuscript. Regarding the comments on the figures that can be found in nhess-2017-337-RC1-supplement:

Figure 3: E. Duo personally created the figure from scratch. The structure of the Disaster Management Cycle is well known in the literature and a conspicuous number of works report

different version. This figure was created considering the most important aspects of the cycle that were useful for this study.

Figure 8 (former Figure 7): We better explained the definition of "DRONE Secondary Inundation" in Section 4.4 to avoid misunderstanding.

Figure 7 (former Figure 8): The figure was slightly modified. We left the boxes (and box numbering) as it was in the previous version as we believe the reader would better follow the description in Section 4.3.

Figure 10 (former Figure 9): We believe the figure is necessary. We reviewed the text in Section 6 to better contextualize it.

REFEREE #2 (nhess-2017-337-RC2 and nhess-2017-337-RC2-supplement)

General comments: The general topic and assessment procedure presented for the manuscript entitled Quick Response Assessment of the Impact of an Extreme Storm Combining Aerial Drone and RTK GPS by Trembanis et al. possesses potential, particularly for practical efforts on the ground to improve recovery in coastal areas facing extreme weather conditions. This is particularly the case for storms producing flooding in local communities. However, substantial revision is needed to make this a solid article. The main issues that need to be addressed are: 1) the lack of clarification in the text specifically with regard to the Quick Response Protocol (QRP) explanation; 2) the need for clarification of texts in a fair number of other instances (see the continued contents of this report for details in addition to the supplemental material); 3) the need to completely overhaul the explanation of the qualitative component of the research as it pertains to the interviews conducted with local stakeholders; and 4) a revision of the general verbiage and sentence restructuring throughout the text (again, please see the rest of this report and supplemental material for reference).

This reviewer also agrees, generally, with the comments made within the first submitted report from Anonymous Referee #1. The following sections of this report provide specific comments organized by manuscript sections, while the supplemental PDF provides both comments in their textual reference as well as technical corrections. The technical corrections provided in the PDF also contain suggestions for improving the text.

A.2.1 We thank the referee #2 for the general comments. The highlighted limitations and suggestions were very useful and we believe that the applied changes address them.

Abstract: There is a need for greater specificity with what is meant by the "comprehensive approach" and the "timing information" that supported the activities of the research. What exactly makes this approach comprehensive? The authors later in the body of the main text make brief mention of the qualitative component of the research. Is the combination of the two what makes this comprehensive? If so, that part of the approach should be mentioned within the abstract text. The official name of the regional EWS should also be used. The abstract would also benefit from having at least one or two of the actual findings provided in the end of the abstract. As it stands, the content contains primarily method description. Providing results or content framed as some kind of key findings would greatly strengthen this abstract.

A.2.2 We completely reviewed the abstract based on the new version of the manuscript.

Introduction: The introduction also focuses very generally on method, providing little mention or explanation of the protocol presented in the research. The introduction also does not address the qualitative part of the research, namely interviews that were conducted (this is not described). A general reframing of the introduction is needed to better set up the structure of what will be presented in the sections that follow.

Some points of clarification in the text are also needed. Particularly in line 25, “to ensure appropriate plans are enacted”, using “plans” is vague. Would this pertain to general land use plans, coastal territorial plans, or developmental plans? This section would benefit from better connection to the kinds of planning tools that the information presented in this research supports. This may also help the research reach a broader audience. Another point is found in line 29, “to assess the impacts to the coastline after the storm,”. Please be more specific. How long after the storm? And why? Would one wait until authorities deem it safe to survey and ensure impacts are assessed as soon as possible to prevent loss of data? Stating "before either natural or human induced recovery process begin..." is not specific enough (the authors should at least state "as soon as possible” prior to these recovery processes). The reason I stress this point is in connection to the practical application of the presented methods. More specifically, how long would a scientist or practitioner wait post-storm to perform these methods and how long is too long a wait (or is this so context specific that there is no way to give a general indication).

Although the introduction makes an attempt to connect to the research to planning and coastal management. This connection can and should be strengthened by providing more elaboration on potential uses of this information and also include mention of particular types of stakeholders such as governmental entities and NGOs.

A.2.3 The introduction was reviewed and improved. Additionally, the specific comments were addressed and the requested information included. See also answer A.1.2.

Section 2: I agree with the previous referee that this section should be renamed as “Case study” rather than “Study area”. I also agree that the information in Section 3 “Storm event” should be part of the case study description in Section 2. The event itself is part of the case study setting and the selection criteria for this location of study. Within the “Case study site and target area” section, there is also no mention of why this particular target area was selected as opposed to others. Why was this particular portion of the coast chosen? If there are unique geophysical characteristics that make this a “unique case” with regard to your selection criteria, this should be stated.

It would also be beneficial to have greater specificity as to what kinds of tourist facilities exist in the case study in order to understand the kind of land usage and potential for damage and general economic impact. The next sentence tries to address this in part, but does not address the types of tourist facilities (or types of residential). E.g. are these high density establishments? Very little demographic or land use information is given in demonstrating an understanding of the case study.

Section 3: This section requires some sentence revision and several points of clarification. Suggestions and elaboration of these points are found in the supplemental material submitted with this review.

A.2.4 The section “Case study” (Section 2) was structured as suggested. The requested information was included. See also answer A.1.3.

Section 4: The first sentence of this section requires major revision. One of the most critical issues in this section (and indeed the manuscript as a whole) is the complete lack of explanation for the collection and analysis of data from stakeholder interviews.

The importance and purpose of the interview method should be provided much earlier than in section 4. This should have been a part of the abstract and introduction, and especially should have had more elaboration in the latter. Important questions that should have been addressed with a proper explanation of the method include: What kinds of interviews? (E.g. structured, semi-structured with open or closed questions?) Were these individual or group interviews? What was the purpose of these interviews? What type of data was collected? What kinds of "local" stakeholders did you interview? And how were they selected? What questions were asked?

The way this is presented, the reader has no idea whether the authors simply walked around the area asking random questions to random people (the brief inexhaustive list in the first bullet is not sufficient explanation). There is no scientific process presented and no explanation or transparency in communicating how this field method was used. Either fix this, or remove this qualitative component altogether from the manuscript. As is, the explanation of this method brings into question the scientific rigor and general quality of the research.

The first three critical tasks listed in bullet points on page 6 are not adequately described in their procedure or parameters. For the first bullet point related to the stakeholders interviewed, the following questions should be addressed in the text: Why these stakeholders? What is (or was) the saturation point or parameter for sufficient representation of stakeholder types?

In general for the QRP, there really needs to be a more structure presented with regard to the sequence of the protocol steps with more elaboration. The sequence of steps could also benefit from a visual illustration (e.g. at least a workflow diagram with minimal explanation).

For line 24 on page 6 that reads "In this study, 7 days were sufficient to complete the aforementioned tasks", not enough detailed is provided. What were the parameters for sufficiency of each of these steps, and how were they met? Within that same paragraph, for the "error analysis and data comparison", what is the significance of these numbers? How do they contribute to the robustness of your research design and execution?

For line 1 on page 7, stating that "The integrated information will help to understand the overall impact of the storm in the surveyed area", is a big promise. However, there is little explanation of how this is achieved. Stating that interviews were conducted with a vague explanation of purpose and nearly zero method description does not automatically mean that the data collected from these interviews was integrated into the broader research pursuit. How exactly was this data analyzed? It needs to be very clear how this qualitative data was used, and prior to this, what type of data was collected in the first place. (E.g. What questions were asked? Did this enable gathering data on risk perception? Identifying priority areas?)

A.2.5 The reviewed version of the manuscript includes specific information on the performed interviews (in Methods, Results and Discussion) and how the collected information supported the local survey. In particular, the interviews were performed asking informal questions to a limited number of people (10 stakeholders: residents, shop or tourist activities owners, fisherman, fireman) focusing on what happened the night of the peak of the event, how they behaved, what damages did they get to properties, etc. The information was mainly used to better organize the fieldwork but some interesting insights on the regional alerting and response chain were highlighted. Additionally, the local protocol was reviewed and, as proposed, it was contextualized within the regional protocol for post-storm assessment.

Section 5: This section needs some sentence revision (see supplemental attachment). The results and findings that have been integrated from the interviews is a missing component to the content of this section.

A.2.6 We revised the text to rephrase the sentences, as suggested.

Section 6: In reference to line 6 on page 11, it should be made very clear what kind of time and other resource saving is made possible and/or enhanced using this protocol and the described methods. There are also several instances that would greatly benefit from more specification (e.g. see instances were "increase", "really detailed", and "prolonged" are used).

A.2.8 We addressed this comment adding the requested information.

Within section 6.2, for the last bullet point guideline on page 12, please explain why this was done and how these points would have would have influenced your results. Line 9 on page 12 also mentions that the team was divided into thematic groups. Explanation is needed for what these thematic groups were and how they were determined.

A.2.9 The Section 6 (which includes the former Section 6.2) does not contain information on what was done. It includes suggestions on how to improve the efficiency of the local survey. The former section was reviewed as proposed and more specific information were added.

Section 6.3 needs further elaboration on what kinds of further analyses should be performed and what kinds of deeper investigations would create a more robust outcome. The statement at the end of this section on potential uses of the protocol is good. However, this use potential and connections to practical application should be made in the beginning of the manuscript as well. The text prior to this section does not provide adequate detail into use potential and connections to practical application.

A.2.10 This section was revisited as proposed and merged with the former Section 6.2 in a single section with suggestions for improvements (Section 6).

Section 7: The sentence in line 28 beginning with "Limitations of the application" is what one would call a "cookie-cutter" sentence that can be copy and pasted into any manuscript as it contains no specificity or uniqueness to the research presented. The sentence needs revision with some hint at the specific limitations and recommendations provided for this research.

A.2.11 We reviewed the conclusions based on the new version of the manuscript.

Please also note the supplement to this comment: https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-337/nhess-2017-337-RC2-supplement.pdf

A.2.12 We thank the referee #2 for the valuable comments in the supplement material. We addressed them in this version of the manuscript.

Integrating regional protocols for post-event assessments with local GPS and UAV-based quick response surveys: a pilot case from the Emilia-Romagna (Italy) coast~~Quick Response Assessment of the Impact of an Extreme Storm Combining Aerial Drone and RTK GPS~~

Enrico Duo[1], Arthur C. Trembanis[~~1~~2], ~~Enrico Duo[2], ~~Stephanie Dohner[~~1~~2], Edoardo Grottoli[~~2~~1], and Paolo Ciavola[~~2~~1]

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Abstract. ~~Developing and implementing a quick response post-storm survey protocol has the potential to improve impact assessments of coastal storms. Pre- and post-event surveys are essential to properly quantify the storm impacts on the coast. In this study, a combination of traditional RTK GPS and Unmanned Aerial Vehicle "drone" platform was utilized as part of a coordinated storm response workflow. The comprehensive approach employed in this pilot case study was conducted on the Emilia-Romagna coast (Italy), in the immediate aftermath of an extreme storm event that impacted the shoreline on the 5th-6th February 2015 called the "Saint Agatha Storm". The activities were supported by timing information on the approaching storm provided by the regional early warning system. We collected aerial photos from a commercial off-the-shelf drone immediately after the Saint Agatha Storm and generated both orthomosaic and digital elevation models utilizing structure-from-motion photogrammetry techniques. The drone-based survey approach allowed us to quickly survey an area of 0.25 km² within a 10-minute flight resulting in a ground sampling distance of 2.5 cm/pixel. Flooding and erosion impacts are analyzed and presented for the target study area. Limitations and possible applications for coastal management of the quick response post-storm surveying protocol are highlighted.~~

Coastal local communities and assets are exposed to flooding and erosion hazards due to impacting extreme storm events that are likely to increase in intensity in the medium- and long-term. Coastal managers are requested to provide risk management plans supported by actions taken at the different phases of the disaster cycle aiming at better understanding and coping with risk. Effective and rapid post-event beach surveys are therefore necessary to collect physical data in the immediate aftermath of an event. Additionally, the inclusion of local stakeholders in the assessment process is essential to properly understand the social dimension of the problem. In this study, a local protocol for post-event assessment, the Quick Response Protocol, was tested on a pilot site on the Emilia-Romagna (Italy) coast in the aftermath of an extreme event occurred in February 2015. Physical data were collected using both Real-Time Kinematic Geographical Positions Systems and Unmanned Aerial Vehicle

platforms. Local stakeholders were interviewed collecting qualitative information on the situation before, during and after the event. Results were analysed and compared with the outcomes of regional reports on the impacts of the event showing a higher level of detail and reliability. The local approach, although improvable from different technical aspects, can be easily integrated in the regional ones improving the resolution and completeness of the regional-scale assessments.

1 Introduction

Extreme storm events have the potential to create coastal flooding and erosion, reshape coastlines, impact infrastructures, and expose populations to hazardous conditions.Coastal flooding and erosion linked with extreme storm events shape coastlines, impact coastal infrastructure, and present hazards to coastal inhabitants that can thus suffer their consequences. The most damaging events consist of a combination of extreme wave heights, storm surge, wind direction, and tidal stage, that interact with the morphology of the beach and adjacent infrastructures generating direct and indirect impacts (Van Dongeren et al., 2017; Viavattene et al., 2017). Given the expectation of increasing storm intensities and occurrence (Bason et al., 2007), accurate and rapid field data collection must occur to best inform risk management and policy decisions (Casella et al., 2016).With expectations of increasing storm intensities and occurrence (Bason et al., 2007), coastal communities are in need of accurate field data to inform management and policy decisions (Casella et al., 2016). To ensure that appropriate (risk) management plans are implementedenacted, precise and high-resolution field geomorphology measurements are required crucial to understand storm effects on the community exposed communities and to provide input for numerical modelling for future impact prediction purposes (Lee et al., 1998; Stone et al., 2004; Nicholls et al., 2007). Additionally, the inclusion of local stakeholders in the assessment process is essential to appropriately address group values, create risk reduction plans supported by locals, and implement the plan with the public (Martinez et al., 2017). Coastal managers are requested to adopt plans and protocols for risk management, ranging from prevention, preparedness, response and recovery phases of the risk cycle. The importance of standardized protocols for risk management is recognized across Europe as an effective way to coordinate field efforts, improve hazard maps, and enhance risk reduction plans (Poljanšek et al., 2017).

Post-storm assessments require capturing the morphologic signature of the event using rapid, quantitative mapping as soon as safe conditions allow following the event but before recovery processes begin (i.e. natural or human-driven) Capturing the signature of a storm event requires a rapid quantitative mapping response to assess the impacts to the coastline after the storm, before either natural or human induced recovery processes begin to take place (Morton et al., 1993; Bush et al., 1999; Morton, 2002). Notably, in order toTo properly quantify these impacts, pre-storm quantitative mapping of the area is necessary before impacts can be attributed to a single stormit is also desirable to collect recent pre-storm elevation data. In recent years, autonomousrobotic platform methodologies for coastal mapping and extreme event impact assessment were proposed and tested to improve traditional, expensive, or time-consuming mapping approaches on both the emergent beach , beyond the traditional GPS, LIDAR, and satellite remote sensing techniques, such as the use of unmanned vehicles for mapping the

~~emerged beach~~ (Mancini et al., 2013; Casella et al., 2016; Turner et al., 2016) and the submerged nearshore area (Trembanis et al., 2013).

