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Surface Elevation Dynamics Assessment Using Digital Elevation Models, Light Detection and Ranging, GPS and Geospatial Information Science Analysis: Ecosystem Modelling Approach

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Abstract**—**Surface elevation dynamics have always responded to disturbance regimes. Creating Digital Elevation Models (DEMs) to detect surface dynamics has led to the development of several methods, devices and data clouds. DEMs can provide accurate and quick results with cost efficiency, in comparison to the inherited geomatics survey techniques. Nowadays, remote sensing datasets have become a primary source to create DEMs, including LiDAR point clouds with GIS analytic tools. However, these data need to be tested for error detection and correction. This paper evaluates various DEMs from different data sources over time for Apple Orchard Island, a coastal site in southeastern Australia, in order to detect surface dynamics. Subsequently, 30 chosen locations were examined in the field to test the error of the DEMs surface detection using high resolution global positioning systems (GPSs). Results show significant surface elevation changes on Apple Orchard Island. Accretion occurred on most of the island while surface elevation loss due to erosion is limited to the northern and southern parts. Concurrently, the projected differential correction and validation method aimed to identify errors in the dataset. The resultant DEMs demonstrated a small error ratio (≤ 3%) from the gathered datasets when compared with the fieldwork survey using RTK-GPS. As modern modelling approaches need to become more effective and accurate, applying several tools to create different DEMs on a multi-temporal scale would allow easy predictions in time-cost-frames with more comprehensive coverage and greater accuracy. With a DEM technique for the eco-geomorphic context, such insights about the ecosystem dynamic detection, at such a coastal intertidal system, would be valuable to assess the accuracy of the predicted eco-geomorphic risk for the conservation management sustainability. Demonstrating this framework to evaluate the historical and current anthropogenic and environmental stressors on coastal surface elevation dynamism could be profitably applied worldwide.

Keywords**—**DEMs, eco-geomorphic-dynamic processes, geospatial information science. Remote sensing, surface elevation changes.

I. Introduction

ASSESSING the health of coastal ecosystems over time is essential for the sustainable management of eco-geomorphology and human settlements in those regions [1], [2]. Coastal zones worldwide have always attracted human settlement (~86% of Australians and ~70% of the global population lives along coasts), but the interaction of eco-geomorphic-dynamic processes and human settlement and associated infrastructure has caused changes to, and in some cases even losses of, coastal environments [2]-[4]. Particularly affected are habitats within and near the intertidal zones, like coastal wetlands [2], [5]-[8].

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The evolution of coastal ecosystems over time is important for conservation assessment and ecosystem management [3], [9]-[11]. The shape of coastal zones and their elevation dynamics are responding to major processes that in some cases are influenced by human activities and changing climate; (i) directly, such as sea level rise and population growth on the coasts, or (ii) indirectly, such as by modifying the catchment of the coast ecosystem dependents [4], and global warming [12]-[14]. The challenges associated with human activities within coastal zones lead to difficulties in selecting judicial decision-making criteria [2]-[4]. There needs to be a framework that can integrate an understanding of coastal behaviors which could then be incorporated into management decisions [15].

Climatic changes have attracted increasing attention from environmental scientists focusing on monitoring the coastal zones in terms of sustainable conservation, as an important approach [10], [16], [17]. This led to the use of several ways to analyze the coastline and elevation dynamics in order to model and investigate the potential changes for rehabilitation of the coasts [17]-[19]. Nowadays, coastal zones, and their associated habitats, are facing more stress from artificial modifications (directly and indirectly) resulting in ecosystem changes (extent and elevation) in the coastal areas [16], [20]. Thus, it is important to evaluate the characteristics of the existing situation and then estimate the future of these coastal areas, using the right and accurate tools, like DEMs for surface dynamics evaluations [10], [17], [21].

