Airborne Lidar Bathymetric Survey for Climate Change

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SUMMARY

From November 2008 to April 2009, data collection for a major Airborne Lidar Bathymetric (ALB) survey project was conducted for the Victorian Government Department of Sustainability and Environment (VicDSE). The survey was conducted for the Future Coasts program, to prepare Victoria's coast for climate change. The effects of rising sea levels due to thermal expansion, glacial and ice sheet melt and increased storm surges due to changing weather patterns can lead to inundation and erosion or accretion. In addition, tsunamis can lead to catastrophic destruction. These events present risks to environmental, social and economic assets. The aims of this program are to identify the types of threats and adaption strategies for the Victorian coastline and inform planning, decision making and strategy development.

The datasets required to determine these issues are elevation models, storm surge models, sea-level rise projections and geomorphology. The elevation data used in the modeling is composed of an accurate, high-resolution topographic and bathymetric DEM. The purpose of the Future Coasts Victorian Bathymetric Lidar Survey is to collect the high resolution seafloor DEM for the entire Victorian coast. The bathymetric and topographic lidar data which has been collected by Fugro LADS will be integrated with existing topographic lidar along the coast to form a seamless DEM across the littoral zone.

The Future Coasts Victorian ALB survey covers the entire Victorian coastline including Port Phillip and Western Port, and extends from 100 m landward of the vegetation line and offshore to either the 20 m isobath or a nominal distance of 4 km seaward of the coastline.

This project involved operations from multiple ALB and terrestrial lidar sensors, sea level observations from a large number of tide gauges deployed along the coastline, accurate modeling of mean sea level and geodetic observations. A number of significant problems had to be overcome which included the huge size of the area, the significant affects of swell on exposed coastlines, the management of water clarity to ensure coverage of the seabed by lidar, maintaining an accurate datum throughout the entire area and producing a common set of products.

The aim of this paper is to discuss the challenges presented by this survey and the solutions adopted to overcome them.

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1. THE SURVEY REQUIREMENT

The Victorian Bathymetric Lidar Survey is part of the Victorian State Government's strategy to assess the vulnerability of the Victorian coast to climate change at a local scale and to develop decision support tools that can be used to address the potential risk. The main purpose of the bathymetric lidar data generated from the project will be to form part of the solution in modeling the impact of extreme weather events and sea-level rise along the Victorian coast. The effects of rising sea levels due to thermal expansion, glacial and ice sheet melt and increased storm surges due to changing weather patterns will potentially lead to inundation and erosion. This will create risks to environmental, social and economic assets. The aims of the project are to identify the types of threats and adaption strategies and inform planning, decision making and strategy development. The elevation information required to assess these issues involve a lidar derived topographic and bathymetric DEM.

The purpose of the Future Coasts Victorian Bathymetric Lidar Survey was to collect a high resolution Digital Elevation Model (DEM) for the entire Victorian coast. The bathymetric lidar data has been integrated with existing topographic lidar data to form a seamless DEM across the littoral zone.

The bathymetric lidar survey was required to map the Victorian coast to a depth of 20m. The survey coverage was required to extend from at least 1km and up to a maximum of 4km offshore, from the line of Lowest Astronomical Tide (LAT). The landward extent of the survey was at least 100m inshore of the vegetation line. The survey was divided into coastal sections based on similar environmental and geographical properties, which were assigned a relative priority by VicDSE.

In addition the survey had to satisfy the following requirements:

- Surveying Topographic Integration Points (TIPs). These are flat open-ground areas usually confined to sports ovals within 1km of the coastline. There were 57 TIPs.
- Filling-in small polygon areas beyond the 4km horizontal limit in certain areas, in Corner Inlet, Port Phillip and Western Port.
- Providing survey coverage for the Snowy River and estuary. This area required a survey resolution of 3m from the estuary to the Princes Highway in Orbost.
- Surveying other inlets including Swan Bay, Anderson Inlet, Corner Inlet, The Bar Lakes Entrance and Mallacoota Inlet.
- A minimum percentage coverage of the seabed was specified for each survey area.

