Construction of a High Accuracy, Seamless, State-Wide Coastal DEM

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Key words: LiDAR, Coast, DEM, Bathymetry

SUMMARY

The Victorian Coastal DEM represents a multi-million dollar investment by the Victorian Government to consider climate change adaptation on the coast. In this project The Victorian Department of Sustainability and Environment (DSE) has collected high resolution elevation data in both the marine and terrestrial environments. Significant planning, surveying and processing has been undertaken to generate a seamless, state-wide coastal DEM.

A combination of aerial, sea and land surveying techniques were used in the construction of the Victorian Coastal DEM. Multiple topographic LiDAR surveys were conducted in the terrestrial environment. In the marine environment one of the largest single-season bathymetric LiDAR surveys ever undertaken covered the entire length of the State, some 2000 linear kilometres. In addition to these airborne surveys, multi-beam sonar was used to fill in gaps where bathymetric LiDAR was unsuitable for data acquisition.

The combination of surveying projects and technologies has involved considerable ground control, data analysis and integration processing. The ground control has been strategically identified to maintain the quality and accuracy of the integrated DEM. The data analysis primarily involved assessing the quality of data and the differences between adjacent topographic to topographic and topographic to bathymetric projects. Automated procedures were developed to integrate the adjacent project datasets.

The Coastal DEM spans a height range of 30m and includes elevations up to +10m and depths down to -20m relative to the Australian Height Datum (AHD). In area, the DEM includes 6,400km^2 of topographic LiDAR coverage, 4,700km^2 of bathymetric LiDAR coverage and 315km^2 of multi-beam sonar coverage. What is likely to be the world's largest seamless, state-wide, high-resolution coastal DEM is now being used to assess the impact of climate change in Victoria.

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1. INTRODUCTION

The Victorian Coastal DEM represents a multi-million dollar investment by the Victorian Government. This is the largest investment towards improving Victoria's understanding of how sea-level rise will impact the State's coast. The project is being funded by the Department of Sustainability and Environment (DSE) and is jointly managed by the Future Coasts Program and Spatial Information Infrastructure (SII).

The coastal DEM is a key component of the Victorian Coastal Vulnerability Assessment (VCVA) shown in Figure 1. The VCVA is the Future Coasts Program response to assessing the physical vulnerability of the Victorian coast. As shown in Figure 1, the coastal DEM has been combined with coastal geomorphology data, sea level rise scenarios and storm tide models to produce zones of potential instability and inundation extents. These outputs will be the fundamental tool in the VCVA used to highlight areas for further investigation, and to assist in planning and policy decisions. For more detail on the VCVA refer to Quadros et al. 2010.

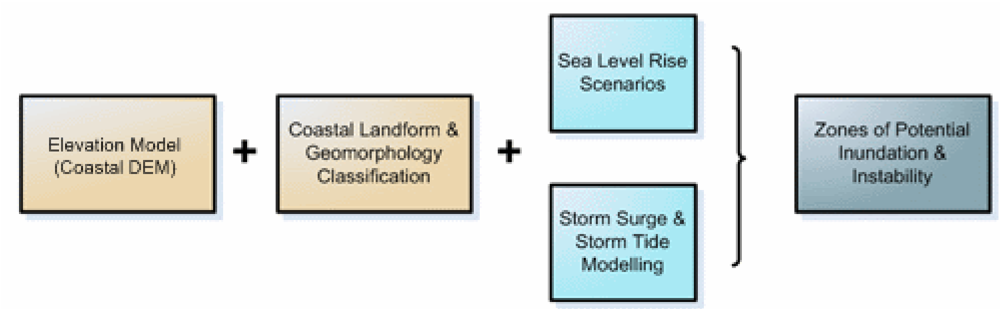

Figure 1: Components of the Victorian Coastal Vulnerability Assessment

2. COASTAL DEM SURVEYS

Over the past two years the DSE has commissioned topographic and bathymetric LiDAR projects along the whole of the Victorian coastline. These projects have been integrated to produce a seamless state-wide coastal DEM. The topographic and bathymetric LiDAR surveys were undertaken with different point densities and vertical accuracies according to instrument capabilities and data use requirements in each of the marine and land environments. The integrated coastal DEM retains the topographic data at a 1m resolution and the bathymetric data at a 2.5m resolution. The extent of the coastal DEM and its data sources are shown in Figure 2.