Detection of surface dynamics and changes can be achieved in several ways. For example, Sediment Erosion Tables or Surface Elevation Tables (SETs), designed by Boumans and Day [19], are a result of the invention of several methods and devices for measuring elevation changes within coastal ecosystems. These SETs have since been modified and developed to allow very accurate surface dynamics measurements [19], [22], [23]. However, SETs are generally costly, cover a limited area, and require long durations – on average up to 20 years – to obtain accurate results [14], [24]. Thus, since remote sensing data of high resolution and accuracy became available – e.g. Light Detection and Ranging (LiDAR) datasets [21] – environmental scientists have used these DEMs for surface dynamics analysis since they are accurate enough, cheaper, and faster and can be based on several modelling methods [21], [25]. DEM analyses may be utilized for ecosystems management, modelling and decision support tools [26].

DEM analyses are carried out adjacent to characteristic geomorphological aspects of the surface [8]. Several software tools can be used to create DEMs. However, a geographic information system (GIS) provides the most advanced and accurate results that can be achieved [25]. A number of data sets, like Shuttle Radar Topography Mission (SRTM) and LiDAR datasets, can be used to suit the purpose of building DEMs [25]. A GIS format can be developed to characterize three specific objectives, namely to identify spatial patterns, to identify scale dependency in form and to allow visualization of results [8].