~~The classic stadia rod and level beach surveying technique, while still functional, has been replaced by time and cost efficient~~ Real-Time Kinematic Geographical Positions Systems (RTK GPS) for ground-based surveys (Morton et al., 1993; Theuerkauf and Rodriguez, 2012)~~. RTK GPS~~ is the ~~preferred~~ traditional method for ~~any~~ data collection requiring highly accurate (~~few centi~~sub-decimeter) positioning measurements and is utilized in the coastal environment for temporal and spatial monitoring of many coastal morphologic features (Larson and Kraus, 1994; Benedet et al., 2007; Hansen and Barnard, 2010; Theuerkauf and Rodriguez 2012). Since the accuracy of beach morphology representation is affected by the sampling point density of the ~~With~~ RTK GPS survey, insufficient resolutions (e.g. representing the beach with traditional profile spacings of more than 100 meters) can lead to imprecise or misleading morphological interpretations ~~s, questions arise regarding the accuracy of beach morphology representation due to insufficient resolution when traditional profile spacings of more than 100 meters~~ ~~are used~~ (Swales, 2002; Berstein et al., 2003; Pietro, et al., 2008; Theuerkauf and Rodriguez, 2012). The ideal resolution of the RTK GPS survey depends on the scale of the study and on its location. Terrestrial laser scanners or total stations improve point density but require similar time and physical effort as RTK GPS, particularly when surveying large areas (Saye et al., 2005; Theuerkauf and Rodriguez, 2012; Lee et al., 2013). Improvements in remote sensing technology have increased ~~point density~~data resolution through airborne lasers (LiDAR) and satellite imagery but the high costs of operations and infrequent surveys render these options impractical for local scales and rapid or frequent repeated surveys (Stockdon et al., 2002; Young and Ashford, 2006; Anderson and Gaston, 2013). A recent LiDAR application was proposed by Phillips et al. (2017) by fixing a laser system on a building to continuously monitor beach profiles. The system provided interesting results for beach recovery analysis and showed great potential for future applications. However, the measurements are performed on a single location, in the cross-shore direction, thus limiting the scope of data and ignoring the varied, three-dimensionality of coastal response. Attempts to alleviate these sampling issues stem from ~~Recent~~ recent improvements in autonomous technology ~~have made~~such as Unmanned Aerial Vehicles (UAVs or drones),~~Unmanned Aerial Systems (UAS) a useful emerging tool in the survey world~~ which accommodates local scales, rapid and frequent surveys, and ~~can be economically feasible~~economic feasibility coupled with accurate results for monitoring hydro-morphological changes in the coastal zone (Berni et al., 2009; Westoby et al., 2012; Casella et al., 2016; James et al., 2017). Moloney et al. (2017) compared surveying methods for coastal dune monitoring in New Zealand. Compared to total station RTK GPS and terrestrial laser scanner methods, the low-cost UAV system resulted the most efficient one, reaching also more accuracy on processed data if compared to total station RTK GPS method. The UAVs resulted ideal to monitor short- and long-term coastal dune systems with elevation data and aerial images. Similarly, Seymour et al. (2017), compared terrestrial laser scanner and UAV, equipped with a RTK GPS system, for coastal monitoring and management in North Carolina (US). This study provided additional insights for field implementation and post-processing, including limitations of UAV data related to the environment (e.g. texture of the surveyed surface, solar angle, etc.). Specific guidelines about these systems were also given and the study claimed that UAVs provide an affordable way to frequently monitor coastal environments at the local scale for coastal management purposes.

Focusing on the social dimension of the problem, it was demonstrated that the inclusion of local people in the processes of coastal risk assessment and preparation of reduction plans, improves the quality of the analysis and has a positive feedback on the population, through increased risk awareness and preparedness (Pescaroli and Magni, 2015; Becu et al., 2017; Gray et al., 2017; Martinez et al., 2017). In this sense, performing interviews of local people in the immediate aftermath of a coastal extreme event can provide important information on the local evolution of the storm as well as on the effectiveness of the implemented emergency preparedness and response phases (Martinez et al., 2017).

Here, a pilot case study application of a quick response approach for local post-storm assessment, utilizing a combination of traditional on-the-ground RTK GPS surveys together with aerial imagery gathered by an UAV for digital photogrammetric reconstruction further supported by qualitative data collection (i.e. interviews of local stakeholders), is presented. This combination of technologies allows for a rapid and holistic coverage of the field site and storm event. The testing was carried out in the Emilia-Romagna region, which managers already adopted effective protocols for coastal risk management and, of interest for this work, regarding early warning system and post-storm hazard and risk assessments (Ligorio et al., 2012; Perini et al., 2015b, 2016). The presented results demonstrate the proposed approach can provide local-scale high-resolution data capturing coastal storm effects. Furthermore, this integrated approach provides detailed insights into the physical and social aspects that can be applied at the local, as well as at regional and national levels, for effective, coordinated cross-disciplinary management purposes.

~~Here we present a pilot case study of a quick response protocol for assessing storm impacts utilizing a combination of traditional on-ground RTK GPS surveys together with aerial imagery gathered by an Unmanned Aerial Vehicle (UAV or drone) for digital photogrammetry reconstruction further supported by qualitative data collection. The presence of an operational Early Warning System in the area is essential for the rapid response planning. This combination of technologies allows for a rapid and more holistic coverage of the field site. The presented results of the pilot test demonstrate that the approach can provide high-resolution data for capturing storm impacts. Furthermore, this integrated approach can provide detailed insights that can be applied at the local, property scale of stakeholders, as well as at regional and national levels for coastal management purposes.~~

2 ~~Study area~~Case study

2.1 Regional settings and study site

Regional Settings

A stretch ~~(~7 km)~~of approximately 7 km ~~of the~~ coastal area ~~of~~ in the Ferrara province (Emilia-Romagna region), located on the Italian side of the Northern Adriatic Sea (~~Fig.~~Figure 1A, ~~1~~B), was surveyed ~~starting in the waning period of~~right after an extreme (low-frequency and high-impact) storm event (hereafter called the Saint Agatha storm, see Section 2.3~~3~~) that occurred on 5-7 February ~~5-7th,~~ 2015. ~~The survey continued for a week following the passage of the storm.~~ The coastal landscape in

Emilia-Romagna is generally comprised of low-lying sandy beaches with limited topographically elevated areas usually in the form of either relict beach ridges or artificial embankments (Armaroli et al., 2012). The shore is comprised of alternating spaces of natural areas with native dunes ~~and~~ intermixed with more prevalent urbanized areas. ~~with tourist facilities and coastal protection structures (i.e. groins and breakwaters). Through continued development and urbanization over the last 60 years as a result of grants to commercial beach concession operators, most~~Most of the shore is now occupied by tourist facilities, residential buildings, and bathing structures often replacing the ancient coastal dune ridges (Sytnik and Stecchi, 2014), as~~.~~ consequence of 60 years of continuous development and urbanization. The touristic beaches are characterized by the presence of private concessions (i.e. properties located on public beach areas, granted to privates for commercial/tourism activities) that provide sun-and-bath and food services since 1970s. Immediately behind the concessions, small residential towns developed and nowadays accommodate many second houses, accommodation and restoration services. These factors combine to increase the area's exposure to coastal hazards (i.e. flooding and erosion), especially in the Ferrara and Ravenna provinces, where some elevations are below Mean Sea Level (MSL) (Perini et al., 2010), and several defence structures (groins, breakwaters, etc.) have been built along the coast in an effort to mitigate shoreline retreat (Armaroli et al., 2012). Since the end of World War II, in fact, a sediment deficit has affected the littoral budget ~~as a result of a~~due to decreased~~ in~~ sediment transport towards the shore by local rivers, mainly caused by anthropogenic controls ~~because of the human interventions~~ on the rivers and their basins (Preciso et al., 2012) and the reforestation of the Apennines (Billi and Rinaldi, 1997). ~~The exposure to coastal flooding is high, especially in the Ferrara and Ravenna provinces, where some elevations are below Mean Sea Level (MSL), (Perini et al., 2010), and several defense structures (groins, breakwaters, etc.) have been built along the coast in the hope that beach retreat would cease (Armaroli et al., 2012).~~This problem has been exacerbated over the last ~~few~~ several decades by land subsidence, ~~which has been caused mostly~~most likely caused by groundwater and gas extraction activities (Teatini et al., 2005; Taramelli et al., 2015).

~~The subsequent vulnerability of local beaches to storm events led to the development of an Early Warning System (EWS), in the framework of the EU FP7 MICORE project (www.micore.eu), with the objective to predict the imminent arrival of a storm as a tool to be used by civil protection agencies and local communities (Ciavola et al., 2011; Harley et al., 2012; Harley et al., 2016). The Emilia-Romagna EWS is operational and is run by executing a daily sequence of connected numerical models (COSMO, SWAN, ROMS, and XBeach), comprised of 22 cross-shore profiles, with the final output transformed into a format suitable for decision-makers and end-users (Harley et al., 2012). The EWS tool is based on storm impact indicators (Ciavola et al., 2011), focusing on water intrusion and the type of exposed assets, which are described as natural or urbanized beaches (Harley et al., 2016).~~

The wave climate for the region is characterized by low wave energy (mean Hs ≈ 0.4 m, Tp ≈ 4 s) with a semidiurnal microtidal regime (neap tidal range= 0.30 m; spring tidal range = 0.8 m). Storm significant wave heights~~s~~ with 1-year return period range up to ~~-~~3.3 m (Armaroli et al., 2009) and storm surges with a 2-year return period are up to 0.6 m (Masina and Ciavola, 2011). These storm events ~~can~~ mainly occur~~, particularly~~ in the fall and winter months (October-March)~~, which comprises the storm season~~. Storms are mainly characterized by ENE waves associated with Bora (NE) winds or by SE waves when~~if~~ caused by

Scirocco (SE) winds. Storm surge events predominantly occur during SE (Scirocco) winds, which ~~also~~ coincides with the main SE–NW orientation of the Adriatic Sea. Bora storm waves are generally large and steep, whereas Scirocco waves are smaller in height but with a longer wave period due to the increased fetched of lower winds speeds across the Adriatic ~~period. This is because the latter are generated over a longer fetch by winds of lower intensity~~ (Harley et al., 2016).

Several methods for storm characterization have been developed and implemented in recent years for the Mediterranean coast. Mendoza et al., (2011) proposed a five-class intensity scale, defining a storm as an event in which the significant wave height exceeds 1.5 m for at least 6 hours (Mendoza and Jiménez, 2006). Moving to a more local perspective, Armaroli et al.~~,~~ (2012) adopted the same physical definition of storm events for the northern Adriatic. Two storms ~~were~~ are considered separated when the significant wave height decreases below the 1.5 m threshold for 3 or more consecutive hours. ~~As a resulting of the combined~~By analysi~~s~~ng ~~of~~ the events and their impacts together, Armaroli et al.~~,~~ (2012) classified a storm as "potentially damaging" when it exceeds the critical wave and total water level (TWL = surge + tide) threshold which are: Hs>=2m and TWL>=0.7m for urbanized beaches; Hs>=3.3m and TWL>=0.85m for natural beaches. ~~The Saint Agatha storm was identified utilizing the nearest offshore buoy and tide gauge (Fig. 1C & 2) records for waves and water levels, and following the Armaroli et al., (2012) storm definition.~~

~~2.2~~ *Case study site and target area*

The pilot case study site is the portion of coast between Porto Garibaldi and Lido di Spina and is characterized by highly developed, low-lying sandy beaches, with ~~commercial~~touristic concessions (with concrete and/or wood buildings) directly facing the sea. The width of the beach ranges from ~20 m to ~150 m. The predominant sediment transport (longshore drift) is directed northward. The southern jetty of the canal harbour (Porto Canale) in Porto Garibaldi ~~Porto Garibaldi~~ traps ~~this~~ longshore sediment, resulting in widening of the beach ~~of~~at Lido degli Estensi and depleting the Porto Garibaldi beach. Erosion appears again in the southern part of Lido di Spina (Nordstrom et al., 2015), as ~~it can be seen~~shown in ~~Fig.~~Figure 1D. The southernmost concession at Lido di Spina defines the southern boundary of the case study. In the whole area, the concessions can be affected by coastal storm impacts during extreme events (Nordstrom et al., 2015). The pilot case study presents areas that are well known at the regional level as coastal risk prone ones~~The whole pilot case study is well known at regional level as coastal risk prone area~~ (Perini et al., 2016; Armaroli and Duo, 2017). The target area of the analysis of this pilot study, is the southernmost portion of the beach at Lido degli Estensi (~~Fig.~~Figure 1E) in the municipality of Comacchio, east of Ferrara and north of Ravenna.

Figure 1. Field study site locations: A) Emilia-Romagna region; B) Coastal regional domain; C) Locations of the nearest tide gauge and wave buoy; D) Pilot case study site; E) Target area for data comparison.

2.2 Coastal alerts and monitoring in Emilia-Romagna

The Emilia-Romagna Region (RER) developed a protocol for coastal storm alert and monitoring, within the framework of a wider system for hydro-geological risk alert, and several agencies and regional services are involved in the process (Ligorio et al., 2012). The daily forecasting of waves, surge and coastal impacts, provided by the Servizio IdroMeteoClima of the Agenzia Regionale per la Prevenzione, l'Ambiente e l'Energia (ARPAE-SIMC), are evaluated, along with the weather forecast, by the regional geological service (Servizio Geologico Sismico e dei Suoli, SGSS), the Centro Funzionale of ARPAE (ARPAE-CF), the regional Servizio Difesa del Suolo della Costa e Bonifica (SDSCB), the technical services (Servizi Tecnici di Bacino, STB), the inter-regional agency of the Po river (Agenzia Interregionale Fiume Po, AIPO) and the Civil Protection.

The forecasting of coastal hazards and impacts is provided through the Emilia-Romagna Early Warning System (E-R EWS), developed in the framework of the EU FP7 MICORE project (www.micore.eu), with the objective to predict the imminent arrival of a storm as a tool to be used by Civil Protection agencies and local communities (Ciavola et al., 2011; Harley et al., 2012, 2016; Jiménez et al., 2017). The E-R EWS is operational and is run by ARPAE-SIMC and the University of Ferrara (UNIFE) by executing a daily sequence of connected numerical models (COSMO, SWAN, ROMS, and XBeach) aiming at reproducing the hydro-morphodynamic response of the beach for 22 representative cross-shore profiles distributed along the regional coast. The final output of the chain is transformed into a format suitable for decision-makers and end-users (Harley et al., 2012). The EWS tool is based on Storm Impact Indicators (SIIs) (Ciavola et al., 2011) focusing on the magnitude of water ingression and the type of exposed assets, which are described as natural or urbanized beaches (Harley et al., 2016). The daily outputs are published on-line at http://geo.regione.emilia-romagna.it/schede/ews/.

From 2017, the RER activated an on-line portal (https://allertameteo.regione.emilia-romagna.it/) where the alerts are published in a GIS-based interface. In case of forecasted over-threshold events, or unexpected ones, the alert is issued to the Civil Protection that forwards it to the local technical services and municipalities, at which point, the monitoring phase begins and updates are issued based on further observations (i.e. waves, water levels, wind, rains, etc.) and forecasting updates. If necessary, the emergency response is activated and implemented by the Civil Protection.

The SGSS oversees data collection and elaboration for coastal risk management purposes (Perini et al., 2015b; Armaroli and Duo, 2017). During and after a coastal event the geological service collects all available information from forecasting, observations, on-line pictures, webcam movies and news. After significant coastal events, the STBs are activated and implement on the ground surveys, documenting local impacts and measuring the water ingression. The SGSS also survey (with DGPS techniques) 18 beach profiles in 13 locations along the coast, belonging to the regional beach monitoring network (Rete di Monitoraggio dei Profili di Spiaggia, REMPS). After an important event, the Civil Protection flies over the impacted areas taking oblique aerial pictures. However, this is not a regular procedure and is infrequently implemented. All the information is elaborated and archived by the SGSS in the public GIS-based coastal information system (Sistema Informativo del Mare e della Costa, SIC; http://ambiente.regione.emilia-romagna.it/geologia/temi/costa/sistema-informativo-del-mare-e-della-costa-sic), in the in_Risk and in_Storm platforms (Perini et al., 2015b).

The RER can be considered acting at the state-of-the-art in coastal alert and monitoring at the EU level (Perini et al., 2015b), as also publicly praised by the European Commission through a press release on the 26 September 2014 (http://europa.eu/rapid/press-release_IP-14-1046_en.htm).