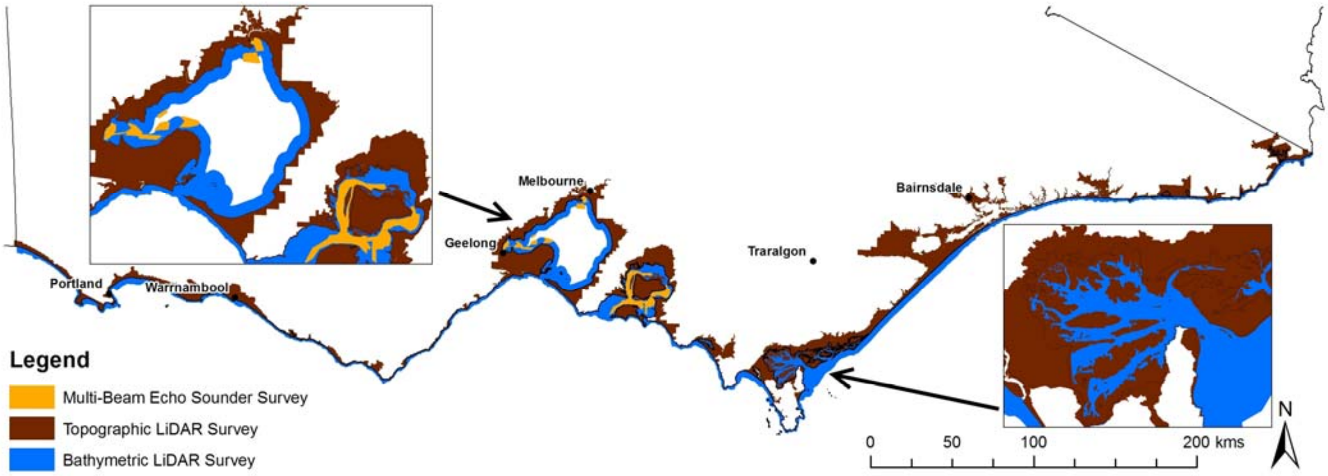

Figure 2: The Victorian Coastal DEM Surveys
Port Phillip Bay and Western Port (inset left) and Corner Inlet (inset right).

2.1 Topographic LiDAR Survey

For project management purposes the topographic LiDAR survey was undertaken in five separate projects. The five surveys were conducted by two aerial survey companies between April 2007 and October 2008. Each of these projects had a number of project partners including Local Government and Catchment Management Authorities. For the Future Coasts Program the topographic LiDAR surveys were required to collect elevation data as close to low tide as possible (within two hours) and up until at least 10m above AHD. In addition, a number of project partners required coverage above 10m above AHD which were included in the surveys. In certain areas, such as Western Port and Corner Inlet, topographic LiDAR surveys were collected at extreme low tides, so the tidal mudflats could be captured in detail. The Corner Inlet inset in Figure 2 shows the extent of the tidal mudflats captured by topographic LiDAR.

The specifications for the topographic LiDAR surveys were:

- ±10cm vertical accuracy @ 1σ
- ±25cm horizontal accuracy @ 1σ
- Generally an average point separation of 0.8m was used to produce the 1m DEM
- Laser foot print size was between 0.25m-0.30m
- Foreshore areas should be captured within 2 hours of a low tide unless otherwise specified as per Western Port and Corner Inlet

All elevation data was supplied relative to the Australian Height Datum (AHD). For each survey AUSGeoid98 was used to transform the ellipsoidal heights generated from the onboard GPS. In addition, control points were collected in flat, open ground within each project to create a further local correction to get the LiDAR data within ±10cm AHD.

2.2 Bathymetric LiDAR Survey

To meet project timelines, it was necessary to collect all the bathymetric LiDAR data within one survey season. The majority of the LiDAR data was collected using the Fugro LADS Mk II system (LADS) between December 2008 and March 2009. Project planning identified that a BLOM Hawk-Eye system (BLOM) would best be suited to collecting data in shallow inlets and bays. This system was used to collect data at four specific locations: Swan Bay, Andersons Inlet, Corner Inlet and Mallacoota Inlet during the same period that the LADS system was operating in other parts of the State.

The landward boundary for the bathymetric LiDAR survey was up to 100m past the vegetation line thereby generating significant overlap with the topographic LiDAR data. In specific locations along the coast flat, open ground areas such as football ovals beyond the 100m line were also included in the survey for use in integration with the topographic LiDAR data (integration sites). The seaward boundary of the bathymetric LiDAR data was limited to -20m AHD, as long as data was collected at least 1km seaward from LAT and could be limited to 4km seaward from LAT.

The specifications of note for the bathymetric LiDAR survey were:

- IHO Order 1 (±50cm) vertical accuracy @ 2σ
- ±3.17m horizontal accuracy @ 2σ
- An average point separation of 5m was used to produce the 2.5m DEM
- Laser foot print size was 2.5m
- AHD heights were computed using a combination of a hydrodynamic modeling and linear interpolation tidal models based on observed tides

Gaps frequently occur in bathymetric LiDAR surveys. To assess and manage the occurrence of gaps within the survey, the State was divided into eight sub-regions. Each sub-region was further divided into one hectare tiles (100m x 100m) and the survey required that at least 85% of tiles must have a minimum coverage of 320 soundings. For this survey 100% (no gap) coverage would be represented by 400 soundings per hectare tile.