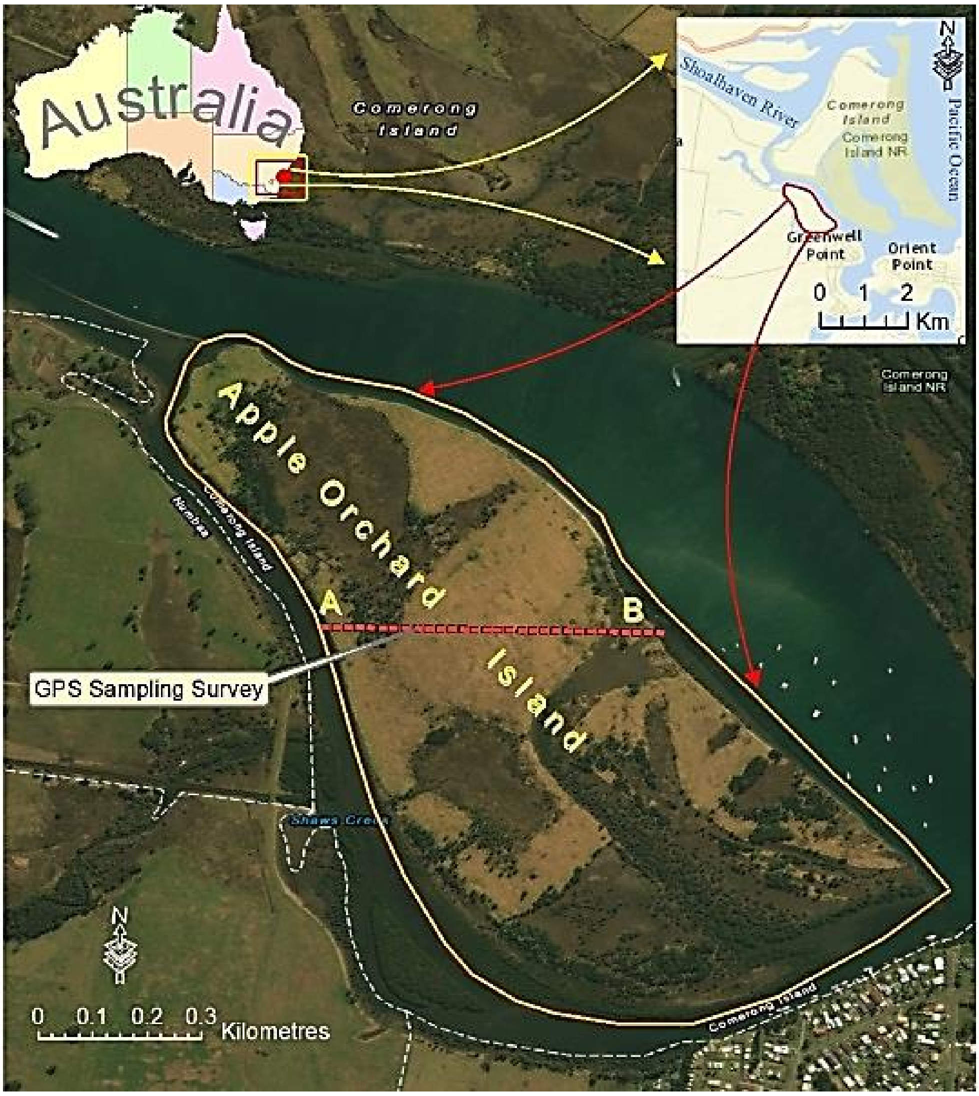

Fig. 1 The study site is located on the southeastern coast of NSW, Australia, at the mouth of the Shoalhaven River catchment south of Comerong Island (34°53'58.0"S 150°43'33.9"E)

DEMs may act to be the best surface elevation dynamics presenters in time scale, cost, and spatial coverage. The LiDAR datasets have empirically proven to be the best datasets to generate DEMs [21], [27], [28]. However, some accuracy and error problems are usually associated with it, which may be related to factors such as the technique that has been used to obtain the dataset and plant canopies, affecting the resulting DEMs, particularly within complicated mixed woody and grass covered areas [21], [27], [28]. Thus, this study examines the associated errors and analyzes the accuracy of different DEMs using infield RTK-GPS surveys as a reference for chosen point clouds.

Detection of threatened zones could help ecosystem managers, agencies and governments to make informed decisions and might change their policy in order to facilitate restoration [29]. This would lead to the development of an eco-geomorphological model technique for the conservation and restoration of such coastal areas worldwide.

A. The Case Study

Any interruption to the natural processes in a particular area needs to be monitored, and modelled reported regarding any environmental degradation, which is an essential for the ecosystem conservation and management [1], [2], [8], [11].. Yet, it needs highly accurate and comprehensive data and methods to measure the dynamism of such eco-geomorphic systems. Thus, Apple Orchard Island in southeastern NSW, Australia (Fig. 1), represents an ideal example of an interrupted coastal area. It is located at the Shoalhaven River mouth and represents a good example where the application of DEMs based on GIS mathematical and triangular tools can be used. Such an undisturbed area with unique ecosystems (e.g. saltmarsh) should reveal disturbances in the coastal regimes, through examining different DEM datasets.

Geomorphological changes to coastal zones can induce complex outcomes for the habitat that are not intuitive due to biological interactions [16].

II. Methodology

This study is based on a comparison of multi-temporal changes in surface elevation stability as the main parameter. The elevation stability in the coastal zones is assessed through continuous monitoring using GIS analytic tools, LiDAR and RTK-GPS survey in the field. The study entails the dynamics assessment of disturbance regimes, such as erosion, sediment delivery and rising sea level in and around tidal reaches. In addition, there are considerable effects of artificial modification in the natural processes that could affect the surface dynamics directly and indirectly.

This paper examines the resultant DEMs from the ground returned LiDAR datasets over time for the chosen, unmodified study site (Apple Orchard Island), in order to detect surface changes. Subsequently, 30 chosen point clouds (using a random sampling method) of LiDAR data, were examined and validated, using infield RTK-GPS and Trimble® base station, to assess, compare and detect any elevation recorded error, which may affect the result accuracy. Remote Sensing (RS) datasets of LiDAR (2004, 2010 and 2016) and one arc-second SRTM (2011) dataset were used with an average of one point-cloud density resolution (~30 cm) to create DEMs. Mathematical and triangular methods of spatial analysis were then used to detect the elevation changes in ArcGIS 10.4 and compared with infield GPS measurements. The Geomorphic Change Detection (GCD) extensions of ArcGIS 10.4 were applied to compare DEMs and detect the size and extent of elevation changes.