~~3~~2.3 Storm event

During the period 5-7 February ~~5-7th,~~ 2015, an extreme (low-frequency and high-impact) storm hit the Emilia-Romagna coast and the whole of the N~~n~~orthern Adriatic Sea, causing extensive flooding of ~~extensive portions of~~ urban and natural areas. The storm occurred in the context of extreme regional weather conditions, which included heavy snow in the Apennines and rain in the alluvial plain of the Emilia-Romagna ~~region~~ (ARPA E-R SIMC, 2015; Perini et al., 2015a, 2015b~~Arpa Emilia-Romagna, 2015; Perini et al., 2015a & b~~). The recorded water level was collected from the tide gauge of ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) located in Porto Corsini, Ravenna (Figure 1C). Wave data was recorded by the ARPA-ER (Agenzia Regionale per la Prevenzione e l'Ambiente dell' Emilia-Romagna) offshore wave buoy located at 10 m depth, 5.5 km offshore from the town of Cesenatico (Figure 1C). ~~As anticipated,~~ The event, referred to by the colloquial name of the Saint Agatha storm, was identified following the Armaroli et al. (2012) storm definition. It began ~~the authors will refer to the storm by the colloquial name of the Saint Agatha storm as it occurred during the feast of Saint Agatha. The storm started~~ at night and lasted for ~~more than two days (~~51 hours~~)~~, making it one of the longest duration storms ~~in the record~~recorded by ~~of~~ the local wave buoy offshore of Cesenatico (~~Fig.~~Figure 1C) since its ~~,~~ deployment~~ed~~ in May 2007. The maximum water level (surge + tide) of 1.20 m was measured at 23:40 GMT on 5~~th~~ February. The non-tidal residual time-serie was assessed based on the tidal predictions (calculated for Porto Corsini using data for the period 2007-2015 with t_tide; Pawlowicz et al., 2002) and showed a peak of 1.27 m in the morning of 6 February (Figure 2). The skew surge for the tidal cycle that included the peak of the total water level was calculated and resulted in 0.92 m. The significant wave height (4.6 m) and period (9.9 s) at the peak were recorded in the morning of 6 February (Figure 2). ~~However, the maximum significant wave height (4.6m) was recorded 8 hours later, on the morning of 6th February (Fig. 2).~~ The wave direction was consistently from the ENE sector for the entire event duration. ~~The recorded water level was provided by the tide gauge of ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) located in Porto Corsini, Ravenna (Fig. 1C). Wave data was recorded by the ARPA-ER (Agenzia Regionale per la Prevenzione e l'Ambiente dell'Emilia-Romagna) offshore wave buoy located at 10m depth, 5.5km offshore from the town of Cesenatico (Fig. 1C).~~

According to the Mediterranean storm classification of Mendoza et al. (2011), the Saint Agatha storm ~~can be~~is assigned to the severity class IV ("Severe"). The storm ~~severity~~ consequences were~~as~~ amplified by the combination of high waves, high water level, and intense rainfall that created combined problems to the local river discharge (Perini et al., 2015a, 2015b~~Perini et al., 2015a & b~~). Furthermore, according to the classification of Armaroli et al., (2012), the Saint Agatha storm was expected to have a strong impact on the coast, exceeding the combined wave and water level hazard thresholds ~~over a wide area~~ (~~Fig.~~Figure 2).

Perini et al. (2015b) reported that the event was forecasted by the regional forecasting chain and the E-R EWS. An alert of Level 1 (out of 3 levels, from 1 to 3) was issued at regional level already on the 4 of February. The day after it was increased up to Level 2. The regional protocol allowed to monitor the evolution of the event with the support of measuring stations (i.e. weather, waves, water levels), webcams, waves and surge forecasts and the EWS alerts (updated every day). The monitoring of the damages started on the 6 of February: while the STBs were visiting the impacted locations from the ground, the Civil Protection implemented a first helicopter flight, providing oblique aerial pictures used later to map storm impacts. Two other flights were performed to complete the survey on the 8 and the 10 of February. In that period, the SGSS collected on-line material such as pictures, movies and news. All the information was archived in the regional database, although the material is currently not available online. However, information on the storm and its impacts are available at the RISC-KIT Storm Impact Database (http://risckit.cloudapp.net/risckit/#/) (Ciavola et al., 2017).

The whole dataset was used to evaluate the impacts along the coast and the observed ingression line (elaborated from aerial pictures and local measurements, where available) was compared with the risk maps produced for the Floods Directive (2007/60/EC) (Perini et al., 2016). Based on this analysis, Perini et al. (2015b) showed that the inundation extension was similar to the inundation scenario defined by an event with a representative return period of 100 years. In specific locations, however, the inundation exceeded the 100 years scenario limit, or, on the contrary, resulted more similar the 10 years flooding scenario.

Severe damages to several concession properties and urban areas were recorded along the coast (Perini et al., 2015a, 2015b). In the Ferrara province, the impacts were mainly confined to the exposed beach, causing significant damage to the concessions (urbanized beaches), to the dune systems (natural areas) and smaller harbours (e.g. flooding of the Porto Canale in Porto Garibaldi). In the Ravenna province, several coastal towns experienced extensive flooding of residential areas (e.g. Lido di Dante, Classe and Savio, where a flood water depth of 2 m was recorded; Perini et al., 2015b).

As part of the quick response effort, the research team performed post-event assessments at several locations in the Ferrara and Ravenna provinces within two weeks after the event. In this work, the analysis of the survey is presented for Lido degli Estensi (i.e. the target area in Figure 1E) in the Ferrara province is shown.

Notably, the event was forecasted by the regional coastal EWS (Perini et al., 2015b). Thus, this extreme event storm provided a unique opportunity to operationalize and evaluate the effectiveness of a comprehensive rapid storm response protocol.

Severe damage to several concession properties and urban areas was recorded along the coast. A description of the impacts at regional level can be found in Perini et al. (2015a & b). As part of the quick response effort, our team was able to visit several locations, in the Ferrara and Ravenna provinces, in the two weeks immediately following the event, with a focus on directly observing and quantifying the impacts of the event, where rapid human post-storm intervention did not occur. While in the Ferrara province the impacts were mainly confined to the exposed beach, causing significant damage to the concessions (urbanized beaches), to the dune systems (natural areas) and smaller harbors (e.g. flooding of the Porto Canale in Porto Garibaldi), in the Ravenna province several coastal towns experienced extensive flooding of residential areas (e.g. Lido di

Dante, Classe and Savio) mainly due the low elevation of the southern part of the regional coastal corridor (Perini et al., 2010). In this paper we present our analysis on the impacts at a local level in the Comacchio municipality (i.e. the target area in Fig. 1E).

Figure 2. Saint Agatha storm hydrodynamic data including significant wave height, Hs (m), wave period (s), and direction of waves approach (nautical degrees), and total water level (m), predicted tide (m) and non-tidal residual (m) inclusive of barometric pressure effects, tide, and storm surge. The start and end time of the storm is referenced to the local storm threshold condition of Hs = 1.5 m and referenced to GMT.

34 Methods

43.1 Quick Response Impact AssessmentProtocol

A local approach for coastal post-storm field surveys, hereafter called Quick Response Protocol (QRP[C1]), was developed and its application in the study area (Section 2) is hereafter presented. The approach was implemented by a team of surveyors, the Quick Response Team (QRT), The authors have developed and present here a coordinated Quick Response Protocol (QRP) for a quick storm impact assessment to be implemented by Quick Response Team (QRT) by integrating E-R EWS (Early Warning System) input, RTK GPS and drone Unmanned Aerial Vehicle (UAV or drone) survey techniques, along with quantitative observation and collection of data through interviews with local stakeholders and damage annotationobservation. In the framework of the risk management cycle, the QRP is shown in its general form in Fig.Figure 3.

Ideally, the response must be activated as soon as possible, prior to recovery processes (natural or human-driven). In this study, The available regional EWS is able to provide early information on the specific coastal areas within the regional domain that are likely to be impacted by an approaching storm. In this case study, the EWS has been operational for several years and is utilized by the Emilia-Romagna regional authority and results made available to the general community (http://geo.regione.emilia-romagna.it/schede/ews/). the on-line regional forecasting system and the E-R EWS (see Section 2.2) provided guidance to the QRT by indicating the specific coastal areas within the regional domain that were likely to be impacted by the approaching storm and when conditions allowed for safe survey activities on-the-ground and in-the-air. Thus, Thus, tthe QRT is able to knowknew in advanceprior to the storm impacting the coast where the protocol quick response will would most likely be needed and prepare in advance for personnel scheduling and survey equipment readiness.

-To detect morphological changes, a base-line of the pre-storm conditions needs to be defined. In general, Tthe pre-storm survey, mainly a topo-bathymetric-bathimetric survey through both RTK GPS and drone UAV techniques, should be performed whenever possible, given enough time and resources. However, it is most critically necessary (i) in case studies where important morphological changes take place over short time-scales and/or (ii) when other sources of information are not available on the pre-storm condition in the likely impacted area. In all other cases, it is possible to assume that the base-line is represented by the most recent available topo-bathymetric dataset, accounting for the limitations linked to this kind of assumption, as it was done for this case study (see Section 3.2).

~~In this study, a pre-storm (October 2014) Lidar derived Digital Terrain Model (DTM) was used as reference for the pre-storm scenario. Moreover, the EWS can provide further guidance to the QRT by indicating when storm conditions have subsided sufficiently to allow survey activities on the ground and in the air.~~

The implementation of the QRP ~~for storm impact assessment~~ included a ~~sequence of steps~~number of field activities to acquire both qualitative and quantitative ~~measurements~~ information o~~f~~n the storm in the immediate aftermath of the event. The critical tasks of the ~~quick response strategy during the days immediately following the storm~~approach included the following activities:

- Conduct interviews of citizens, shopkeepers, restaurant owners, and other local stakeholders;
- Annotate the visible damage to coastal ~~defenses~~defences, buildings, infrastructures;
- Take pictures of the horizontal flood limits and vertical flood marks;
- Map and ~~Quantitatively m~~measure the vertical elevation of flood marks on buildings and defen~~c~~se structures;
- Map the horizontal flood limit~~ by means of RTK GPS;~~;
- Survey of the beach by means of RTK GPS (profiles and control points) and ~~aerial drone~~UAV flights.

In this application, the survey tasks focused on the emerged part of the beach as the UAV system was not capable of acquiring reliable information in the submerged area. In general, for micro-tidal environments, the RTK GPS technique can be used to survey the intertidal area of the cross-shore profiles. This information could be used in comparison with the pre-storm dataset, when covering the same area. However, this data would not be suitable to perform reliable 2D morphological analysis. Some possible improvements of this and other aspects are given in Section 6.

The QRP steps provided the necessary data to allow for an integrated analysis of the storm ~~impacts~~effects on the coast. The need to conduct rapid field survey activities in this study required the contribution of several people: at least 2 to 3 skilled operators were necessary to accomplish all the tasks in the field, every day. Depending on the alongshore extent and width of the coast that needs to be covered, the implementation of the protocol could last from a few days to a few weeks. In this study, 7 days were sufficient to complete the ~~aforementioned tasks~~tasks along a total beach extent of almost 7 km for the case study site (~~Fig.~~Figure 1D), resulting in the integrated assessment rate of 1 km per day. In total, 10 profiles and more than 40 flood limits and flood marks were surveyed with RTK GPS technique~~.~~. ~~and 6~~Six k~~ilometers~~m of beach were surveyed with the ~~drone~~ UAV and ~~a further~~more than 50~~ 50-60~~ GCPs (Ground Control Points) were surveyed on the ground with RTK GPS for use in the drone data processing, error analysis and data comparison.

The data processing and analysis of the acquired information is further described in the next sections, specifically focusing on the target area (~~Fig.~~Figure 1E). The integrated information will help to understand the overall effect of the storm in the surveyed area. The scientific aim of the QRP is to provide useful input to coastal managers for hazard and risk assessment purposes (Figure 3), integrating the post-storm information collected at the regional level.

With regards to the stakeholder interviews, in this study, these were used mainly to understand which local areas were mostly impacted, in order to better organize the field activities, and to understand the timing of the storm impact evolution.

The integrated information will help to understand the overall impact of the storm in the surveyed area. The scientific aims of the QRP can also provide useful input to the coastal managers for hazard and risk assessment purposes (Fig. 3).

Figure 3. The Quick Response Protocol (QRP) in the framework of the Disaster Management Cycle.

34.2 Pre-storm cConditions

The pre-storm conditions of the subaerial beach and backshore were assumed to be represented by the available LIDARLiDAR-derived DTM from October 2014. The dataset was used as reference for the morphological variations of the emerged beach due to the storm impact, as no major events occurred in the period before the surveybetween October 2014 and the Saint Agatha event.

3.3 Stakeholder interviews

Local stakeholders (SHs) were interviewed by the QRT on the morning of the 7 of February 2015. The interviews were mainly based on informal questions on the recent experience, focusing on the timing of the evolution of the flood event; what the people were doing before, during and after the event; if they were alerted and prepared. They were also requested to give an interpretation of the causes of the impacts of the event. Ten SHs were interviewed in Porto Garibaldi (Figure 1D), the town in the north of Lido degli Estensi. The group included mainly owners of commercial or touristic services (e.g. concessions, restaurants, shops and others), a resident, a fisherman and a fireman. In this work, the interviews were mainly used to understand which local areas were mostly impacted, to better organize the field activities, and to understand the temporal evolution of the storm impacts.

34.34 Ground RTK GPS survey

Field measurements relative to flood limits, flood marks, and beach profiles were undertaken using a RTK GPS (Trimble R6). All measurements were referenced to WGS84 UTM33N coordinates and the national geoid Italgeo99 for elevation. The flood limit denotes the maximum water progression on the plan view, and it is evidenced by the presence of objects and debris moved inland by the water during the storm. It was associated with a GPS location (see Figure 4A). These points are hereafter called “GPS Floodlines”, hereafter called “GPS Floodlines” in the study (Fig. 4A). A flood mark denotes the maximum water depth at a specific location where the water level was clearly visible, for example, walls, buildings, trees or dunes (e.g.

~~Fig.~~Figure 4B). These points, hereafter called “GPS Floodmarks”, ~~are~~ were associated with a GPS location and a measured water depth, e.g., with a simple meter (see Figure 4B)~~and an observed water depth~~.

~~-~~Cross-shore beach profiles were also surveyed ~~in order to~~to have a comparison (i.e. *a posteriori*) with the post-storm Digital ~~Elevation~~ Surface Model (D~~E~~SM) generated from the ~~drone~~ UAV photogrammetric~~y~~ analysis (see Section 3.5). Ten cross-shore profiles were measured throughout the surveyed area highlighted in ~~Fig.~~Figure 1D. The measurements were taken on the bare ground and thus excluding variation in the elevation due to debris, wood or others. ~~The~~ Two profiles belong~~ing~~ to the case study target area ~~are two~~ (Profile 1 and Profile 2 in ~~Fig.~~Figure 1E). These profiles ~~were then~~were used to provide a ~~validation/~~quantification of error (i.e. RMSE) of the ~~drone~~ UAV processed data.

Figure 4. Examples of “GPS Floodline” (A) and “GPS Floodmark” (B) measurements.

34.45 UAV survey and photogrammetric process~~Drone Survey and Ground Control Points~~

A commercial off-the-shelf ~~unmanned aerial vehicle (UAV)~~ UAV, the DJI Phantom Vision 2+, was used to conduct the aerial remote sensing imagery capture. The survey was performed with manual flight controls used to fly in a lawn-mower pattern (e.g. boustrophedon flight pattern) back and forth across the beach. Manual flights were performed as, at the time of the survey, the team did not have at its disposal automatic flight tools and software. This approach influenced the results (as expected) and this aspect will be emphasized and discussed in the following sections. Photos were automatically collected every three seconds from elevations between 40-60 m, ~~-~~at speeds of less than 4 m/s ~~with manual flight controls used to fly in a lawn-mower pattern (e.g. boustrophedon flight pattern) back and forth across the beach~~. The UAV camera utilized a fixed focal length and constant exposure. The resulting ground sampling distance and image overlap were estimated to be ~2.5 cm/pixel and ~70%, respectively. ~~with 65-75% overlap between images resulting in more than five photos per common point within the survey domain. The drone camera utilized a fixed focal length, constant exposure, and timed image capture every five~~[C2] ~~seconds.~~ The UAV approach enabled surveying of the target area (~0.15 km^2; Figure 1E) within a 10-minute flight collecting more than 550 images. ~~Fourteen~~ Ground Control Points (GCPs) were ~~taken~~ measured using an RTK GPS (Trimble R6) for use within the photogrammetric process~~in correcting the UAV digital elevation model~~. The GCPs were selected identifying objects on the beach (e.g. coloured plastic objects, wood or concrete platforms, etc.) that were considered easily detectable from the images. However, the resolution of the acquired images allowed detection of 14 GCPs for the target area (Figure 1E) that were used in the photogrammetric process.

A commercially available photogrammetry software package, specifically Pix4D Pro (Version 3.0.13), was used to stitch the collected UAV photos into one continuous orthomosaic by matching points within overlapping ~~photos~~ images utilizing ~~s~~Structure-from-M~~m~~otion (SfM) algorithms. The application of ~~drone~~ UAV-based SfM photogrammetry for coastal morphology assessment has been recently demonstrated ~~recently~~ by the studies of Casella et al.~~,~~ (2014; 2016), Turner et al.~~,~~

(2016), Dohner et al.~~,~~ (2016) and Scarelli et al. (2017). ~~Drone photo post-processing~~The process followed the step-wise ~~process~~ procedure illustrated in ~~Fig.~~Figure 5. ~~,~~ Images were initially matched ~~whereby photos are matched~~ using embedded GPS metadata from the UAV, characterized by poor accuracy (few meters). A sparse point cloud is created based on the identified matching points and the calculated initial image camera positions. Then, ~~then~~ GCPs are ~~added~~ manually identified on the pictures and their GPS information are used to reduce the error in georeferencing, as their position is measured with higher accuracy (few centimetres) than the images~~to the mosaic to constrain error with the more accurate RTK GPS positioning for horizontal and vertical control~~. A dense point cloud is therefore generated by densification of the corrected sparse cloud. The ~~Orthophoto mosaics are then reduced to dense points clouds with elevation values calculated from the stitched mosaic. Digital Elevation Models (DEMs)~~DSM and orthomosaics are then ~~and mesh models are~~ created from the dense point cloud. The dense cloud was not cleaned during the process, meaning that the points representing debris, wood or other objects were not removed and affected the final products. This limitation, presented in other published works such as Casella et al. (2014), will be stressed and discussed in the following sections and specific remedies will be proposed in Section 6. The D~~E~~SM and orthomosaic were then exported for ~~use in comparison to the RTK GPS survey~~the analysis (see Section 4~~5~~). A summary of the information of the Pix4D report is given in Table 1 while, the distribution of the GCP vertical errors assessed by the photogrammetric software, is shown in Figure 1E ~~The drone based survey approach allowed to quickly survey an area of 0.25 km^2 within a 10-minute flight resulting in a ground sampling distance of 2.5 cm/pixel.~~.