2.3 Multi-Beam Echo Sounder (MBES) Survey

In the environments that the bathymetric LiDAR survey was unable to capture sufficient suitable data, multi-beam echo sounding equipment (MBES) was used. These “gap” surveys were required in Western Port and Port Phillip Bays. The primary reason for unsuccessful bathymetric LiDAR survey was ongoing turbidity. The MBES data was collected with the same accuracy and point density specifications as the bathymetric LiDAR data to ensure consistency between the two sources.

Figure 3 shows the occurrence of bathymetric LiDAR “gaps” in the north and south of Western Port Bay. The pink area was surveyed using MBES, which is more effective than bathymetric LiDAR in turbid water.

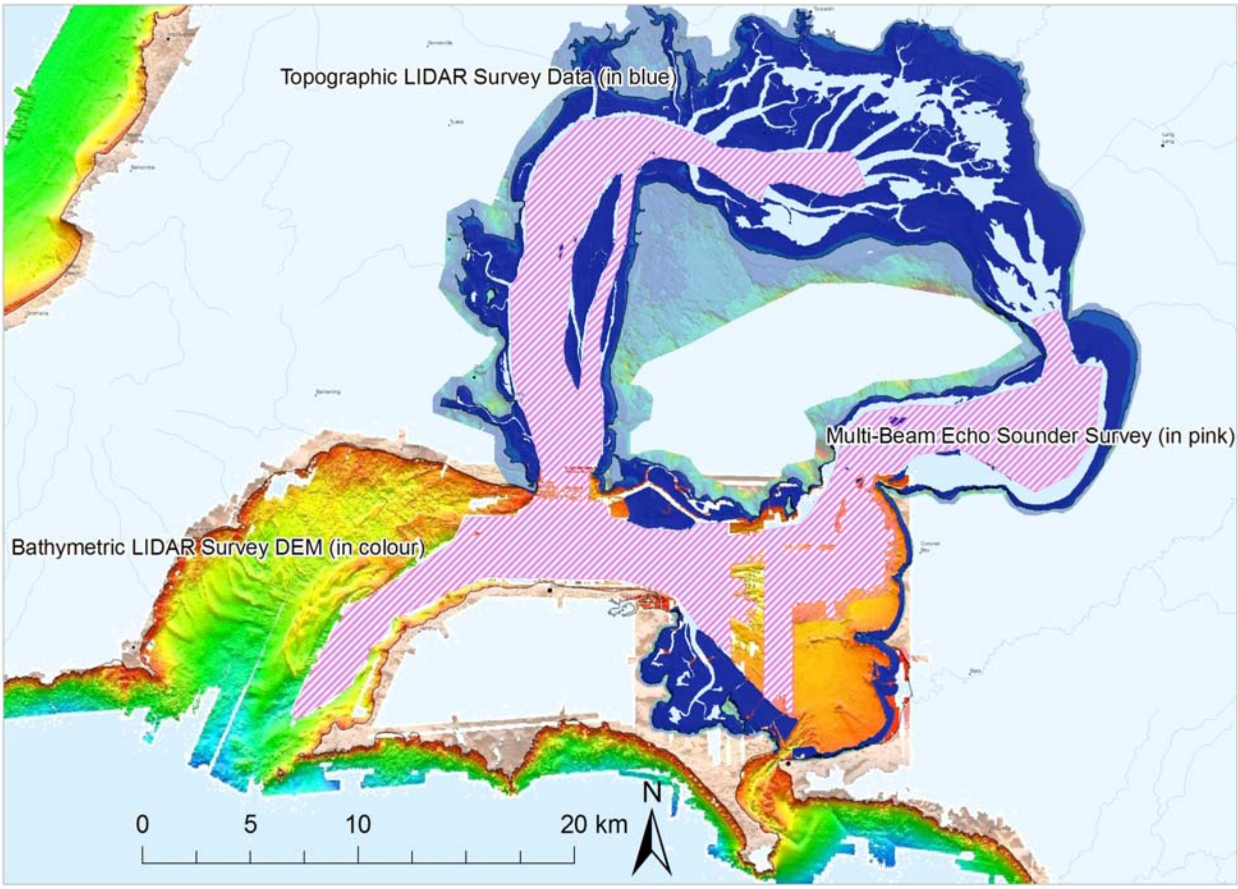

Figure 3: Western Port Bay Bathymetry Surveys

3. INTEGRATING COASTAL LiDAR SURVEYS

The key features common to integrating each of the topographic to topographic and bathymetric to topographic LiDAR surveys are:

- Ground control
- Data overlap
- Difference analysis
- Data merging

The following discussions on survey integration are based on an address of these features.