III. Results and Discussion

Results show significant changes to the elevation and change distribution on parts of the island as a result of implementation of modelling using GIS tools (Fig. 2). This will allow resource managers to make more informed decisions by evaluating the potential consequences of altering the existing situation.

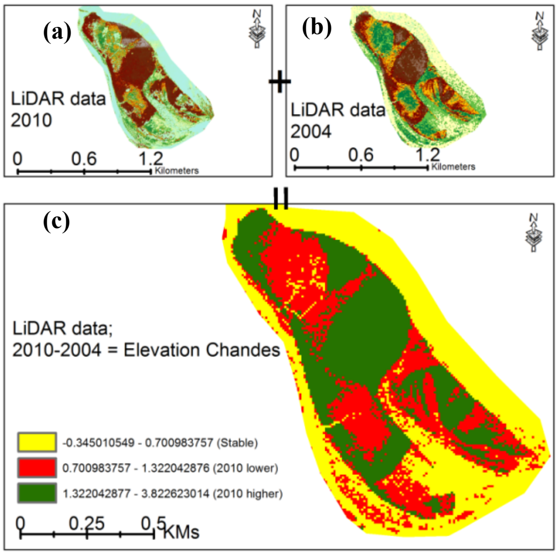

Fig. 2 The temporal differential of the case study elevation shows; (a) LiDAR based DEM of 2010, (b) LiDAR-based DEM of 2004, and (c) elevation changes over the 6-year period, red is loss, green is accretion, stable parts are yellow

Creating and comparing DEMs using LiDAR LAS format datasets is the most accurate method and permits a clear comparison of the metadata. In general, LiDAR datasets need some interpolations and modifications before it is used, according to the purpose of the project. Within this paper, vegetation cover occurring in the dataset needed to be cut virtually in order to obtain ground level which could then be used to investigate surface dynamics as shown in Fig. 3.

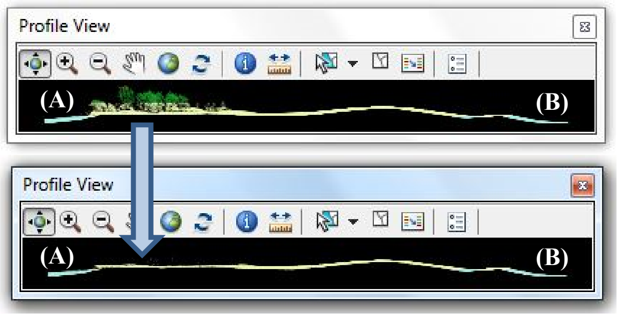

Fig. 3 The cross-section of Apple Orchard Island presents a profile of the dataset along the A-B sampling line (located on Fig. 1), that compares before and after cutting the tree canopy to get the ground surface. Fieldwork sampling was conducted along the same cross-section

Creating ground-leveled-DEMs is an accurate way to analyze surface dynamics with a centimeter grid resolution. However, cutting tree canopies created a new problem of missing values within cut areas in the LiDAR datasets. In other words, getting the surface elevations represented by using a LAS file as a point cloud of the ground level without vegetation canopy affects the resultant DEM resolution and accuracy, as shown in Fig. 4.

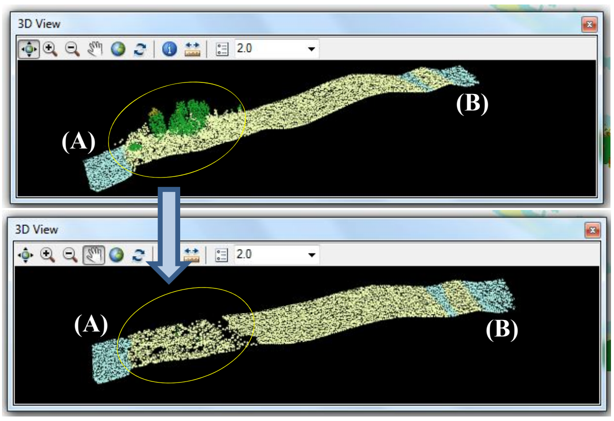

Fig. 4 The 3D view of the A-B cross-section on Apple Orchard Island shows the dataset before and after cutting the tree canopy that resulted in missing values