The following products were required in 2 km tiles on the Universal Transverse Mercator (UTM) grid relative to Australian Height Datum (AHD):

- Raw bathymetric first return lidar data in x,y,z,I (Intensity) format with a 5m average resolution
- Raw bathymetric last return data (ground) lidar data in x,y,z,I format with a 5m average resolution
- DEM at 2.5m resolution
- Contours in ESRI Shapefile format at 1m intervals
- Aerial photography in Tiff format

In addition, the following products were required in 2 km tiles on the UTM grid relative to GRS80 height datum:

- Raw bathymetric first return lidar data in x,y,z,I format with a 5 m average resolution
- Raw bathymetric last return lidar data in x,y,z,I format with a 5 m average resolution

An aerial photography mosaic was also required of each survey area in ECW format.

The schedule required data to be collected by April 2009 and a staggered delivery of the survey data, requiring coastal areas bordering high priority regions to be delivered first.

2. THE STRATEGY ADOPTED TO COMPLETE THE WORK

In order to complete the work within the required timeframe two ALB systems and two terrestrial lidar systems were employed, as follows:

- The entire coastline from 100m behind the vegetation line offshore to the 20m isobath was surveyed using the LADS Mk II system
- Certain nominated small bays and inlets were surveyed using the Hawk Eye II system to a nominal depths of around 10m
- The drying areas in the northern part of Western Port were surveyed using topographic lidar at low water spring tides
- All TIPs were surveyed using topographic lidar and ALB

Data was collected along the entire Victorian coastline using the LADS Mk II ALB system. The Hawk Eye II ALB system was used to survey Swan Bay, Anderson Inlet, Corner Inlet, The Bar Lakes Entrance, Snowy River and estuary and Mallacoota Inlet. The drying parts of Western Port were surveyed at low water using the using the ALS50-II topographic lidar, as these areas could not be surveyed when inundated, due to extremely high levels of turbidity. TIPs were surveyed by topographic lidar in a direction perpendicular to the coastline, and these lines were repeated using ALB. This provided an accurate and repeatable interface between the topographic and bathymetric DEMs.