3.1 Integrating Adjacent Topographic LiDAR Surveys

Each topographic LiDAR survey was designed to overlap with its adjacent LiDAR surveys. The overlapping data enabled an assessment of the differences between adjacent projects. The majority of the adjacent LiDAR surveys were within ±5-10cm of each other and equally correlated to the ground control. In these scenarios the DEM was merged from one project into the other along several hundred metres of overlap. The algorithm used applied a linear transition from one dataset into the other.

An example of one such topographic LiDAR integration was at Anglesea on the south west coast. In this area there was approximately 700m of along-coast overlap between two separate LiDAR surveys: the South-West LiDAR survey and the Port Phillip LiDAR survey. The mean difference between the two datasets was 9cm with the South-West LiDAR data generally higher. A ground control survey was conducted in the overlap to assess the accuracy of each project in the overlap. Figure 4 shows a section of this survey with the reduced levels of each survey point and the differences to each LiDAR project. The mean difference of the control to the Port Phillip survey was 2cm and for the South-West survey it was 13cm in the same direction. Based on these findings, the Port Phillip data was retained in the majority of overlap and the transition between datasets was restricted to the 100m of overlap nearest to the South-West survey.

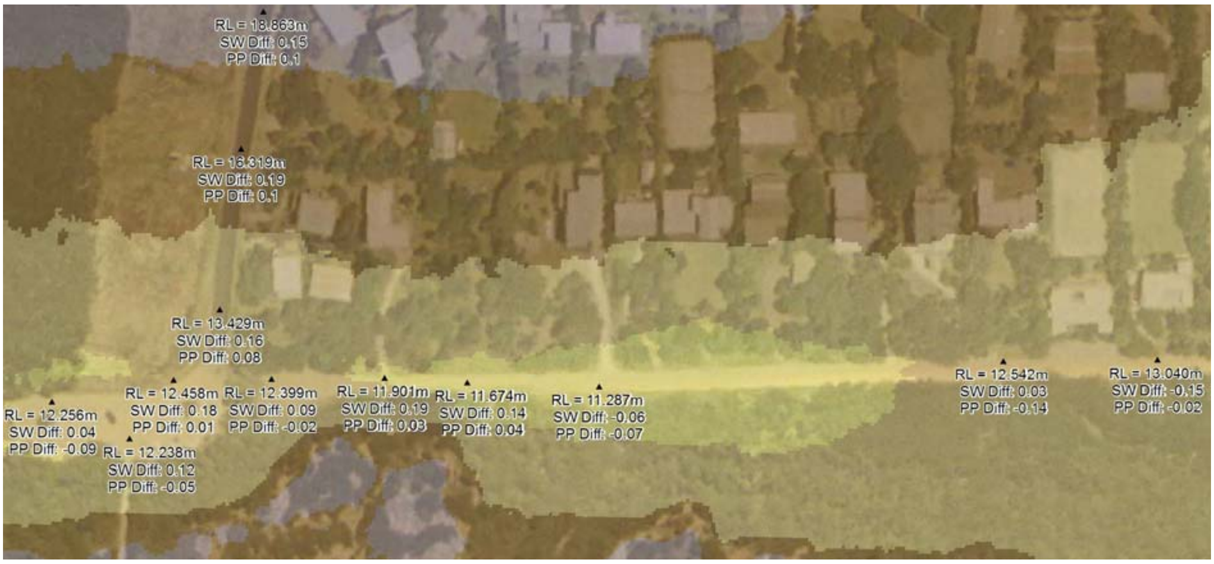

Figure 4: Topographic LiDAR Integration Ground Truth Analysis in Anglesea

In a second integration example, a significant height difference was initially detected in the along-coast overlap between the Ninety-Mile Beach LiDAR survey and South Gippsland LiDAR survey near Port Welshpool in the State's south east. The mean difference between the two LiDAR surveys was 43cm with the Ninety-Mile Beach survey higher. In this instance a leveling survey based on a 3rd order vertical mark was undertaken in the overlap area by DSE. A leveling exercise was conducted along the open road shown in Figure 5 and into the overlap between the two LiDAR surveys. Differences show the leveled heights compared to the Ninety-Mile Beach data are suitable leading into the overlap with the South Gippsland data, but are significantly high in the overlap. The differences to the South Gippsland LiDAR data were acceptable in the overlap. In this instance an error in the datum definition on the western boundary of the Ninety-Mile Beach survey was detected and subsequently corrected so that both projects were better matched in the overlap.