Table 1. Pix4D Report Summary.

Keypoints	median of 17344 per image
Calibrated images	581 out of 583
Optimization	Relative difference initial vs optimized parameters: 0.08%
Matches	median of 1198.54 per calibrated image
3D GCPs	14 GCPs; mean RMS error = 0.026 m
Overlapping images for pixel	>5

Figure 5. Sequence of processing steps used in the photogrammetric workflow of UAV images. Main details of each step are given in the dashed boxes.~~Sequence of processing steps used in the analysis of UAV photos to generate data output products.~~

4~~5~~ Results

~~With the goal of demonstrating the reliability of an integrated assessment of the storm impacts, implemented following the QRP, the results~~The results of the post-event assessment are presented in the following. First, a summary of the interviews is given. Then, the results ~~-~~of the RTK GPS and UAV ~~extensive on-ground~~ surveys ~~effort during the week following the storm~~ are presented (and compared) for the target area (~~Fig.~~Figure 1E) of the pilot case study (~~Fig.~~Figure 1D). ~~The results are presented in sequential sections showing comparisons between the on-the-ground (RTK-GPS) and aerial drone survey results.~~

4.1 Summary of the interviews

Many of the SHs reported that on the evening of the 5 of February (Thursday) the water level inside the Porto Canale of Porto Garibaldi (Figure 1D) was approaching the level of the embankments (~1.8 m above MSL) due to the combined effect of the canal discharge and the sea conditions. At that moment, the emerged beaches were already impacted by high water levels and waves. The overflow of the canal started between 01:00 and 02:00 GMT and continued till 04:00, mainly because of the oscillations of the water surface following wave propagation inside the canal. Early Friday morning, the situation was still critical, it only improved at lunch time, when the stormy sea conditions began to subside. Some of the SHs claimed that they did not remember a similar event in the last 30, 50 or even 60 years.

For the local people in Porto Garibaldi it was already clear on the 5 February 2015, that a strong coastal event was approaching their towns. However, several SHs claimed that no clear local alert to the population was given and none of those interviewed knew about the regional E-R EWS. Basically, local know-how and experiences were their only instruments to understanding and preparing for the situation (e.g. deploying sand bags). They also reported that the Civil Protection arrived at the location on the 6 of February (Friday), at approximately 13:00 GMT, bringing sand bags and assistance.

4~~5~~.~~1~~2 ~~Topographic Profiles and Digital Elevation Model~~Elevation data ~~Surface~~

An indication of the ~~reliability~~ quality of the ~~DEM~~ DSM produced from the analysis of the ~~drone~~ UAV images is given comparing it with the RTK GPS cross-section points (see ~~Fig.~~Figure 1E). The comparison is shown in ~~Fig.~~Figure 6 for both profiles. For both datasets the assumed (i.e. *a priori*) vertical uncertainty is shown, namely ±15 cm for drone derived data and ±5 cm for RTK GPS data, illustrated by the shaded outlines. ~~It is important to note that e~~O~~levation o~~utliers were deleted from the ~~drone~~ DSM~~derived d~~ data extracted for Profile 1 and 2 when they were visually determined to be clearly not representative of the terrain surface. However, it was not possible to correct the variations induced by debris or other small objects affecting the DSM in a similar manner and where therefore retained in the surface. Profiles were smoothed using a moving average for the~~A smoothing~~ DSM and RTK GPS derived data to reduce noise~~of the profiles (drone and RTK GPS derived) was also applied~~. The Root Mean Square Errors (RMSEs) of the vertical elevation between the ~~ground measured (~~RTK GPS~~)~~ and ~~remote sensing (drone)~~DSM data were 14 cm and 12 cm for Profiles 1 and 2, respectively. Note that Profile 2~~, with an RMSE of 12 cm,~~ is located in the central portion of the survey area, where more precision was expected due to greater image overlap and

GCP control targets~~,~~ while, P~~p~~rofile 1~~, with an RMSE of 14 cm,~~ is closer to the edge of the domain where the ~~drone DEM~~ DSM is expected to be less accurate. Since the ~~drone~~ DSM data comes from a commercial ~~off-the-shelf~~software ~~unit~~ and thus relies on ~~RTK GPS ground control points~~GCPs for positioning accuracy, the ~~drone~~ UAV surveys are therefore not wholly independent of the GPS system. Nevertheless, the ~~drone survey~~approach~~s~~ provide a useful and efficient ~~extension of the RTK GPS ground surveys~~dataset to integrate RTK GPS measurements.

This ~~target study~~comparison aimed ~~to give~~at giving an indication of ~~precision~~ accuracy and reliability of the resulting ~~drone~~UAV-derived DSM ~~DTM~~ which was corrected using the available ~~RTK GPS ground control points~~GCPs. The ~~drone data~~DSM, while overestimating the elevation in the higher portion of the Profile 1, with the strongest difference o~~i~~n the order of 25-30 cm, converged with the RTK GPS profile in the lower portion of Profile 1 near the swash zone. For Profile 2, ~~most~~ many of the morphological features were captured, including the storm berm (with a vertical error on the berm top of ~15 cm). The slopes of the emerged foreshore are comparable for both profiles: for Profile 1 the calculated slope ~~calculated~~ was 0.016 for the ~~drone d~~UAV-derived profile, while it resulted in 0.014 for the RTK GPS profile. The same slopes calculated for Profile 2 resulted in 0.021 and 0.018, respectively. This profile convergence is implemented in further morphological change analysis as shown in Section 4.4~~5.3~~.

Thus, the foreshore slope, berm shape, and berm crest locations are well captured by the ~~drone~~ UAV-derived DS~~E~~M in ~~Fig.~~Figure 6. The largest disagreement between the ~~drone~~ DSM and RTK GPS profiles occurs landward of the berm in the back portion of the beach (around 30 cm for Profile 1 and 20 cm for Profile 2). A combination of factors possibly contributed to this difference including lower sampling resolution of the RTK GPS compared to the UAV, the manual flight that does not allow for a full control on flight altitude and images overlap the inclusion of non-terrain elevations such as wood and debris in the DSM, and other affecting factors such as the texture of the beach surface and the position of the sun (see Sections 5 and 6 for the discussion of these limitations and proposed remedies, respectively).

~~A combination of factors may have contributed to this difference including lower sampling resolution of the RTK GPS compared to the drone, higher uncertainties in the drone elevations, and inclusion of non-terrain elevations such as wood and debris in the DEM (see Section 6.1).~~

Figure 6. Comparisons between the February 2015 post-storm observed RTK GPS profile survey and post-storm UAV-derived DSM for Profiles 1 and 2. The error bands, defined *a priori* (±15 cm for UAV and ±5 cm for GPS) for visualization purposes, are shown. The RMSE calculated *a posteriori* between the RTK GPS and UAV-derived data are reported~~Comparisons between the February 2015 post-storm observed GPS profile survey and post-storm drone DEM for Profiles 1 and 2~~.

~~**5.2 Coastal Flooding**~~

~~In Fig. 7, the results obtained for the flood extent from the drone derived data are shown in comparison with the GPS observed Floodline and Floodmarks. The drone orthomosaic was analyzed to extract the floodline extent by observing the debris line that was deposited inland (i.e. "Drone Floodline" in Fig. 7). In order to also take into account visible areas in the drone~~

orthomosaic that were reached by the water through small paths but that are not included in the main flooded area (defined as previously described in Section 4.4), several spot areas, hereby and in Fig. 7 called “Drone Secondary Flood” areas, were defined. Notably, the high resolution of the orthomosaic enabled to extract a really detailed continuous flood extent, if compared to the GPS survey.

An agreement is seen between the “Drone Floodline” and the RTK GPS derived flood line (“GPS Floodline”). As both depend on the observation of objects and debris moved inland during the storm that remained visible during both the GPS survey and in the drone orthomosaic, the comparison can be considered as validation of the drone orthomosaic for remote sensing of storm floodlines. The flooding was mainly limited to the subaerial beach in front of the concessions (Fig. 7). Some of the concessions, however, experienced an indirect flooding where the limit of the flood reached the border of the concessions and the water found a path to flow in to the properties (Fig. 7, A, B, C, D). A water depth of 30cm was measured in the location of the flood mark (Fig. 7, A).

Figure 7. Observed “GPS Floodline” and “GPS Floodmark” (green and red circles), drone (red solid line and light blue polygons) flood extent comparisons: the box on the left shows an overview of the target area while on the right (A, B, C and D) some spot-focuses are given.

45.33 Erosion and Ssedimentation pPatterns

The erosion and sedimentation patterns are shown in Fig. 8Figure 7. The drone derivedmorphological variations patterns (Fig. 8Figure 7, A1, B1 and C1) were obtained from the comparison between the DTM of October 2014 and the post-event UAV-derived DSEM generated by the drone. The results are only presented for the area limited by the GCPs. Notably, asT the drone derived DSEM included non-terrain objects and buildings, thus the analysis of the morphological features only focused on the emerged beach. The results are only presented for the area limited by the GCPs. The inclusion of non-beach features in the drone derived DEMDSM, mainly because of the presence of different sized debris, affected the non-uniformity of the drone derivedthe shown patterns.

The morphological features are recognizable in the drone orthomosaic (Fig. 8, A). A general lowering of the backshore can be noted especially from the drone results (Fig. 8, A1), which actually corresponds to the area where the differences between the RTK GPS profiles and the drone derived one were higher (see Section 5.1 and Fig. 6). From Based on the drone results (Fig. 8Figure 7, A1) a formation of a storm berm is clearly visible running alongshore with a varying width of 20 to 50 m. The vertical deposit is interrupted by erosion scour channels due to some return flows (Fig. 8Figure 7, A1). Seaward of the depositional area (i.e. the storm berm) a negative variation pattern highlights the erosion of the ordinary berman erosion pattern highlights a trough formation, which emphasizes intensifies just in front of the scour channels (Fig. 8Figure 7, A1). Thus, the berm vertically grew and moved landward during the storm as result of motion of sedimentssediment transport in the breaker zone (Fig. 8Figure 7, A1). At the same time, a small portion of deposition in the intertidal area potentially corresponds to the development of a low tide terracethe intertidal bar, just at the edge of the analyzed domain. However, the domain does not include the lower intertidal area. Therefore, it is not possible to evaluate the morphological variation of the lower limit of the foreshore. A general lowering landward of the storm berm can be noted (Figure 7A1), which corresponds to the area where the differences between the RTK GPS profiles and the UAV-derived one were higher (see Section 4.2 and Figure 6). Thus, this variation can be subjected to error or even representing an artefact. Focusing on the selected frames (~~Fig. 8~~Figure 7~~,~~ B, B1, C, C1), visible scour channels are highlighted, that possibly developed from the footpaths ~~which provided~~thereby providing ~~the~~ ~~fastest~~ preferential pathways for water retreat seaward following storm conditions~~the water to flow back to sea during the storm~~. This highlights the UAV's ability to map finer resolution features such as scour channels.

~~Figure 8~~Figure 7. Morphological variations: (A) the ~~drone~~ UAV-derived orthomosaic of the target area, where morphological features are visible along with the position of the GCPs; (A1) the difference between the post-event ~~drone~~UAV-derived D~~E~~SM and the pre-storm ~~Lidar~~LiDAR-derived D~~E~~TM. In B, B1 and C, C1 enlargements of the main features are given. The morphological variations are only shown for the area surrounded by the GCPs.

4.4 Coastal flooding

In Figure 8, the results obtained for the flood extent from the UAV-derived data are shown in comparison with the RTK GPS observed flood limits and marks. The orthomosaic was analyzed to extract the flood line by observing the debris that deposited on the beach (i.e. "Drone Floodline" in Figure 8). The high-resolution of the orthomosaic enabled the extraction of a detailed continuous flood extension, in comparison to the RTK GPS survey. Utilizing the orthomosaic, it was observed that several areas, that were not included in the main flooded areas, were reached by the water through small paths. Those spots, hereby defined "Drone Secondary Flood" areas, were identified and reported in Figure 8.

An agreement is seen between the "Drone Floodline" and the RTK GPS derived flood line ("GPS Floodline"). As both depend upon the independent observation of objects and debris moved inland during the storm, the comparison can be considered as validation of the orthomosaic. The flooding was mainly limited to the beach in front of the concessions (Figure 8). Some of them, however, experienced secondary flooding where the limit of the flood reached the border of the concessions and the water found a path to flow in to the properties (Figure 8A, B, C, D). These impacts were also observed during the collection of picture and damage observation, but it was not possible to understand the extension of the flooding from the ground, as the private concessions were fenced and admission was not allowed.

The maximum elevation reached by the water was calculated using the RTK GPS measurements (i.e. "GPS Floodline" and "GPS Floodmark" points) and extracting the elevation of the UAV-derived DSM along the "Drone Floodline". The calculated average elevations reached by the water resulted in 1.634 m and 1.645 m for RTK GPS and UAV data, respectively. The associated standard deviations were 0.079 m and 0.196 m, respectively. The same analysis using the "Drone Floodline" was performed on the pre-storm DTM and it resulted in an average elevation of 1.663 m, with standard deviation equals to 0.093 m. A water depth of 30 cm was measured in the location of the flood mark (Figure 8A).

Figure 8. Observed "GPS Floodline" and "GPS Floodmark" (green and red circles), UAV (red solid line and light-blue polygons) flood extension comparisons: the box on the left shows an overview of the target area while on the right (A, B, C and D) some spot-focuses are given.

A general lowering of the backshore can be noted especially from the drone results (Fig. 8, A1), which actually corresponds to the area where the differences between the RTK GPS profiles and the drone derived one were higher (see Section 5.1 and Fig. 6).

56 Discussion and Recommendations

In this section the results are discussed, along with their limitations, with focus on the summary of the local interviews and the comparisons between RTK GPS and UAV-derived data. A focus on the integration of the regional assessment with the local information is given.

The interviews to local SHs were useful at giving a picture of what happened during the night between the 5 and the 6 of February 2015 (see Section 4.1). The evolution of the event described by people was consistent with the observations. The interviews focused on the impacts in Porto Garibaldi mainly due to the overflow of the canal harbour. However, the interviewed could give indications on the impacted areas in the surroundings (i.e. Lido degli Estensi and Spina) and thus helping the research team at better organizing the field activities. An interesting aspect that was highlighted was that the population did not receive specific alerts. However, coastal managers reported that several alerts were issued before the event to municipalities and Civil Protection agencies (Perini et al., 2015b). The fact that the Civil Protection reached the location only on 6 of February (Friday), after the peak of the event, supports the hypothesis that, even if the alert was issued from the regional to the municipality level, there was a communication problem between the managers, the people in charge of responding to the emergency and the local population. This was also indirectly confirmed by the interviewed fireman who claimed that they were not even prepared to act on coastal locations. It also appeared that the population of the area was not aware of the on-line E-R EWS that they could have monitored. These aspects support the idea that more effort should be spent improving the preparedness and response of the Civil Protection and the awareness of the local population, especially by improving the communication channels and spreading the risk knowledge. These aspects were also reported by Martinez et al. (2017), about the same event and the same locations, in the wider framework of the aims of the EU FP7 RISC-KIT Project (GA 603458; www.risckit.eu) (Van Dongeren et al., 2017). Pescaroli and Magni (2015) also highlighted the importance of this aspects based on the analysis of interviews to local people in Cesenatico (Figure 1C). The limitations of the interviews here presented are mainly related to the lack of a standardized methodology, as the questions were mainly informal, and the limited number of people involved. A standard approach (e.g. using prepared questionnaire) can produce more reliable information that can be statistically analyzed, if the number of interviewed is large enough. Several examples of methodological approaches for stakeholder interviews and the analysis of their outcomes exist in the literature, for diverse purposes (Pescaroli and Magni, 2015; Becu et al., 2017; Gray et al., 2017; Martinez et al., 2017), that could be adapted to be applied during a post-storm assessment.