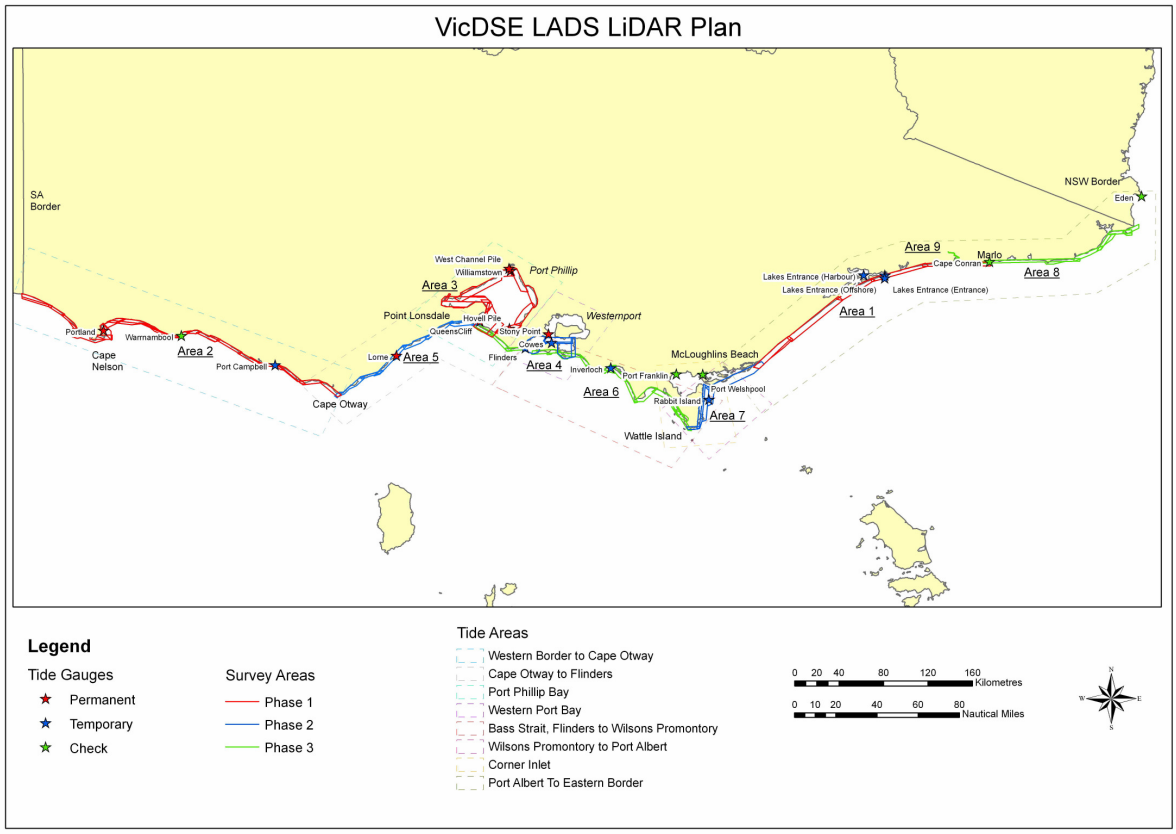
The entire project was managed by Fugro LADS Corporation (FLC), formerly Tenix LADS Corporation, and the majority of data was collected using the LADS Mk II ALB system. BLOM Aerofilms collected and processed data using the Hawk Eye II ALB system. AAM Hatch collected and processed data using topographic lidar systems. A number of tide gauges were deployed and maintained by FLC staff. Cardno Lawson Treloar (CLT) provided specialist advice to propagate the tide levels and datum throughout the survey area, provided data from permanent tide gauges and also collected some additional tide data. Geodetic support was provided by local survey company Geomatix. All data was quality controlled by FLC staff who also integrated all the data into combined DEM and contour products.

Due to size of the survey area and the exposed nature of the coastline, the survey was planned in three major sections: West, Central and East. Each section was planned in a separate database which was created in the LADS Mk II planning and data processing system (Ground System - GS). Each database contained up to three of the priority areas nominated by VicDSE. The data collection was initially planned to be undertaken in three phases, with one VicDSE area from each database included in each phase. In this way during each phase of the operation there was planned to be an area from the West, Central and East parts of the coast open to provide suitable weather alternatives. Whilst this approach was adopted at the start of data collection, significant challenges as a result of persistent swell on the west coast resulted in Area 2 remaining active for the entire survey period, and a period of good weather on the far east coast allowed Area 8 to be completed early.

The breakdown of the survey areas, survey databases and survey phases are provided below:

Vic DSE Area Number	Area Name	Database	Survey Phase
1	McLoughlins Beach to Marlo	08_14vdse_E	Phase 1
2	South Australia Border to Cape Otway	08_12vdse_W	Phase 1
3	Port Phillip	09_13vdse_C	Phase 1
4	Western Port	09_13vdse_C	Phase 2
5	Cape Otway to Point Lonsdale	09_13vdse_C	Phase 2
6	Point Nepean to Wattle Island	09_13vdse_C	Phase 3
7	Wattle Island to McLoughlins Beach	08_14vdse_E	Phase 2
8	Marlo to NSW Border	08_14vdse_E	Phase 3

These areas are depicted in the following image:



This approach ensured that the surveys were progressed in an order corresponding to the VicDSE priorities. It further ensured alternate areas were available on the west coast, east coast and in a sheltered bay during each phase, in the event of poor environmental conditions. It also followed the important survey maxim of divide and conquer, which enabled areas to be completed progressively, in lieu of trying to survey the entire coast as a single activity.

3. SURVEY OPERATIONS

Prior to commencing the work trial flights were conducted over known benchmark areas off Adelaide to confirm the operation of the LADS Mk II system. A reconnaissance of the west coast areas was conducted during the deployment to Essendon airport on 26 November 2009. Survey flight operations commenced on Thursday 27 November.