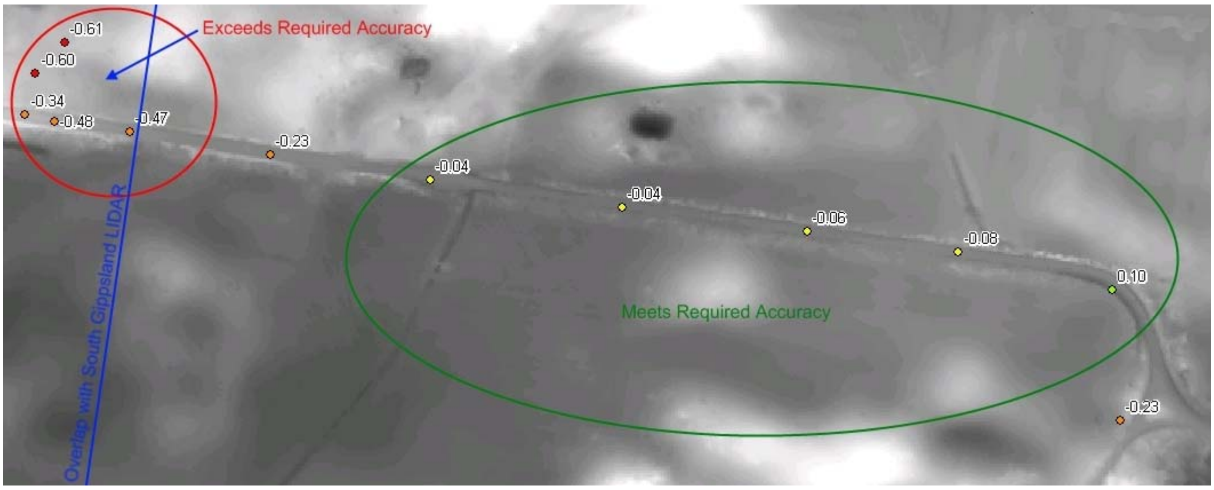

Figure 5: Topographic LiDAR Integration Ground Truth Analysis near Port Welshpool. Differences shown are compared to the Ninety-Mile Beach LiDAR survey.

3.2 Integrating Bathymetric and Topographic LiDAR Surveys

The bathymetric LiDAR survey was undertaken as a single project and was delivered as a seamless product along the coast. The only join required was with the topographic LiDAR data. Initially a difference analysis was performed between the two datasets by subtracting the bathymetric LiDAR DEM from the topographic LiDAR DEM. The region of overlap varied between the two data sets, although on average, was approximately 50m and covered the inter-tidal and foreshore zones. As the elevation in the foreshore regularly changes more weighting was placed on the difference analysis at the integration sites which consisted of stable, flat, open ground areas.

Figure 6 shows an example of the difference analysis near Rosebud in the south of Port Phillip Bay. At this location there were two integration sites where the mean difference between the topographic and bathymetric surveys was found to be 0.33m with topographic LiDAR higher. This difference was consistent in this area which pointed to a systematic bias most probably due to errors in the datum definition in the bathymetric LiDAR survey. The red areas in Figure 6 indicate larger differences due to the presence of vegetation in the bathymetric survey data. By virtue of its shoal biased design, the bathymetric (LADS) system effectively collects the equivalent of topographic LiDAR "first return" data over land.

The differences between the bathymetric and topographic LiDAR along the coast were generally less than 0.40m. This difference is within the expected range based on the relative accuracy of each dataset. As the topographic LiDAR defines the ground surface more accurately, its values were retained in all areas above the vegetation line. It is the foreshore zone where the integration between bathymetric and topographic LiDAR data sets fundamentally occurs. The foreshore was suitable as the location to merge the two data sets for two key reasons. Firstly, the foreshore is a constantly changing environment and each of the topographic and bathymetric data sources could be just as valid as each either. Secondly, the availability and reliability of any ground truth in the foreshore region is rare making it difficult to demonstrate that one data set is more accurate than the other.

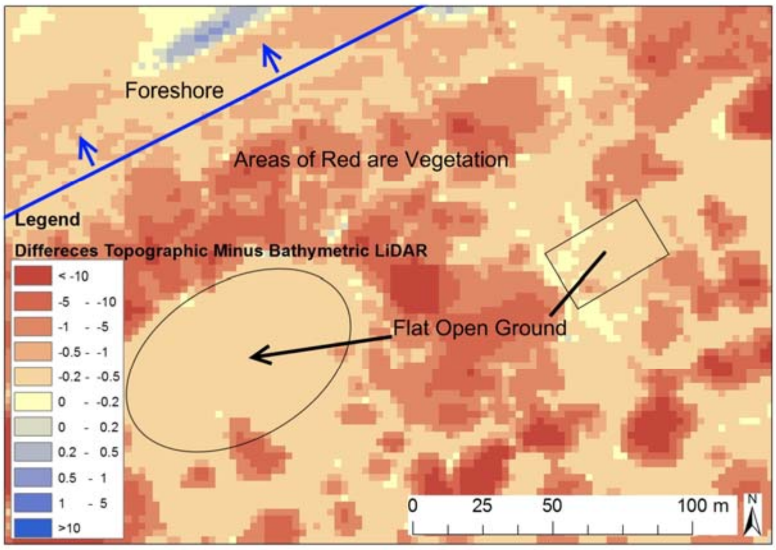

Figure 6: Topographic LiDAR Ground DEM Minus Bathymetric LiDAR First Return DEM near Rosebud

The integration of the 2.5m bathymetric DEM and 1m topographic DEM was conducted in the overlapping foreshore data at the time of the LiDAR survey.