Missing LAS values mean missing point cloud coverage and then using such datasets would result in a reduced DEM grid resolution and higher error proportion within these sections of the datasets. Thus, more accurate and trustable DEM analysis and results can be obtained if infield GPS surveys are undertaken to correct and evaluate the ground represented by after cutting datasets. Therefore, fieldwork was conducted to examine the resultant DEMs from ArcGIS 10.4 with 30 check points (as a landmark) geodatabase using the centimeter resolution RTK Trimble GPS (see Fig. 5) in combination with a local base-station, for more accuracy.

Fig. 5 Infield RTK and Trimble GPSs equipment

B. Error Detection and Correction

Generally, data collected using GPS can provide three-dimension maps (at least) at any time regardless of the weather conditions. However, while we used GPS to collect and gather accurate data close to the real readings, we need to consider some boundaries such as error detection and correction.

The quality of the gathered data can be measured by several factors, such as data error rate (or data accuracy), consistency, integrity, compatibility, tolerance rate, accessibility, and the duration of collecting the data as well as the data lifespan [30]. The diversity between the real reading and the data gathered is called the data error rate which is correlated with the gathering technique (see Table I and Fig. 6). For example, an elevation of 382 m in the gathered data when its real location is 377 m may be considered incorrect in the gathered database. However, occasionally the real readings are unknown. Besides, error readings are often difficult to detect or correct. To detect and correct errors and enhance the gathered data's accuracy, we can follow the steps listed below:

a) Find the optimum sampling method to gather the required data, such as random sampling, systematic sampling, etc.
b) Assign the samples' dimension;
c) Chose the location of the samples based on the quality.
d) Make a comparison between the gathered data and the database in order to correct the error readings; we can use the most useful technique to find the difference between both real and gathered data, such as differential correction.

These steps can help to set and detect most errors that can occur throughout the data gathering progress [31].

This study proposes differential correction and validation techniques to detect and correct the gathered data using ArcGIS within a geo-database and a Trimble® base station (Trimble® R8 GNSS/R6/5800 GPS Receivers).

If there are no database providers in the proposed field, our Trimble® base station can be set up as a reference station, which will be located over an accurately surveyed reference location. Any error in the reported reference location can be added to errors in the corrected data.

Differential correction and validation is an important technique that can be used to improve the quality of data gathered by comparing two or more receivers (i.e. GPS and base station). Note that it uses a base station receiver at a known position and GPS at unknown positions. The data gathered from the base station at the known location are utilized to calculate the data error rates. Then, the reading of the GPS can be compared with the data gathered by the base station and the offset diversities are employed to eliminate errors, as well as find the real location. The base station location needs to be very accurate as the differential correction position accuracy depends on the accuracy of the coordinates of the base station which is called a control point. However, the corrected position is not completely true, due to the low frequency of the GPS timing code and the fact that the kinds and scales of errors that impact on the two receivers are not identical.