~~In this section the authors discuss the results, along with their limitations, with focus on the comparisons between gps and drone derived data. Then, practical and general recommendations are given in order to provide possible ways to improve the QRP application and the quality of the data.~~

~~6.1 Discussion~~

~~The variability in vertical accuracy seen in the drone derived data was mainly related to the flight parameters (manual flight, variable altitude and timed image capture), the number and type of GCPs used to constrain the DEM and SfM equations used in each software processing workflow. A recent study by James et al., (2017) provides practical suggestions for photogrammetric considerations (i.e. modifications to drone flight characteristics) control considerations (i.e. the number and spacing of GCPs) that echo the operational findings from our study, namely that overall DEM improvement is achieved through increased numbers of overlapping imagery and greater number of distributed GCPs. Of note with regards to our DEM analysis, non-terrain objects (i.e. human structures and debris) were not removed from the point cloud during processing and remained in the resulting DEM as was seen also in a similar storm response study by Casella et al., (2014). Thus, objects such as wood, litter and buildings, locally affected the represented surface and, consequently, the comparison with the post-storm RTK GPS observations and the pre-storm DTM data, which only represented the terrain surface. Notably, the profile comparisons show disturbances that can be due to these aspects. Also, the drone derived DEM should be considered valid in the area limited by the GCPs.~~ The RMSEs of 14~~ cm~~ and 12 cm~~ vertically,~~ that were calculated between the ~~drone~~ processed DS~~E~~M ~~from photogrammetry processing using GCPs~~ and the RTK GPS data (see Section 4.2 and ~~Fig.~~Figure 6)~~,~~ are similar for both analyzed profiles and comparable with the LiDAR~~dar-~~derived data uncertainty. In comparison with error estimates of drone products reported by recent studies, the resulting RMSE values of the~~ drone~~ DS~~E~~M compared to the traditional RTK GPS profile surveys are comparable (Casella, 2014 ~~&~~ and 2016; Dohner et al., 2016) or higher (Turner et al., 2016; James et al., 2017; Scarelli et al., 2017). The low accuracy of the DSM product is attributed to aspects related to both the field implementation and the photogrammetric process. A recent study by James et al. (2017) provides practical suggestions to improve the quality of the field survey (e.g. modifications to drone flight characteristics, the number and spacing of GCPs, etc.). Overall DSM improvement is achieved through increased numbers of overlapping imagery, that can be properly controlled, for example, with automated flights that can also constrain the variability of the flight altitude. GCPs plays a major role on the quality of the photogrammetric products, being able to increase the accuracy of DSMs of one order of magnitude, when properly used (e.g. Moloney et al., 2017).~~This is attributed to manual flights and inappropriate GCP selections which were unidentifiable due to image resolution at the survey altitude.~~ In addition, the UAV-derived DSM should be considered valid in the area limited by the GCPs. The number, position and accuracy of the measured GCPs, that should be easily detectable from the images, are thus extremely important. In this application, the selected GCPs (i.e. objects found on the beach) were not always detectable from the images (because of the low resolution) and their distribution was not uniform, although conspicuous in number (14 GCPs for 0.15 km^2). Following Seymour et al. (2017), it is possible to assume that the inaccuracy of the final product can be also due to the (combined effect of the) homogeneous texture of the beach surface and the high position of the sun during the flight (that in this study was performed at 12:00 GMT). Overexposure and smooth (in elevation and colour) surfaces can indeed undermine the SfM processing. Regarding the photogrammetric reconstruction, non-terrain objects (i.e. human structures and debris) were not removed or filtered from the point cloud during processing and remained in the dataset as was seen also in a similar storm response study by Casella et al. (2014). Thus, objects such as wood, litter and buildings, locally affected the represented surface. This, consequently, influenced the comparison with the post-storm RTK GPS observations, which only represented the terrain surface~~However, the resulting drone DEM was still able to well capture morphological features~~. The quality of the products can be further improved~~.~~ (see Section 6 for proposed improvements). However, the shown DSM was still able to capture key morphologic features (i.e. berm and scour channels).

~~The drone derived orthomosaic offered a very easy and quick way to assess the flood extent of the event. The general agreement with the RTK GPS on the ground observations confirmed the close geopositioning of the images and provided a validation of the assessed flood extent. Notably, the opportunity to observe the flooding extent from the drone data made it possible to define a really detailed and continuous floodline. In order to obtain the same results with a GPS survey, the operator should increase the point sampling (or even use a continuous sampling method). This implies prolonging the field activities on the beach. Also, the drone point of view is essential to have a complete view of the flood line evolution while, from the GPS point of view, the random distribution and spreading of the debris can mislead the operator.~~

The morphological patterns (see Section 4.3) derived from the drone data gave an opportunity to assess the morphological response of the beach at a ~~very~~ detailed resolution. The results showed the erosion of the ordinary berm and the formation of a storm berm.~~From a geomorphologic point of view, the formation of an intertidal bar after a storm event was also noticed by Armaroli et al., 2013.~~ The scouring channels highlighted in ~~Fig. 8~~Figure 7 were potentially triggered by the presence of concrete pathways of local activities that concentrated and accelerated the return water flux during the storm. ~~In order to~~To reduce the formation of these scouring channels and the consequent worsening of beach erosion, a reasonable ~~choice~~ option would be to remove, or at least retreat landward, the pathways during the winter season (Nordstrom et al., 2015). The level of detail of the outcomes suggests that it is possible to use UAV-derived products to calculate volume variations, as already confirmed by the literature on the topic (e.g. Turner et al., 2016).

The UAV-derived orthomosaic offered a rapid way to map the flood extension (see Section 4.4). The general agreement with the RTK GPS on-the-ground observations confirmed the close geopositioning of the images and provided a validation of the assessed flood extension. The opportunity to observe the flood extension from the UAV data made it possible to define a detailed and continuous flood line. To obtain the same results with a RTK GPS survey, the operator should increase the point sampling (or even use a continuous sampling method). This implies prolonging the field activities on the beach. Also, the aerial point of view is essential to have a complete view of the flood line evolution while, from the RTK GPS viewpoint, the random distribution and spreading of the debris can mislead the operator. The maximum elevations reached by the water, separately assessed considering RTK GPS measurements and the UAV-derived data, were comparable (~1.65 m), although the second one was characterized by higher uncertainty. As the maximum total water level measured during the storm was 1.20 m (P. Corsini tide gauge, Figure 1C; see Section 2.3), a component of ~0.45 due to wave run-up and set-up must be considered for the water to reach the estimated average elevations on the emerged beach. This value is comparable to the same component calculated using the formula proposed by Suanez et al. (2015) for storm conditions (i.e. 0.40 m and 0.53 m, respectively), considering the average slopes of 0.015 and 0.02 (which are representative of those calculated for the Profiles 1 and 2 analyzed in this study, see Section 4.1) and the hydrodynamics of the storm (see Section 2.3). On the other hand, it is lower than the component calculated with the traditional formula by Stockdon et al. (2006), which resulted in 1.14 m for both slopes (i.e. dissipative conditions).

When compared with the post-storm regional assessment reported in Perini et al. (2015b), the proposed survey approach for local assessments can produce very detailed and accurate data. Indeed, the flood ingression extracted from the dataset of Perini et al. (2015b) is not as accurate and detailed as the information that can be capture with drones flying at ~50 m height. Moreover, the regional analysis of the flood ingression was not implemented in this case study because the Civil Protection flight was performed too late, when the markers of the limit of the inundation were no longer identifiable from the helicopter (Armaroli C., personal communication). Thus, a direct comparison between the two observed flood extensions was not possible. However, the comparison of the regional flood maps (T10 and T100; Perini et al., 2016) with the "Drone Floodline" is shown in Figure 9, for the target area. In this location, the inundation extension was lower than the extension calculated for the 10 years return period event (T10). This is in contrast with the evidences of Perini et al. (2015b) at regional level and for the two reported examples of Lido di Savio and Cesenatico (see Section 2.3) that showed more similarity with the 100 years (T100) scenario. This difference can be attributed to the fact that the regional maps are calculated with a static approach, not grounded in process-based formulas or models, applying a constant total water level (1.49 m and 1.81 m for T10 and T100, respectively) at the shoreline and propagating the inundation with a modified bathtub-based approach over a 2 m resolution LiDAR DTM form 2008 (more details in Perini et al., 2016). Thus, site specific processes (e.g. wave run-up and set-up) are not properly considered, probably leading to the differences highlighted above. This hypothesis is also supported by the fact that the assessed maximum elevation reached by the water is close to the average between the levels used to calculate the T10 and T100 scenarios. Therefore, the observed flood line should have been located between the T10 and T100 flood limits.

Regarding the morphological analysis, the variations captured from the UAV can be used to calculate more accurate volume changes, at local level, than those that can be calculated on representative beach profiles along the coast. The regional approach indeed only focuses on a limited number of beach profiles along the coast. Moreover, the regional protocol does not include any attempt to involve local people with interviews or other methods as the STBs, activated after the event, mainly collect qualitative information through direct observations and pictures (see Section 2.2).

Finally, the level of detail of the shown UAV-derived products as well as the efficiency of the field survey, make the presented approach very effective for the post-storm assessment when compared with pure RTK GPS or terrestrial laser scanner based approaches, as confirmed by the literature. For example, Moloney et al. (2017) estimated that to complete the survey (including set-up time) of the same area (i.e. a coastal dune test area of 85 m x 65 m) the RTK GPS technique required ~13.45 hours, the laser scanner ~3.66 hours, while the UAV only ~1.15 hours. The field efficiency of the UAV was also higher (10^4 and 25 times faster than the RTK GPS and laser scanner ones, respectively) in terms of rate of measured points per hours. Even considering that an RTK GPS survey can be completed by 1 skilled person, while the UAV needs 2-3 people like the laser scanner, the proposed approach results in more efficient and comprehensive data acquisition. Focusing on costs, while adopting low-cost UAVs, such as the one used in this study or in Moloney et al. (2017), and a licensed photogrammetric software, the RTK GPS survey method is less expensive. However, the higher costs of UAV-based surveys are balanced by the efficiency and the speed of the field activities.

In this sense, the proposed QRP can be very helpful at integrating and completing the regional protocol for post-storm assessment. As the regional authorities do not have sufficient manpower and instruments to perform such local detailed assessments along the whole coast, it is advisable to integrate local protocols (such as the QRP) in the regional one. The proposed approach can be performed at local level by academic and private survey teams (such as the QRT) that can be activated as STBs are (see Section 2.2), after the coastal event. The regional assessment, indeed, would benefit from the inclusion of more local, qualitative and quantitative information. By properly organizing the tasks assignments at different locations on the coast (i.e. the most impacted areas), it will be possible to activate a quick, coordinated protocol in the immediate aftermath of an event acting at regional and local level. This will provide more holistic data coverage, filling gaps and increasing the details and reliability of the assessments.

Figure 9. Comparisons between the observed "DRONE Floodline" and the flood scenarios (T10 and T100) computed by Perini et al. (2016).

6.2 Suggestions for possible improvementsPractical Recommendations

Through the initial rapid response field collection effort the research team determined specific methodologies to ensure quality data following a major storm event. With respect to remote sensing drone survey, the placement and quantity of GCPs, plays a critical role in the resulting DEM and its uncertainty. In order to obtain high quality data, the following suggestions are given and should be implemented in the QRP.vertical and horizontal errors shown in Fig. 9, the following guidelines are suggested for flight planning and GCP distribution:

- Perform drone flight surveys at the same altitude and image overlap. This is easily done with an autopilot and mission planning application available to phones and tablets.
- Survey a significantly larger domain (~10% buffer) than needed for data collection. Survey domain edge photos are often removed due to low overlap between images and data is lost.
- Distribute GCPs throughout survey domain and near boundaries to prevent skewing within the DEM.

- ~~GCPs should be flat, large, and uniquely shaped or marked in such a manner as to be confidently identified from aerial images.~~
- ~~On the ground photos of GCP locations should be taken to give a concept of exactly where the RTK GPS point were taken on the target object and within the context of the survey domain.~~
- ~~Remove outlier and/or non-terrestrial points from the dense point cloud such as storm debris, people, and vehicles for surface calculations~~

The use of automatic flight planning can considerably improve the quality of the survey allowing the control of flight altitude and image overlap. The UAV survey should be planned on a larger domain (~10% buffer) than needed for data collection. Survey domain edge photos are often removed due to low overlap between images and data is lost

The GCPs should be distributed throughout the survey domain and near boundaries to prevent skewing within the DSM product. As anticipated, the GCPs should be easily detectable as playing an important role in maximizing the accuracy of the photogrammetric products. This depends on both the quality of the images (that depends on the camera system, the type and altitude of the flight) and of the type of GCPs. An example of GCPs used during the survey can be found in Figure 10 with images of good (A, B) and poor (C, D) quality ones. Proper GCPs can be prepared using flat wood panels painted with two contrasting colours (e.g. red/white, yellow/black). In this case, however, the surveyors must bring them in the filed while in this application the GCPs were selected using the objects found on the beach. On the ground, photos of GCP locations should be taken to have the idea of exactly where the RTK GPS point were taken on the target object and within the context of the survey domain

As suggested in Section 5, environmental conditions (e.g. texture of the beach surface and sun conditions; Seymour et al., 2017) can influence the accuracy of the products and the operators should consider these aspects when planning the field activities.

The photogrammetric process can also be improved, for example, by spending more effort in cleaning and filtering the point cloud, thus minimizing the effect of debris and others on the final products.

As anticipated in the Section 3.1 the post-storm survey did not include the submerged area. To extend the protocol to this part of the beach, other innovative approaches should be adopted, such as near-shore low-cost autonomous surface systems (e.g. Hampson et al., 2011). However, it is beyond the aim of this work to include these aspects in the protocol.

~~A visual representation of the bulleted list is presented in Fig. 9 with images of positive (9A and 9B) and poor (9C and 9D) quality GCPs.~~

Qualitative observations and interviews are also ~~important~~significant and should be performed as soon as possible and as detailed as possible during the implementation of the QRP. It is important to adopt standard approaches for stakeholder involvement and interview a large number of people in order to allow statistical analysis of qualitative information and increase representativeness.

~~Thus, t~~The larger is the number of people involved for the post-event survey, the faster~~est~~ the data can be the ~~collection of data~~collected. In addition, ~~as~~ the team can be divide in ~~thematic~~ groups with specific tasks (e.g. performing interviews, RTK GPS or UAV surveys, etc.), speeding up the survey process. Planning the activities is crucial for ~~the good~~efficient and high-quality performance of the QRT~~team~~. This can be additionally supported by activities completed~~performed~~ during the non-storm season, such as instrument maintenance and preparation, monitoring of the ~~EWS~~ warning system performances, tasks planning and assignment, etc.

To provide more accurate qualitative outcomes further analyses should be performed. This paper only presents the analysis of a small portion (Figure 1E) of the whole case study (Figure 1D) and deeper investigations (e.g. including forcing, sediment and volume change analysis, possibly supported by numerical models; including more detailed socio-economic aspects for precise impact assessments; etc.) are needed to provide more robust outcomes. However, the QRP has been demonstrated to be a proper approach to quickly assess the storm effects at local level in the immediate aftermath of an event, as a combination of technologies and planning approaches. Thus, in the framework of coastal management (Figure 3), a proper application of the protocol can produce useful information that can be used at local, regional and national levels in order to: (i) update hazard and risk maps; (ii) provide detailed information for flood-damage curves calibration (see, as example, the study of Scorzini and Frank, 2017); and (iii) provide insights for risk mitigation and management plans. Finally, as suggested in Section 5, the QRP can be integrated in regional protocols, improving the reliability of the regional hazard and risk assessments.

Figure 10~~9~~. Photos A and B at the top demonstrate practical GCPs based on unique shapes, colors, and ability to see from a high altitude. Photos C and D, on the bottom, demonstrate error-inducing GCPs due to their height off the ground and indistinguishable shape, size, and color in aerial images.