The first step in the integration was to trim the 2.5m resolution bathymetric LiDAR data so that it only existed below the vegetation line. An example of the vegetation line over the LiDAR difference grid is shown in Figure 7. In the final DEM product all heights above the vegetation line are defined solely by the topographic LiDAR data.

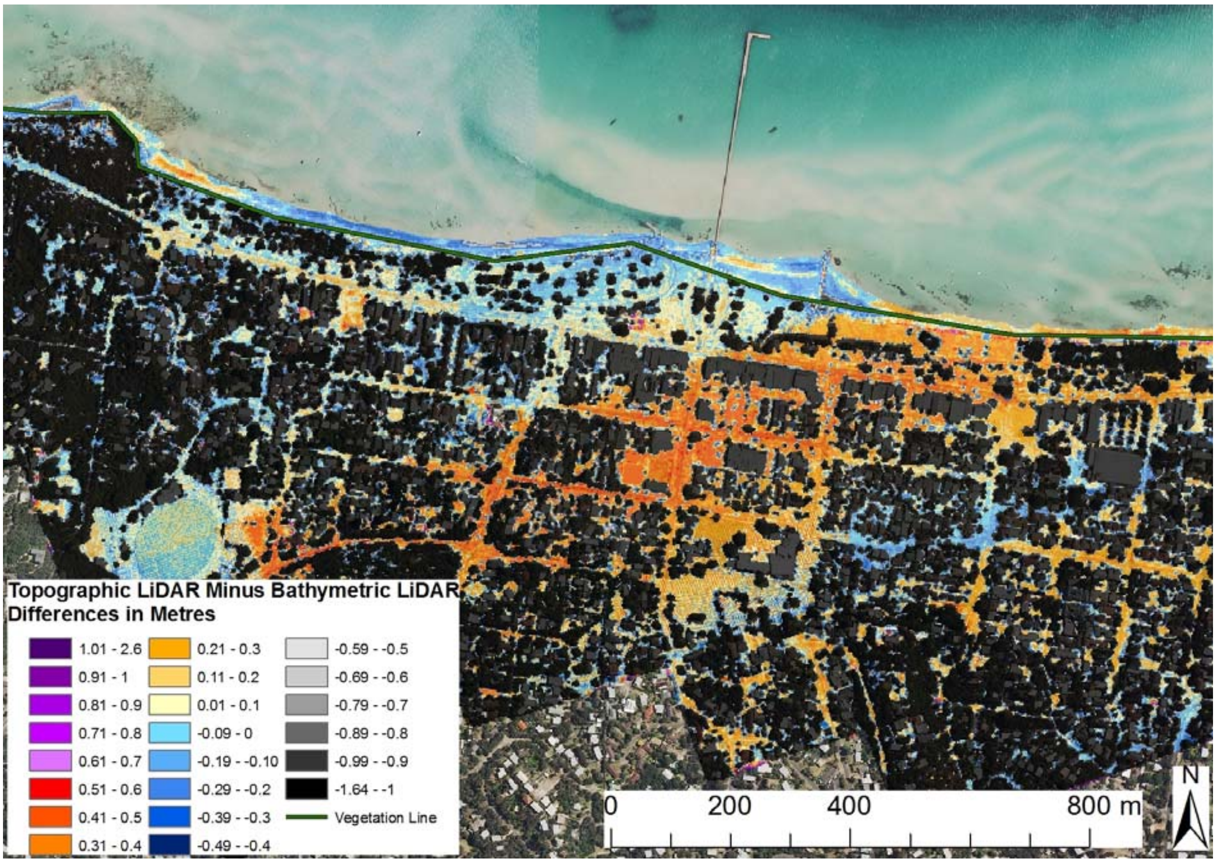

Figure 7: Topographic LiDAR Ground DEM Minus Bathymetric LiDAR First Return DEM around Rosebud. The Vegetation Line is Highlighted Against the Difference Grid.

Once the bathymetric LiDAR DEM was trimmed to the vegetation line, it was re-sampled from 2.5m to 1m to facilitate a merge process with the topographic LiDAR data. The topographic LiDAR data did not require trimming as its content ended in the foreshore zone.

A raster merge process was applied to blend elevations in each data set based on the distance from the pixel to the edge of each dataset within the area of overlap. An equal distance weighting was applied to each data set. The effect of the merge process was the removal any vertical offset between the two LiDAR data sets.