Operations were undertaken from Essendon Airport, Melbourne. A small data processing facility was established in offices in Moonee Ponds, however data was backed up and couriered overnight to FLC's Adelaide office on completion of each flight. All final data processing was conducted at the Fugro LADS Adelaide office.

Two specialist maintainers and a comprehensive set of AS and GS spares were deployed to the field site. This approach ensured that the progress of the survey was not adversely affected by defects. No significant AS failures occurred that affected the survey data quality.

From 27 November to until 24 December 2008, 15 flights were flown during the 29 day period. Unsuitable weather was experienced in 10 days. Operations were planned in the Priority 1 areas; however strong winds and sea conditions meant that most of these flights were focused on Area 3 - Port Phillip during late November and early December and in Area 2 along the West coast in the run up to Christmas. Several flights were attempted to Area 1 during this period; however persistent swells and the resultant high levels of turbidity along the Ninety Mile Beach forced these sorties to be diverted to other areas. As a result the highest priority area could not be commenced prior to Christmas. To offset any delays in the overall progress that this may have caused, Area 5 - Cape Otway to Point Lonsdale was commended earlier than planned.

Operations resumed following Christmas on Monday 29 December 2008 and continued until 3 April 2009. During this period 58 flights were flown over 96 days. 37 days were unsuitable due to poor weather, and an additional seven sorties were aborted after takeoff due to bad weather in the survey area and alternative areas.

During this second part of the survey, flying operations were initially conducted in Area 1 along the Ninety Mile Beach as swell and water conditions had improved considerably. Once Area 1 had been completed, operations were commenced in Areas 7 and 8 to take advantage of the good conditions along the east coast of Victoria throughout January. In early February the LADS aircraft forward deployed to an operating base at Mount Gambier airport between Tuesday 3 and Thursday 5 February to take advantage of an unusually calm period along the west coast, which allowed the majority of Area 2 to be competed. By mid February flying operations were being conducted in all areas as weather conditions allowed. This pattern continued with areas gradually being completed up until the end of flying operations. Overall 73 flights were flown which equated to a total of 420 hours 32 minutes flown of which 287 hours 34 minutes was spent on task collecting survey data.

The Hawkeye II ALB system conducted operations inside Swan Bay, Anderson Inlet, Corner Inlet, The Bar Lakes Entrance, the Snowy River and estuary and Mallacoota Inlet. Operations we conducted from 17 March 2009 to 2 April 2009. A total of seventeen flights were conducted during this period of which 15 were effective survey flights**.** The aircraft was based at Essendon to survey Swan Bay and Anderson Inlet. Corner Inlet was flown from West Sale airport, Mallacoota Inlet and the Snowy River estuary was flown from Merimbula and The Bar Lakes Entrance was flown during the transit between Essendon and Merimbula. A total of 36 hours 43 minutes were flown of which 21 hours and 12 minutes was spent collecting survey data**.**

TIPs were surveyed by topographic lidar between 20 December 2008 and 3 January 2009. A total of seven flights were conducted over this period collecting topographic lidar data over 57

individual TIPs along the entire Victorian coast. Data from these flights were used to check the accuracy and consistency of the bathymetric lidar systems.

Drying areas of in Western Port were surveyed using topographic lidar from Essendon on two deployments. These flights were timed to occur close to the lowest spring tide levels when the tide fell to less than 0.3 m above LAT, so as to maximise the coverage of the drying banks. Five flights were initially flown between 5 and 13 January 2009. During this deployment full coverage of the banks was not achieved, thus a second deployment was undertaken to Western Port between 7 and 8 November 2009.