~~6.3 General Recommendations~~

~~In order to provide more accurate qualitative outcomes further analyses should be performed. This paper only presents the analysis of a small portion (Fig. 1E) of the whole case study (Fig. 1D) and deeper investigations are needed to provide more robust outcomes. However, the QRP has been demonstrated to be a proper approach to quickly assess the storm impacts along the coast in the immediate aftermath of an event, as a combination of technologies and planning approaches. Thus, in the framework of coastal management (Fig. 3), a proper application of the protocol can produce useful information that can be used at local, regional and national levels in order to, as example: (i) update hazard and risk maps; (ii) provide detailed information for flood-damage curves calibration (see, as example, the study of Scorzini and Frank, 2015); (iii) provide insights for risk mitigation and management plans.~~

7 Conclusions

This case study illustrates the potentialities and benefits of an integrated approach combining ~~aerial drones~~Unmanned Aerial Vehicles (UAVs) together with on the ground Real-Time Kinematic Geographical Positions System (RTK GPS) surveys and qualitative data collection through stakeholders' interviews for coastal storm impact assessments at local level. The presented protocol was applied at a pilot case study in the Emilia-Romagna coast, after the impact of an extreme coastal storm, and results were presented and discussed, for demonstration purposes, on a small portion of the pilot case study.

~~Limitations of the application were highlighted and recommendations for improvements were given.~~ As a general remark, (i) interviewing local stakeholders and people in charge of emergency response tasks can be extremely useful at supporting the organization of the field activities, as well as at detecting lacks on the alert chain, preparedness and response emergency phases; (ii) the ~~drone~~ UAV approach was found to be effective for ~~flooding and erosion~~erosion and flooding ~~impact~~ assessments, being able to provide detailed, continuous and two(three)-dimensional information, with ~~a limited time effort on~~less time spent in the field in comparison with the traditional RTK GPS ~~methodologies~~surveys and other approaches.

The main limitation of the analysis of the interviews was due to the lack of a standardized approach, that should be adopted (and adapted) from the literature. The main limitation of the drone products was linked to the field implementation and lacks in the photogrammetric process. Specific suggestions for improvements were given, such as the use of automated flights, proper GCPs and the cleaning of the point cloud during the photogrammetric process.

Regarding the proposed general approach, further applications can directly support hazard and impact assessment at local and regional level, and thus addressing coastal management needs. Indeed, the outcomes of the analysis were compared with the post-event assessment performed by the regional authorities highlighting that the proposed protocol for local assessment can be easily integrated in the regional ones, improving the details and reliability of the regional assessments.~~Notably, further applications of the approach can directly support hazard and risk assessment efforts at local and regional level (e.g., hazard and risk maps updating, calibration of flood-damage curves, etc.), and thus addressing coastal management needs.~~

Competing interests

The authors declare that they have no conflict of interest.

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Captions

Figure 1. **Field study site locations: A) Emilia-Romagna region; B) Coastal regional domain; C) Locations of the nearest tide gauge and wave buoy; D) Pilot case study site; E) Target area for data comparison.**

Figure 2. Saint Agatha storm hydrodynamic data including significant wave height, Hs (m), wave period (s), and direction of wave approach (nautical degrees) and total water level (m) inclusive of barometric pressure effects, tide, and storm surge. The start and end time of the storm is referenced to the local storm threshold condition of Hs = 1.5 m and referenced to GMT.

Figure 3. The Quick Response Protocol (QRP) in the framework of the Disaster Management Cycle.

Figure 4. Examples of “GPS Floodline” (A) and “GPS Floodmark” (B) measurements.

Figure 5. Sequence of processing steps used in the analysis of UAV photos to generate data output products.

Figure 6. Comparisons between the February 2015 post-storm observed GPS profile survey and post-storm drone DEM for Profiles 1 and 2.

Figure 7. Observed “GPS Floodline” and “GPS Floodmark” (green and red circles), drone (red solid line and light-blue polygons) flood extent comparisons: the box on the left shows an overview of the target area while on the right (A, B, C and D) some spot-focuses are given.

Figure 8. Morphological variations: (A) the drone orthomosaic of the target area, where morphological features are visible along with the position of the GCPs; (A1) the difference between the post-event drone-derived DEM and the pre-storm Lidar-derived DEM. In B, B1 and C, C1 enlargements of the main features are given. The morphological variations are only shown for the area surrounded by the GCPs.

Figure 9. Photos A and B at the top demonstrate practical GCPs based on unique shapes, colors, and ability to see from a high altitude. Photos C and D, on the bottom, demonstrate error-inducing GCPs due to their height off the ground and indistinguishable shape, size, and color in aerial images.Figure 1. Field study site locations: A) Emilia-Romagna region; B) Coastal regional domain; C) Locations of the nearest tide gauge and wave buoy; D) Pilot case study site; E) Target area for data comparison.

Figure 2. Saint Agatha storm hydrodynamic data including significant wave height (m), wave period (s), direction of waves (nautical degrees), total water level (m), predicted tide (m) and non-tidal residual (m). The start and end time of the storm is referenced to the local storm threshold condition of Hs = 1.5 m and referenced to GMT.

Figure 3. The Quick Response Protocol (QRP) in the framework of the Disaster Management Cycle.

Figure 4. Examples of “GPS Floodline” (A) and “GPS Floodmark” (B) measurements.

Figure 5. Sequence of processing steps used in the photogrammetric workflow of UAV images. Main details of each step are given in the dashed boxes.

Figure 6. Comparisons between the February 2015 post-storm observed RTK GPS profile survey and post-storm UAV-derived DSM for Profiles 1 and 2. The error bands, defined *a priori* (±15 cm for UAV and ±5 cm for GPS) for visualization purposes, are shown. The RMSE calculated *a posteriori* between the RTK GPS and UAV-derived data are reported.

Figure 7. Morphological variations: (A) the UAV-derived orthomosaic of the target area, where morphological features are visible along with the position of the GCPs; (A1) the difference between the post-event UAV-derived DSM and the

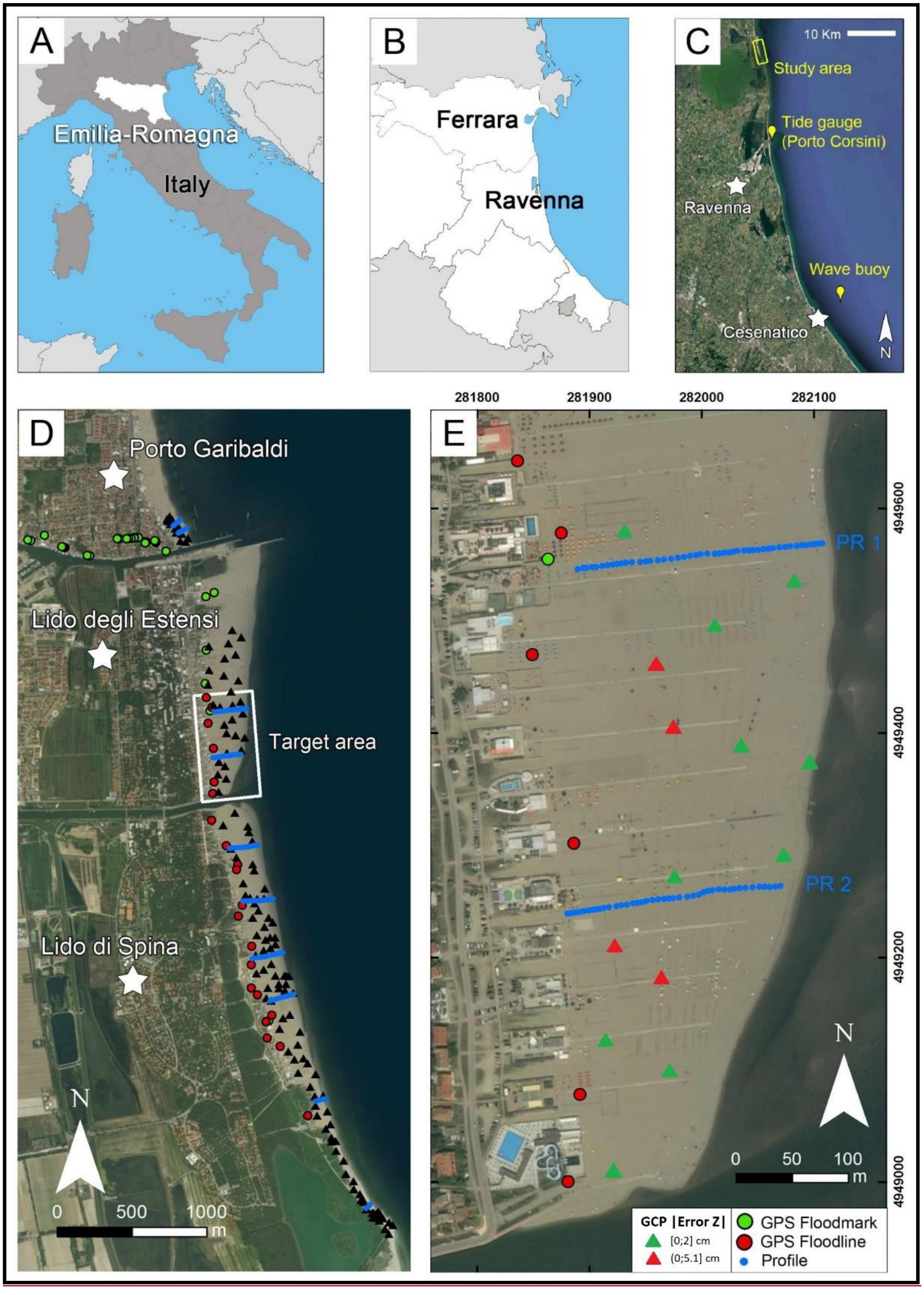
pre-storm LiDAR-derived DTM. In B, B1 and C, C1 enlargements of the main features are given. The morphological variations are only shown for the area surrounded by the GCPs.

Figure 8. Observed “GPS Floodline” and “GPS Floodmark” (green and red circles), UAV (red solid line and light-blue polygons) flood extension comparisons: the box on the left shows an overview of the target area while on the right (A, B, C and D) some spot-focuses are given.

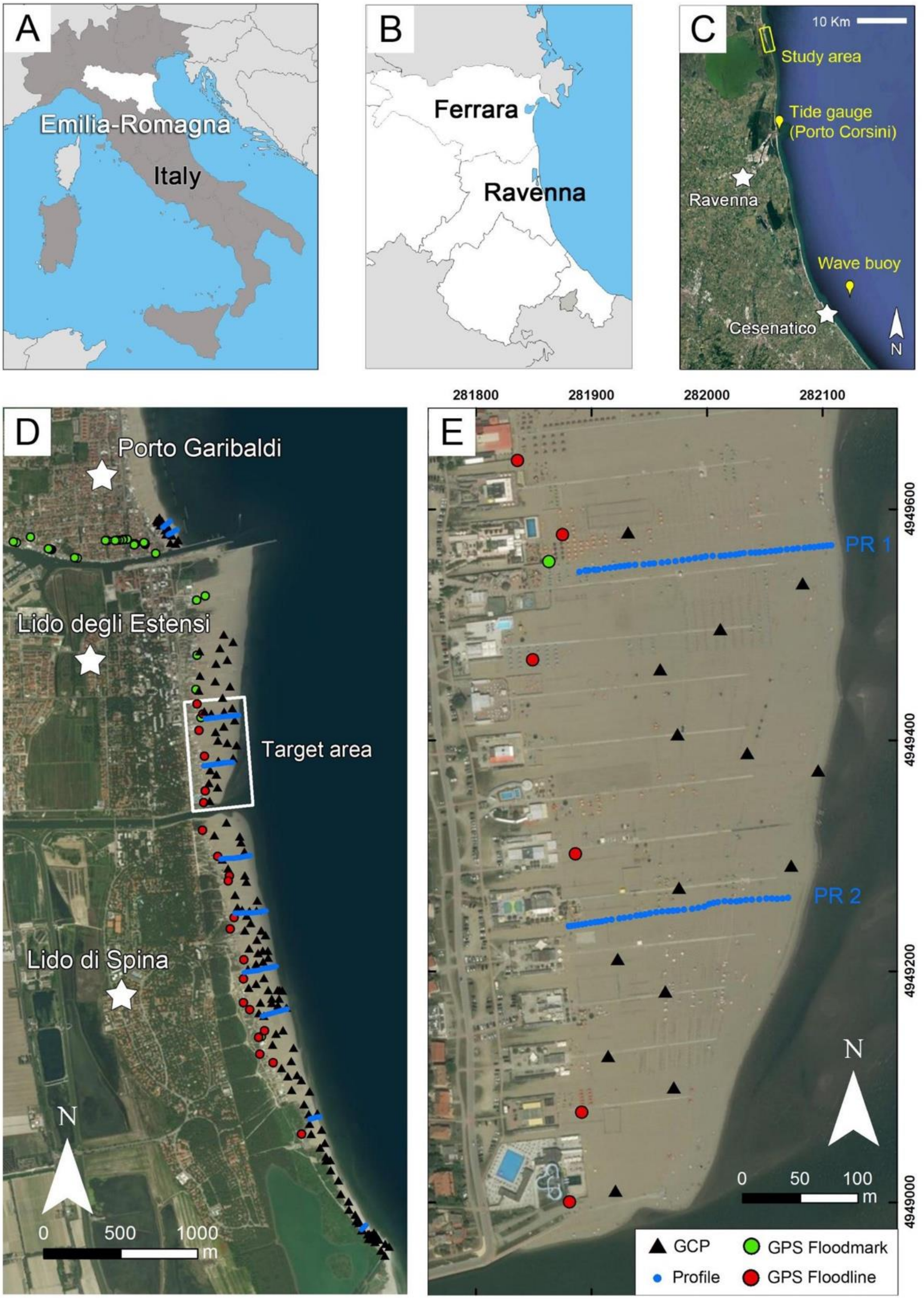
Figure 9. Comparisons between the observed "DRONE Floodline" and the flood scenarios (T10 and T100) computed by Perini et al. (2016).

Figure 10. Photos A and B at the top demonstrate practical GCPs based on unique shapes, colors, and ability to see from a high altitude. Photos C and D, on the bottom, demonstrate error-inducing GCPs due to their height off the ground and indistinguishable shape, size, and color in aerial images.

Table 1. Pix4D Report Summary.



A
Emilia-Romagna
Italy
B
Ferrara
Ravenna
C
10 Km
Study area
Tide gauge
(Porto Corsini)
Ravenna
Wave buoy
Cesenatico
N
D
Porto Garibaldi
Lido degli Estensi
Target area
Lido di Spina
N
0 500 1000 m
E
281800 281900 282000 282100
4949600 4949400 4949200 4949000
PR 1
PR 2
N
0 50 100 m
GCP |Error Z|
[0;2] cm
(0;5.1] cm
GPS Floodmark
GPS Floodline
Profile


A
Emilia-Romagna
Italy
B
Ferrara
Ravenna
C
10 Km
Study area
Tide gauge
(Porto Corsini)
Ravenna
Wave buoy
Cesenatico
N
D
Porto Garibaldi
Lido degli Estensi
Target area
Lido di Spina
N
0
500
1000
m
E
281800
281900
282000
282100
4949600
4949400
4949200
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PR 1
PR 2
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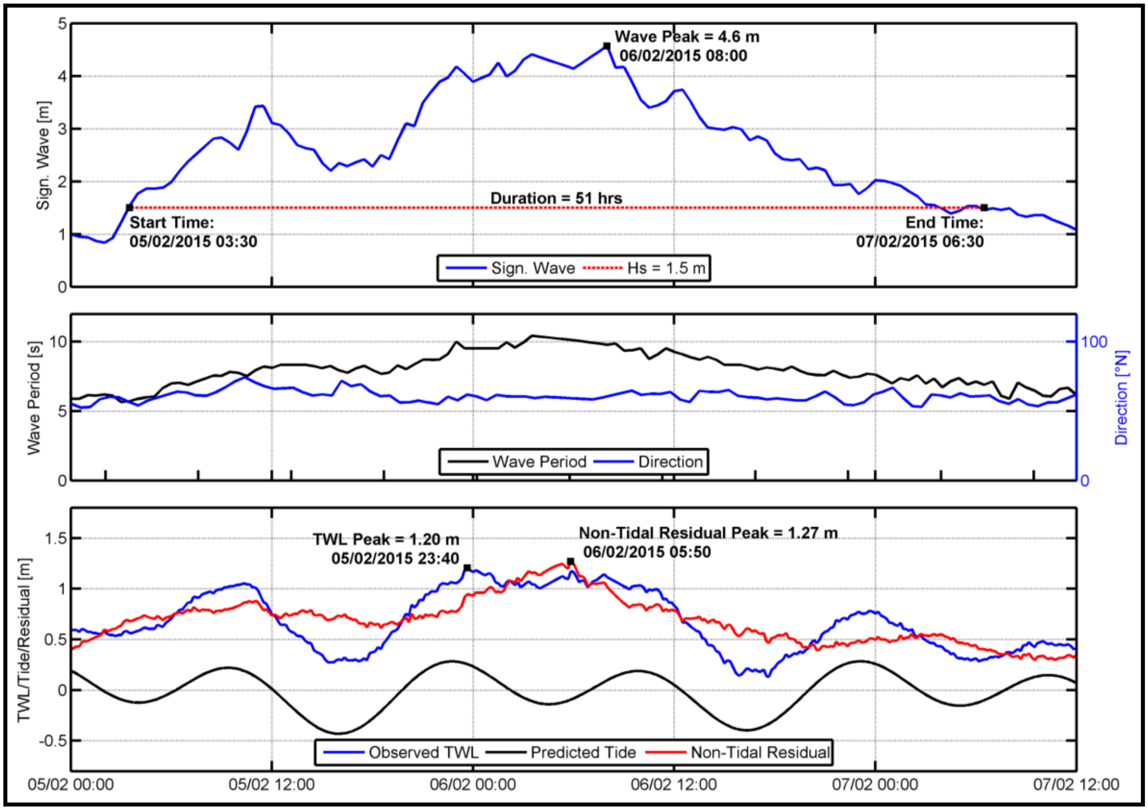
0
50
100
m
GCP
GPS Floodmark
Profile
GPS Floodline

~~Fig.~~Figure

1.