TABLE I
THE REAL READING OF THE GPS, THE LIDAR DATA AND THE DATA ERROR RATE

no.	Distance/m	Coordinators	DEM / Elevation	GPS / Elevation	S. Deviation	Anomaly (error)
1	0	34°53'49.1"S 150°43'10.3"E	0.454	0.443	0.007	-1.138
2	16	34°53'49.2"S 150°43'11.2"E	0.922	0.943	0.015	-0.638
3	32	34°53'49.1"S 150°43'11.7"E	2.041	2.082	0.029	0.501
4	48	34°53'49.2"S 150°43'12.5"E	1.696	1.697	0.001	0.116
5	64	34°53'49.2"S 150°43'13.2"E	1.406	1.477	0.050	-0.104
6	80	34°53'49.1"S 150°43'14.2"E	1.212	1.230	0.013	-0.351
7	96	34°53'48.9"S 150°43'15.2"E	1.109	1.096	0.009	-0.486
8	112	34°53'48.7"S 150°43'16.0"E	1.470	1.482	0.009	-0.100
9	128	34°53'48.5"S 150°43'17.1"E	1.658	1.677	0.014	0.096
10	144	34°53'48.3"S 150°43'18.0"E	1.718	1.729	0.008	0.148
11	160	34°53'48.0"S 150°43'18.7"E	1.796	1.847	0.036	0.265
12	176	34°53'47.9"S 150°43'19.6"E	2.043	2.059	0.011	0.478
13	192	34°53'47.6"S 150°43'20.4"E	1.835	1.817	0.013	0.236
14	208	34°53'47.5"S 150°43'21.1"E	1.971	1.986	0.011	0.405
15	224	34°53'47.3"S 150°43'22.0"E	2.046	2.058	0.008	0.477
16	240	34°53'47.0"S 150°43'22.8"E	2.057	2.073	0.011	0.491
17	256	34°53'48.5"S 150°43'24.1"E	1.852	1.838	0.010	0.257
18	272	34°53'49.5"S 150°43'25.1"E	2.066	2.081	0.011	0.499
19	288	34°53'49.5"S 150°43'25.9"E	2.158	2.176	0.013	0.594
20	304	34°53'49.3"S 150°43'27.2"E	2.162	2.179	0.012	0.597
21	320	34°53'49.1"S 150°43'27.9"E	2.141	2.160	0.013	0.579
22	336	34°53'49.1"S 150°43'28.4"E	2.012	2.083	0.050	0.502
23	352	34°53'49.2"S 150°43'28.8"E	1.807	1.817	0.007	0.236
24	368	34°53'49.3"S 150°43'29.1"E	1.041	1.022	0.013	-0.560
25	384	34°53'49.3"S 150°43'29.4"E	0.937	0.925	0.009	-0.657
26	400	34°53'49.3"S 150°43'29.6"E	1.054	1.040	0.010	-0.541
27	416	34°53'49.4"S 150°43'29.7"E	1.210	1.221	0.008	-0.360
28	432	34°53'49.4"S 150°43'29.8"E	1.450	1.461	0.008	-0.120
29	447	34°53'49.4"S 150°43'29.9"E	1.587	1.606	0.013	0.025
30	463	34°53'49.4"S 150°43'30.0"E	0.530	0.520	0.007	-1.061
		Average;	1.581	1.594	0.014	0.013

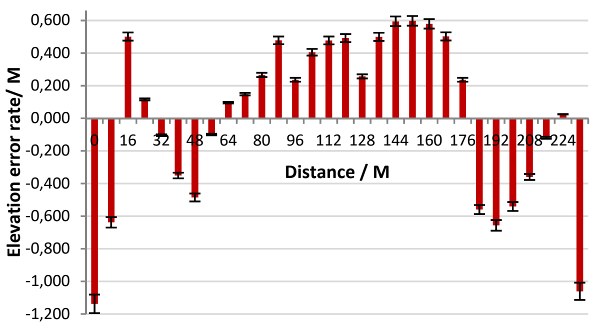

Fig. 6 Anomalies (errors) of the GPS and DEM elevation measurements comparison of the chosen 30 point cloud and sampled data

IV. CONCLUSION

Lidar datasets have proven to be superior to create DEMs in order to evaluate surface dynamics. However, result accuracy may vary depending on the landuse class and vegetation canopy. Thus, bare lands such as deserts or roads would produce more accurate results than grass-covered areas or forested landscapes.

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