4. WEATHER

Weather conditions off the coast of Victoria are notoriously highly variable and the summer of 08/09 was no exception with strong winds, low cloud, extreme temperatures, smoke from bush fires, and storm driven swells from the Southern Ocean effecting operations at certain times. In particular Area 2 – South Australian border to Cape Otway, was particularly affected by significant swells and during calmer periods by low cloud. The general pattern appeared to be one of calm hot periods dominated by slow moving high pressure systems, interspersed every week or so by a progression of low pressure systems just south of the coastline that brought strong south south-westerly winds and large swells.

The general approach of maintaining a central operating base and being able to operate in at least three geographically separated areas proved to be critical in managing the overall weather conditions and allowed operations to continue. Over the entire survey period 45 days were considered unsuitable for survey operations and flights were either cancelled or not scheduled on those days. Nine flights out of 73 had to be aborted due to poor weather conditions encountered after take off and on 25 flights out of 73 were operations were diverted to a different survey area due to unsuitable conditions.

5. GEODETIC CONTROL AND POSITION FIXING SYSTEMS

Horizontal control for the data collection was based on the World Geodetic System 1984 (WGS84). All data was post-processed relative to the 1994 Geodetic Datum of Australia (GDA94) through the application of the post-processed Kinematic GPS positions. Coordinates refer to the UTM projection, Zone 54 Central Meridian 141 East for all data west of Lorne and Zone 55 Central Meridian 147 East for all data to the east. At the request of DSE, data collected in Area 5 between Cape Otway and Lorne was initially processed on Zone 55 and then shifted to Zone 54 on export.

Throughout the survey, the real time position of the LADS MkII system was derived from an Ashtech GG24 GPS receiver. Fugro OmniSTAR Wide Area Differential GPS corrections from the Fugro OmniStar Virtual Base Station (VBS) service were received using an

OmniStar 3510LR system and applied to the raw GPS position as received by the GG24 GPS Receiver.

L1/L2 carrier phase KGPS post-processed positions were determined relative to the VicDSE GPSNet base stations. A post-processed position of the aircraft was determined relative to the nearest GPS Base station using GrafNAV software. These positions were imported into the Ground System and applied to all soundings.

Additional GPS base stations were established in far eastern Victoria to support Hawk Eye II operations at Mallacoota and in the Snowy River.

The positioning systems were subject to checks prior to, during and following data collection to ensure position accuracy was achieved. Based on the results of the static position check, dynamic comparisons, navigational checks and theoretical calculations, IHO Order-1 position accuracy was achieved.

6. VERTICAL CONTROL AND TIDES

A reconnaissance of areas suitable for the deployment of tide gauges was conducted between Tuesday 11 and Friday 14 November 2008.

Observed tides were supplied from a combination of temporary and permanent gauges. Wharf mounted Valeport 740C gauges were installed at Warrnambool, Port Campbell, Apollo Bay, Rhyll and Port Franklin by FLC surveyors. Seabed mounted Valeport Midas WLR gauges were also installed by FLC surveyors off Waratah Bay, Corner Inlet, Rabbit Island, Seaspray, Cape Conran and Gabo Island. A temporary RBR tide gauge was installed by CLT staff off Lakes Entrance. Data was obtained from permanently installed tide gauges at Portland operated by National Tidal Facility, at Lorne, Queenscliff, Hovell Pile, West Channel Pile, Fawkner Beacon and Breakwater Pier Williamstown operated by Port of Melbourne Corporation, Point Richards Beacon and Corio Bay operated by Victorian Regional Channels Authority, Stony Point owned by Patrick Ports, Lakes Entrance inner channel operated by Gippsland Ports and Eden operated by the Manly Hydraulics Laboratory. Separate tide models were established for each survey area by hydrodynamic modeling using a combination of observed and predicted tides. Models for each area were carefully integrated with adjacent areas to ensure that a seamless and accurate datum was established along the Victorian coastline.

7. QUALITY CHECKS

A number of checks were built into the design of the survey. The bathymetric and topographic DEMs were tied together through the TIPs. ALB data was checked by means of the TIPs on land and depth benchmarks in the water. Cross lines were conducted throughout

all survey areas. In addition, where the areas surveyed by each system overlapped, this data was compared.