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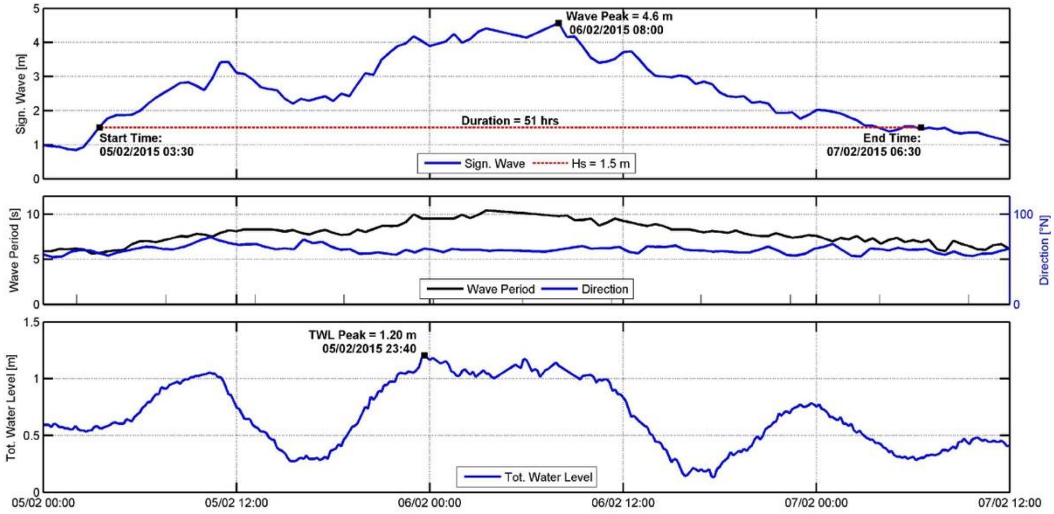
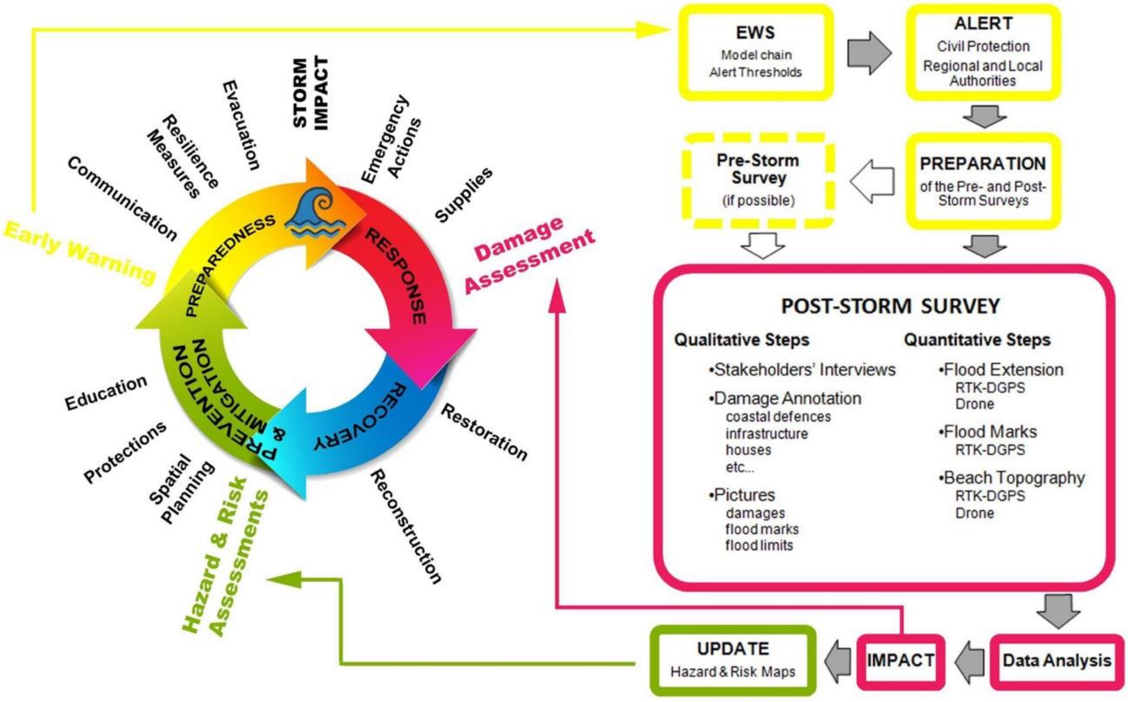
06/02/2015 08:00
Sign. Wave [m]
Duration = 51 hrs
Start Time:
05/02/2015 03:30
End Time:
07/02/2015 06:30
Sign. Wave
Hs = 1.5 m
Wave Period [s]
Direction [°N]
Wave Period
Direction
TWL Peak = 1.20 m
05/02/2015 23:40
Non-Tidal Residual Peak = 1.27 m
06/02/2015 05:50
TWL/Tide/Residual [m]
Observed TWL
Predicted Tide
Non-Tidal Residual
05/02 00:00
05/02 12:00
06/02 00:00
06/02 12:00
07/02 00:00
07/02 12:00

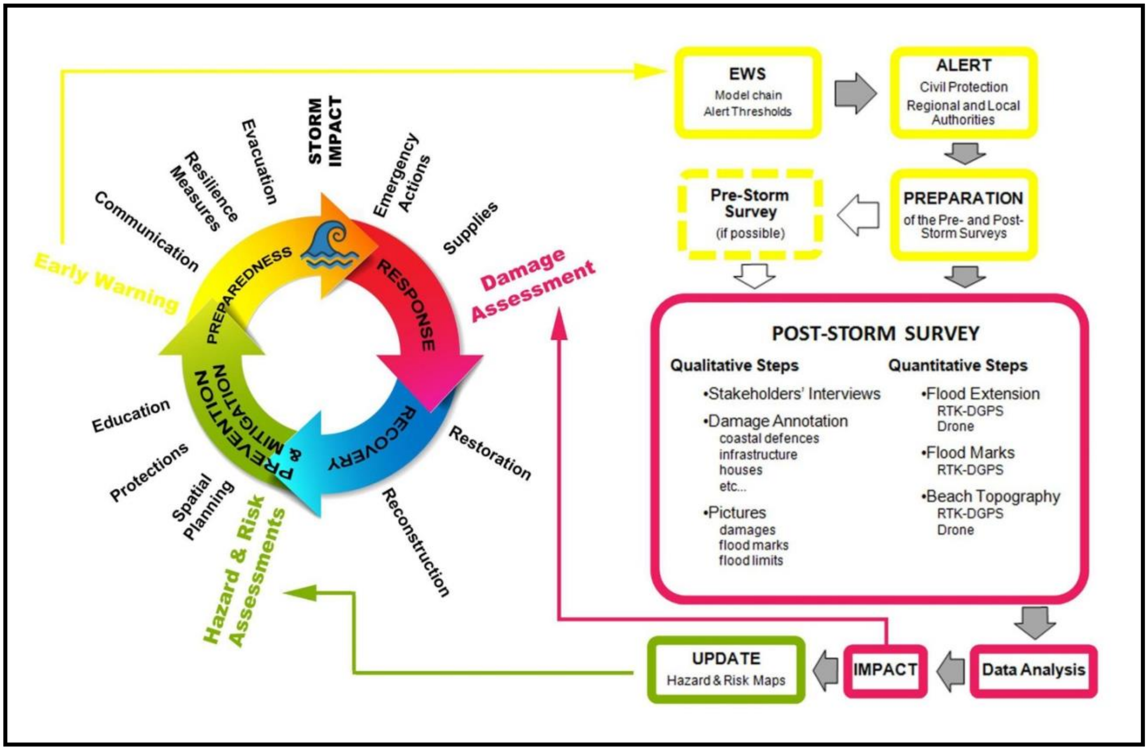


Wave Peak = 4.6 m
06/02/2015 08:00
Sign. Wave [m]
Duration = 51 hrs
Start Time:
05/02/2015 03:30
End Time:
07/02/2015 06:30
Sign. Wave
Hs = 1.5 m
Wave Period [s]
Direction [°N]
Wave Period
Direction
TWL Peak = 1.20 m
05/02/2015 23:40
Tot. Water Level [m]
Tot. Water Level
05/02 00:00
05/02 12:00
06/02 00:00
06/02 12:00
07/02 00:00
07/02 12:00

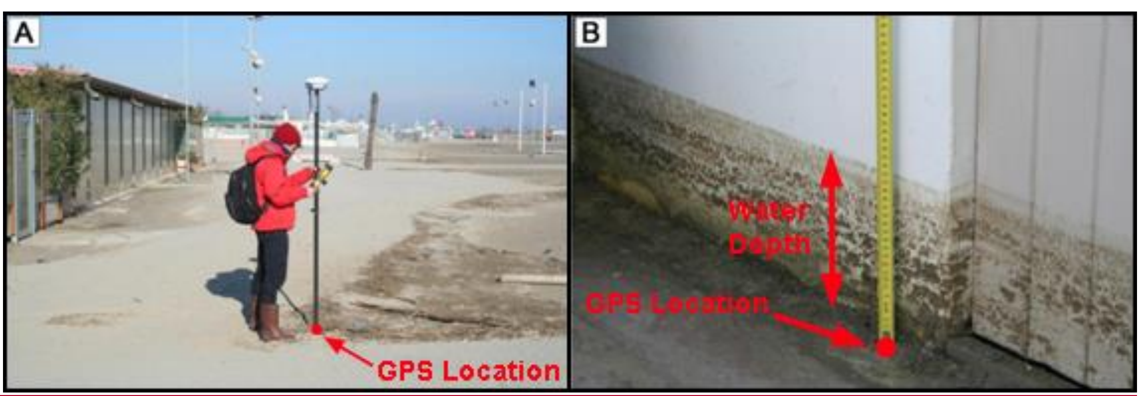
~~Fig.~~Figure 2.



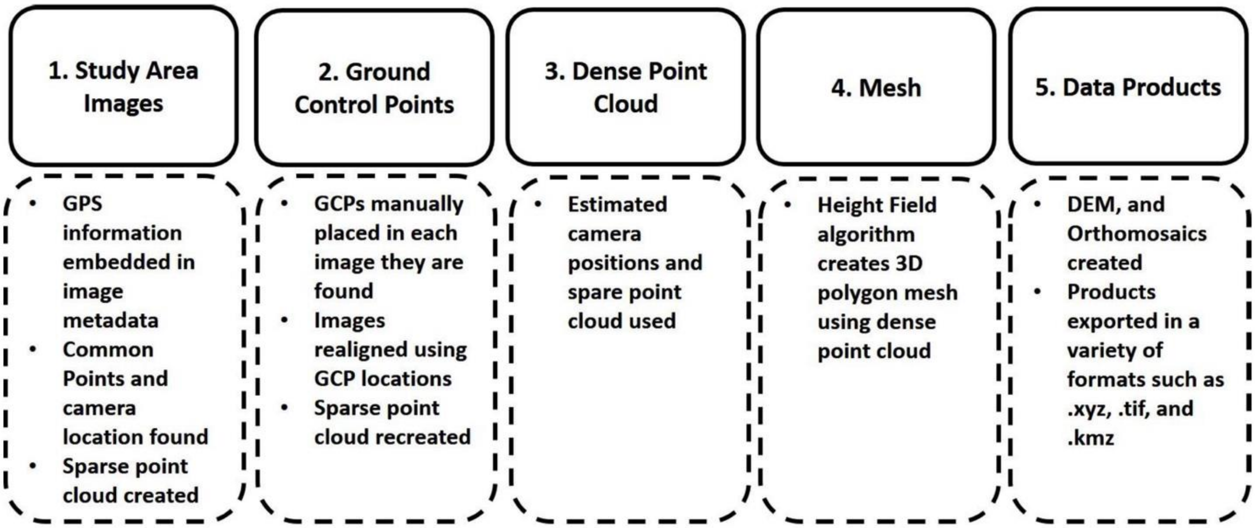
EWS
Model chain
Alert Thresholds
ALERT
Civil Protection
Regional and Local Authorities
Pre-Storm Survey
(if possible)
PREPARATION
of the Pre- and Post-Storm Surveys
POST-STORM SURVEY
Qualitative Steps
•Stakeholders' Interviews
•Damage Annotation
coastal defences
infrastructure
houses
etc...
•Pictures
damages
flood marks
flood limits
Quantitative Steps
•Flood Extension
RTK-DGPS
Drone
•Flood Marks
RTK-DGPS
•Beach Topography
RTK-DGPS
Drone
Data Analysis
IMPACT
UPDATE
Hazard & Risk Maps
Early Warning
Damage Assessment
Hazard & Risk Assessments
STORM IMPACT
PREPAREDNESS
RESPONSE
RECOVERY
PREVENTION & MITIGATION
Communication
Resilience Measures
Evacuation
Emergency Actions
Supplies
Restoration
Reconstruction
Education
Protections
Spatial Planning