The merge process on the overlapping data was undertaken at 1m resolution. Following the merge, the overlapping data was also re-sampled to 2.5m. In effect, two resolution versions 1m and 2.5m, were created for the overlapping foreshore areas. One of each of these was then suitable for use with the original land or marine LIDAR data sets.

4. THE FINAL PRODUCTS

The fully integrated seamless +10m to -20m coastal DEM is provided as separate topographic and bathymetric DEM data sets to preserve their original resolutions. Furthermore, the characteristics of the source bathymetric data allow for the generation of very useful value added products.

4.1 Topographic DEM Products

In December 2009 a seamless 1m state-wide topographic DEM was released to the public. Figure 8 shows a section of the topographic DEM around Corner Inlet in eastern Victoria. In this area a join was made between two LiDAR surveys near Port Welshpool. The final product contains a seamless transition between two source projects even within the exposed tidal mudflats.

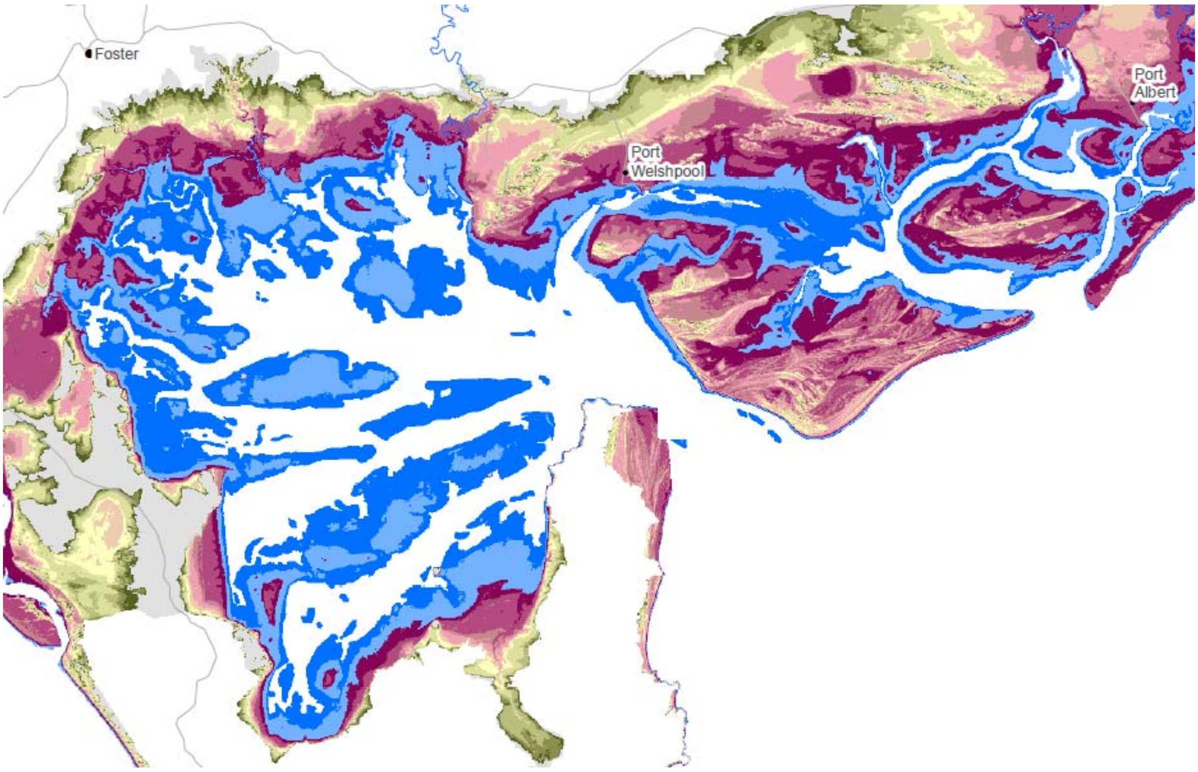

Figure 8: The Seamless Topographic DEM around Corner Inlet, Eastern Victoria

4.2 Bathymetric DEM Products

In Figure 9 a section of the bathymetric LiDAR data is shown near Warrnambool in western Victoria. Unavoidable gaps in the LiDAR data exist due to turbidity and depth. However, areas of reef and sand are still clearly present in the data.