Depth benchmarks are generally selected in flat areas of seabed and are used to check the quality of the depth data. They are areas approximately 250m x 250m and are established at various depths and flown as often as possible during the survey to confirm system performance and precision. For this survey seven historical benchmark areas were utilized from previous LADS operations for a Port of Melbourne Corporation survey (2007) in the Great Sands area of Port Phillip. These depth benchmark areas had been established in depths between 1.3 m and 14.4 m. Two additional benchmarks were established in deeper water (20.0 m and 23.7 m) to provide statistics across a wider depth range. Depth benchmarks were flown on a total of 35 occasions and benchmark comparisons were conducted.

Topographic Integration Points (TIPs) were selected by VicDSE in flat areas to enable an analysis of the precision of the topographic data to integrate the topographic and bathymetric DEMs. A total of 57 locations were selected and these were typically football fields which were reasonably close to the coastline. These were all surveyed using the ALS50-II topographic lidar system to define a reference surface. Two TIPs were also surveyed using RTK GPS. In addition one TIP on the Mornington Peninsula was surveyed 15 times during the survey and used as a topographic benchmark. In addition, 39 cross lines were flown throughout the survey area to check the internal consistency of the data.

For the Hawk Eye II data the data was collected on GRS80, transformed to LAT then adjusted to heights from TIPs and depths from Seabed Control Areas (SCAs).

Topographic lidar data was collected on GRS80 and transformed to LAT and adjusted using ground control and checked using redundant ground control.

8. DATA PROCESSING

Data processing is normally conducted at the field site. However due to the large size of this survey, and the close proximity of the operating site to the Fugro LADS survey depot in Adelaide, the LADS Mk II data was backed up in Essendon, then transferred to Adelaide by courier and processed.

All data processing was controlled by work instructions and procedures which have been certified ISO-9001:2008 Quality Assurance standards.

The first part of the processing involved applying KGPS positions from the local GPS base station to the raw data and digital images. Following this, the data was processed on the GS to produce depth, position and a series of confidence parameters. Preliminary tides were applied and final verified tides reapplied at a later time. Each sounding and associated confidence data were stored in the database.

The data was then available for operator review and editing, which involved the following stages:

- pre-validation
- validation
- checking
- quality control
- approval

Prevalidation is a review of the data quality to determine whether the survey objectives have been met or whether the data should be reflown. It is conducted as soon as possible following the flight by a senior hydrographic surveyor.

Validation is the detailed inspection and editing of the data. All features are inspected and incorrect returns due to turbidity or noise are removed or edited. Comments are recorded for each edit made, and attributes can be assigned to the data consistent with the S-57 format which is used for nautical charting. All operator interactions during the validation phase are logged so that complete traceability is maintained. The validation is conducted by hydrographic surveyors or GIS graduates who operate the AS and are familiar with the data and trained in the data processing procedures.

Checking is an independent assessment of the data in which a review is conducted of the validation process. The checking is conducted by a senior hydrographic surveyor or GIS graduate who manage AS operations and who will have a number of years experience as a validator and as an AS operator.

The quality control procedure is a thorough independent review of the data. It is undoubtedly the most important phase of the process. The position, depth, run and other relevant attributes are extracted from the database for use in the generation of TIN models and gridded data sets to produce contour plots, sun-illuminated colour-banded images, coverage check plots and difference plots. Anomalies found are digitally recorded and reported for remedial action.

The final phase of the data processing process is the approval of the data. During this activity all processes including the quality control products and report are reviewed, including any subsequent remedial actions. The data is either accepted, referred for rework or in a small number of cases rejected. This process is conducted by the most senior staff who manage surveys and are IHO Category A trained and certified hydrographic surveyors.