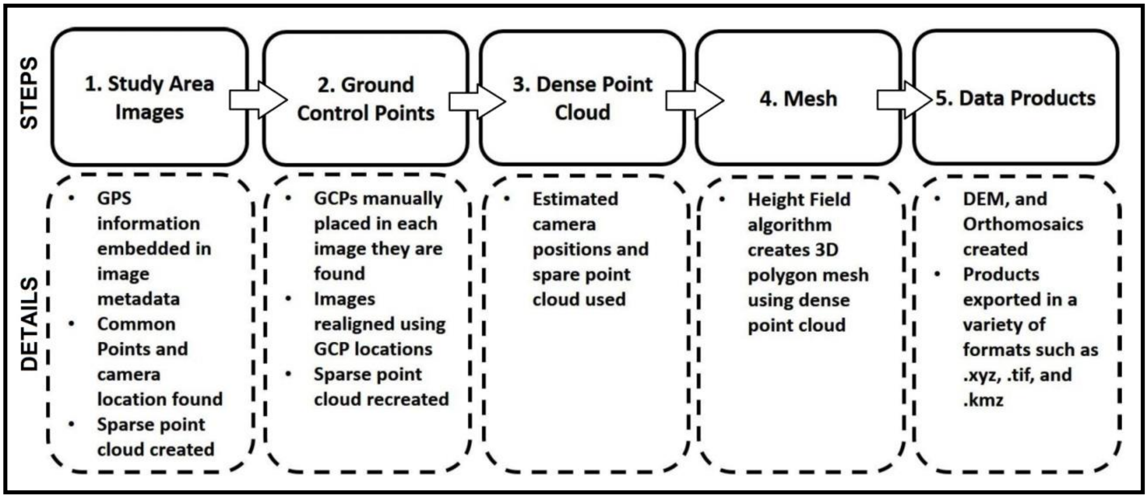


~~Fig.~~<u>Figure</u> **3.**

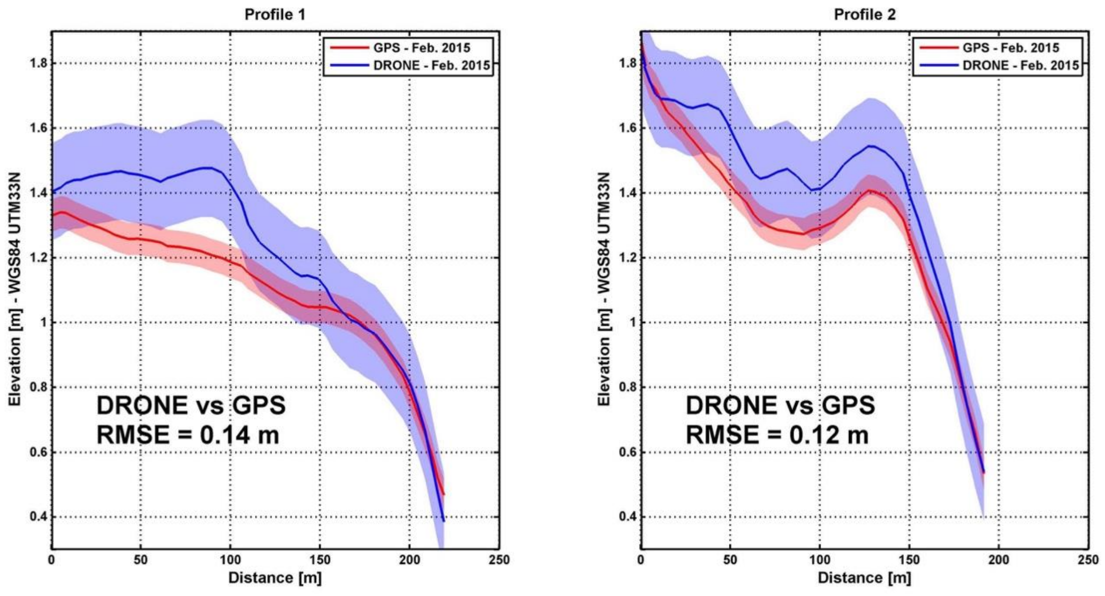


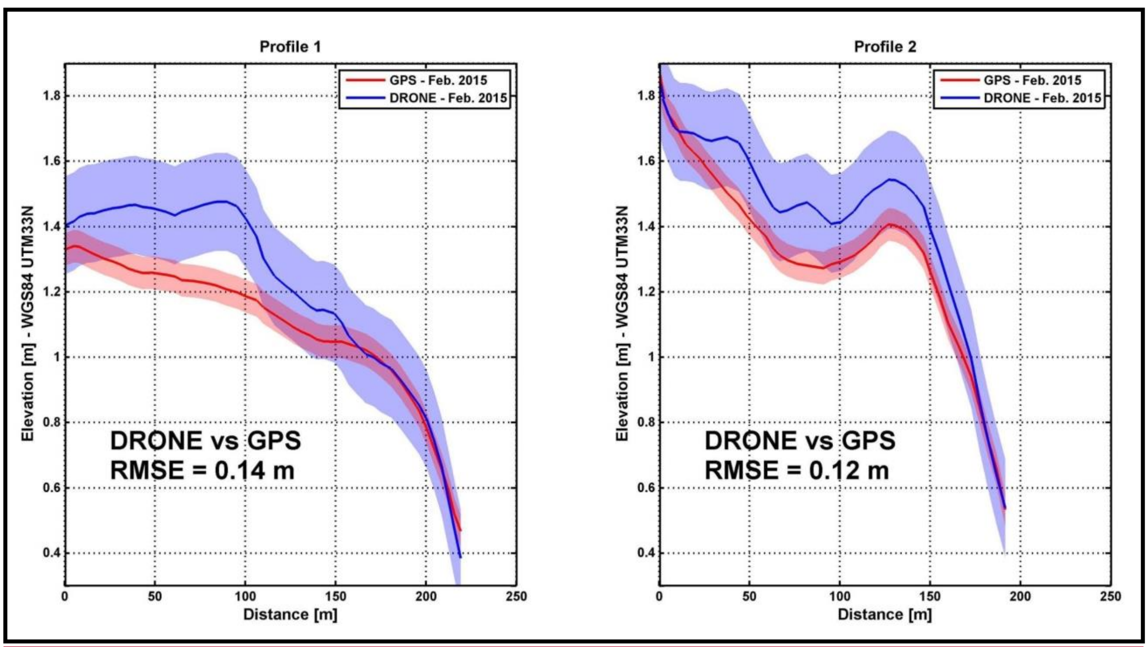
~~Fig.~~Figure **4.**


1. Study Area Images
2. Ground Control Points
3. Dense Point Cloud
4. Mesh
5. Data Products
• GPS information embedded in image metadata
• Common Points and camera location found
• Sparse point cloud created
• GCPs manually placed in each image they are found
• Images realigned using GCP locations
• Sparse point cloud recreated
• Estimated camera positions and spare point cloud used
• Height Field algorithm creates 3D polygon mesh using dense point cloud
• DEM, and Orthomosaics created
• Products exported in a variety of formats such as .xyz, .tif, and .kmz


STEPS
DETAILS
1. Study Area Images
2. Ground Control Points
3. Dense Point Cloud
4. Mesh
5. Data Products
• GPS information embedded in image metadata
• Common Points and camera location found
• Sparse point cloud created
• GCPs manually placed in each image they are found
• Images realigned using GCP locations
• Sparse point cloud recreated
• Estimated camera positions and spare point cloud used
• Height Field algorithm creates 3D polygon mesh using dense point cloud
• DEM, and Orthomosaics created
• Products exported in a variety of formats such as .xyz, .tif, and .kmz

~~Fig.~~ Figure 5.


Profile 1
GPS - Feb. 2015
DRONE - Feb. 2015
Elevation [m] - WGS84 UTM33N
Distance [m]
DRONE vs GPS
RMSE = 0.14 m
Profile 2
GPS - Feb. 2015
DRONE - Feb. 2015
Elevation [m] - WGS84 UTM33N
Distance [m]
DRONE vs GPS
RMSE = 0.12 m


Profile 1
GPS - Feb. 2015
DRONE - Feb. 2015
Elevation [m] - WGS84 UTM33N
Distance [m]
DRONE vs GPS
RMSE = 0.14 m
Profile 2
GPS - Feb. 2015
DRONE - Feb. 2015
Elevation [m] - WGS84 UTM33N
Distance [m]
DRONE vs GPS
RMSE = 0.12 m

~~Fig.~~Figure 6.

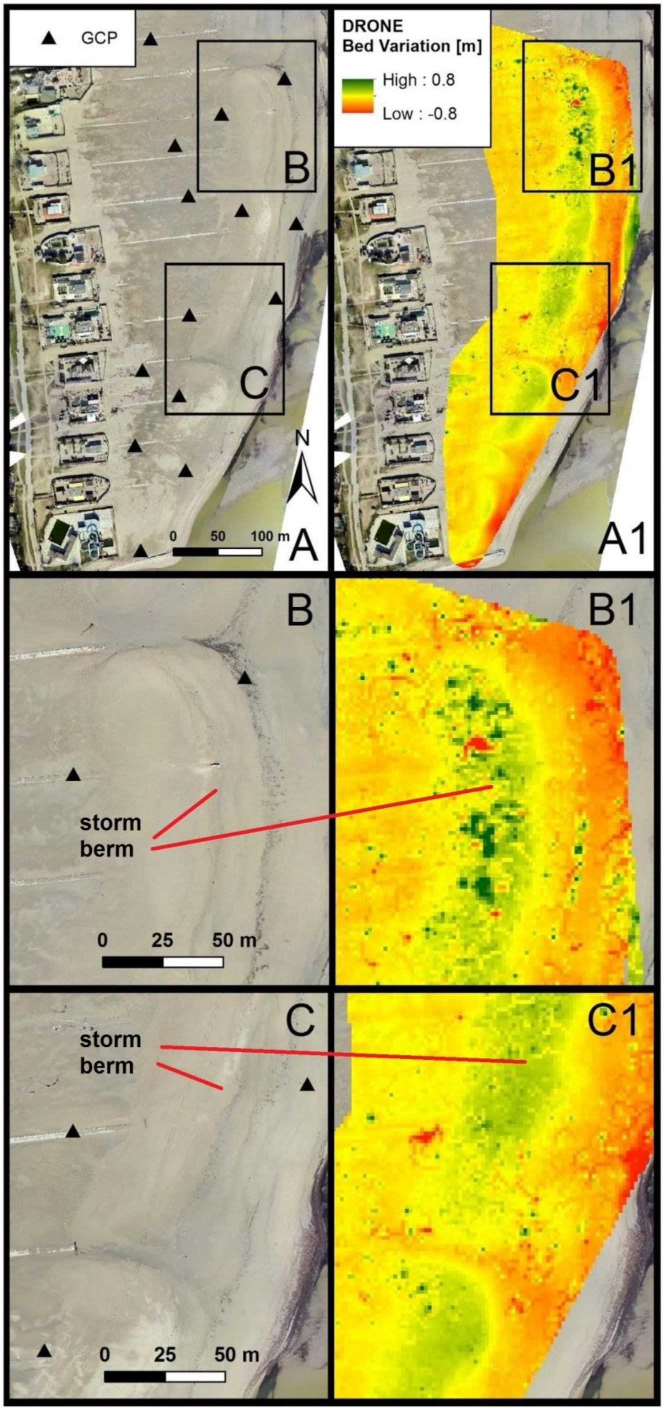
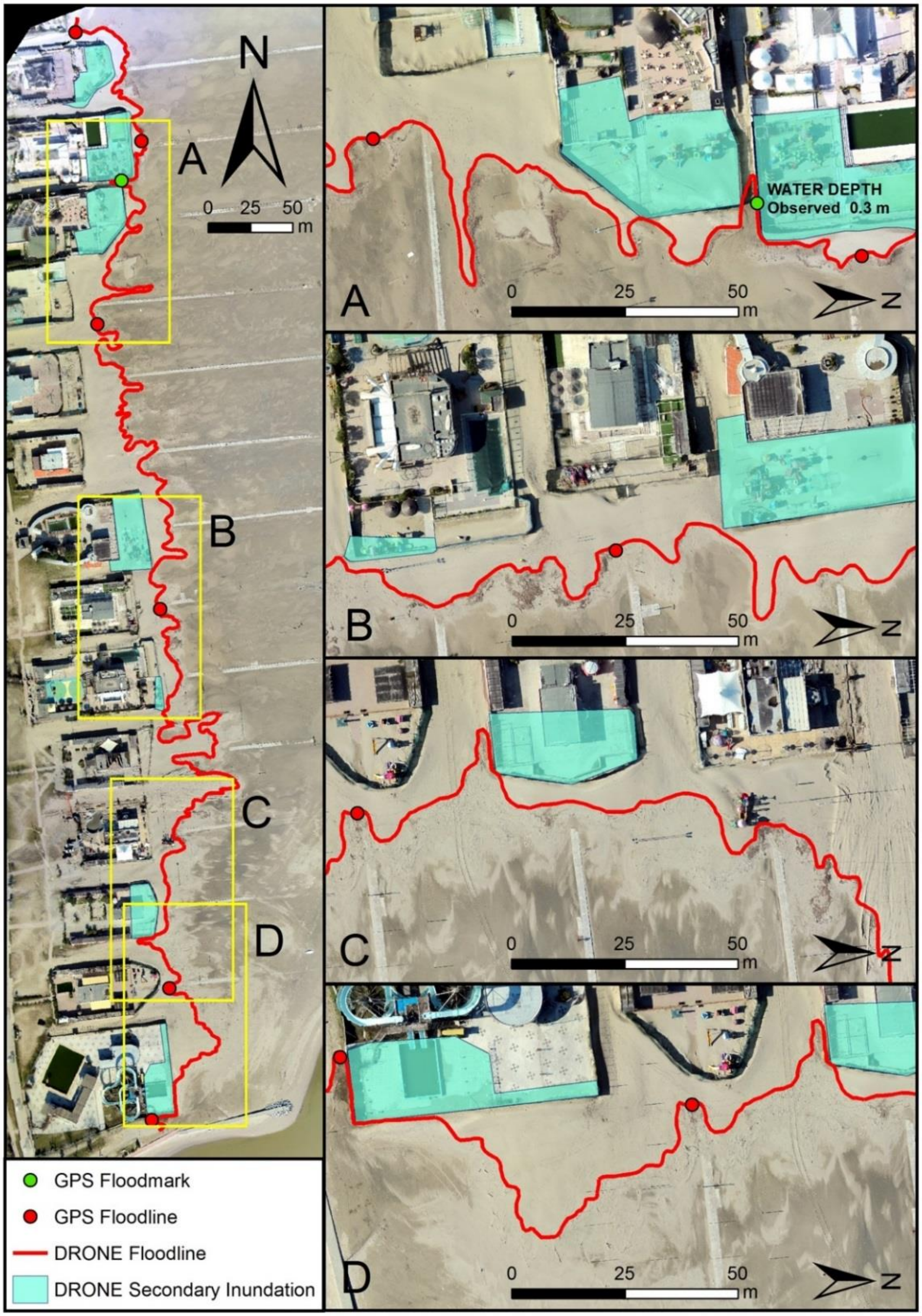
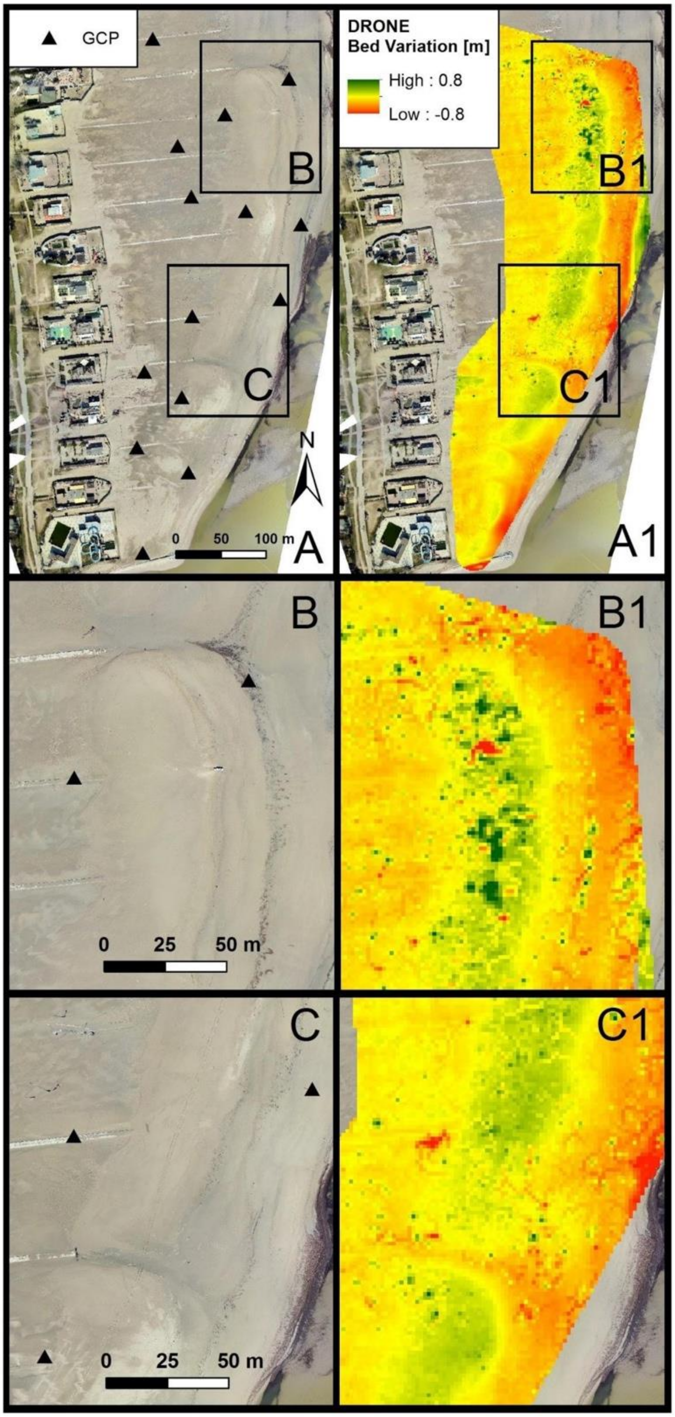

GCP
DRONE
Bed Variation [m]
High : 0.8
Low : -0.8
B
C
B1
C1
N
0
50
100 m
A
A1
B
B1
storm
berm
0
25
50 m
C
C1
storm
berm
0
25
50 m

Figure 7.



~~Fig. 7~~Figure 8.


GCP
DRONE
Bed Variation [m]
High : 0.8
Low : -0.8
B
B1
C
C1
N
0 50 100 m
A
A1
B
B1
0 25 50 m
C
C1
0 25 50 m

~~Fig. 8.~~

Figure 9.


A
B
D
C

~~Fig.~~Figure

~~9~~10.

Table 1.

Keypoints	median of 17344 per image
Calibrated images	581 out of 583
Optimization	Relative difference initial vs optimized parameters: 0.08%
Matches	median of 1198.54 per calibrated image
3D GCPs	14 GCPs; mean RMS error = 0.026 m
Overlapping images for pixel	>5