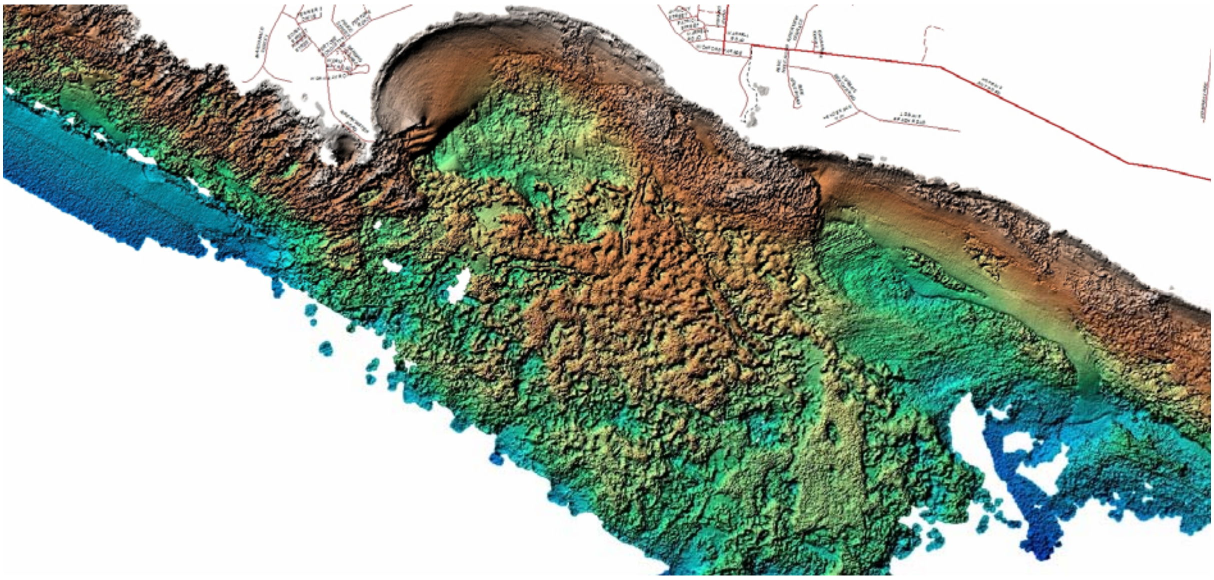

Figure 9: Bathymetric LiDAR DEM at Warrnambool (created by Worley Parsons)

In addition to providing the primary bathymetry data product, the bathymetric LiDAR data also contains useful reflectance data. The reflectance values differ depending on the water depth and type of seafloor and offer a different representation of the various substrate features that have been detected.

Figure 10 shows the same area with bathymetry values shown in colour on the left and the reflectance values shown in colour on the right. The reflectance image clearly highlights particular areas of the seafloor, which is being further investigated by Worley Parsons and Deakin University in a Marine Habitat Classification project.

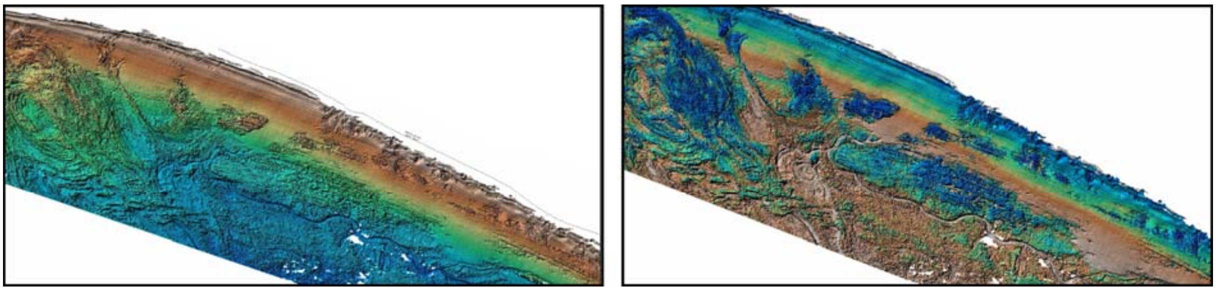

Figure 10: Bathymetry (left) and Reflectance (right) near the South Australia Border (image created by Worley Parsons)

4.3 Seamless Coastal DEM Products

The final DEM product is a seamless, state-wide 2.5m bathymetric and 1m topographic DEM. A sample map of the coastal DEM is shown around Chelsea in Port Phillip Bay in Figure 11. The seafloor in this area is generally sand with the bathymetry showing a gradual change in elevation.

Figure 11: Seamless Bathymetric and Topographic Coastal DEM around Chelsea

5. CONCLUSION

The high-resolution Coastal DEM was successfully constructed for the whole of the Victorian coast. It is already being used successfully in many local and state-wide coastal planning and policy applications across Victoria. The next stage for the DEM is to contribute to the Future Coast Program's communication and information tools to ensure the data is used in future coastal management decisions and adaptation responses.

REFERENCES

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BIOGRAPHICAL NOTES

Dr. Nathan Quadros completed his PhD in 2009 by developing a methodology to delineate the littoral zone using LiDAR data and tide models. He is currently managing the acquisition, delivery and quality assurance of the Victorian state-wide coastal bathymetric and topographic LiDAR project.

Rick Frisina works as Acquisition Manager for DSE's Coordinated Imagery Program. He has been involved in the development of QA procedures for aerial survey data with DSE since 2001.

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