These processes were assisted by the digital photographs taken at 1 hertz using the downward looking two mega pixel digital camera. These geo-referenced images are automatically displayed by the GS with the ALB data. The images are automatically rotated to north-up and are linked to the data so that the position of the soundings can be seen on the digital images. They assist in the interpretation and correlation of features in the data on the coastline, islands

and islets, drying rocks, rocks awash, shallow rocks, kelp, beacons, buoys, boats, jetties, buildings and trees with the imagery. The quality of imagery and zoom functionality even enables discernment of small artifacts in the data such as birds.

The processing of the data to meet the VicDSE survey requirement was customised to meet the specific customer requirement as described in the Scope of Work. All features within the water of a temporary nature, such as buoys, were removed from the dataset. All piers, jetties and bridges were also removed. All man made objects along the coast which the water must flow around, such as solid wharfs and breakwaters, were retained in the dataset.

The data collected by the topographic lidar system and Hawk Eye II ALB system were processed by AAM Hatch and BLOM Aerofilms personnel respectively. This data was then reviewed by the same quality control process as was applied to the LADS data, as previously described. Following quality control the data was then accepted or remedial action directed as required.

At the time of writing this paper (March 2010) all LADS ALB data relative to LAT had been fully processed, accepted and products produced and delivered to VicDSE. Topographic lidar data had been delivered, quality controlled, accepted and integrated into products. There have been some quality related issues with the processing of the Hawk Eye II data. The data from Swan Bay, Corner Inlet and The Bar Lakes Entrance has been accepted following a number of rounds of quality control. The Mallacoota Inlet data has recently been quality controlled and the Anderson Inlet data has just been received for quality control. Once these data sets have been approved, final products in these areas will be able to be created and delivered to VicDSE.

9. INTEGRATION OF THE DATA AND PRODUCTS

The data from the LADS Mk II, Hawk Eye II and topographic lidar systems were collected and processed separately and then quality controlled prior to acceptance and integration into a common set of products. Separate data sets in 2 km tiles were required in four formats: first and last return data relative to both AHD and GRS80. Imagery was required in two formats: geo-tiff image format in 2 km tiles and ECW format of larger areas. DEM and contour formats were also produced in 2 km tiles. There were 2085 tiles covering the areas surveyed by LADS Mk II data alone, and with the requirement for the seven data formats to be delivered in 2 km tiles, this required 14,595 individual data tiles. This clearly demonstrates the importance of the ISO 9001 accredited quality system to manage these processes.

For all data deliveries the following sign convention was used:

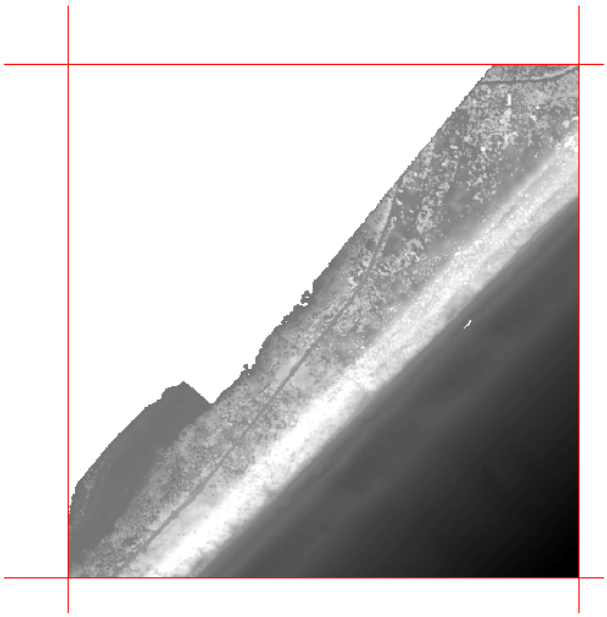
- Elevations above sea level (0m) are Positive
- Elevation below sea level (0m) are Negative

Products were created from the final approved data set from the data processing phase.
The first return and last return data in format x,y,z,I were exported from the GS by entering bounding coordinates for an entire area (NW and SE coordinates). Data was clashed at a 4 m radial range to provide data at 5 m resolution. 2 km tiles were automatically generated from the entire exported area and with the required file naming convention automatically assigned to each tile by the GS.

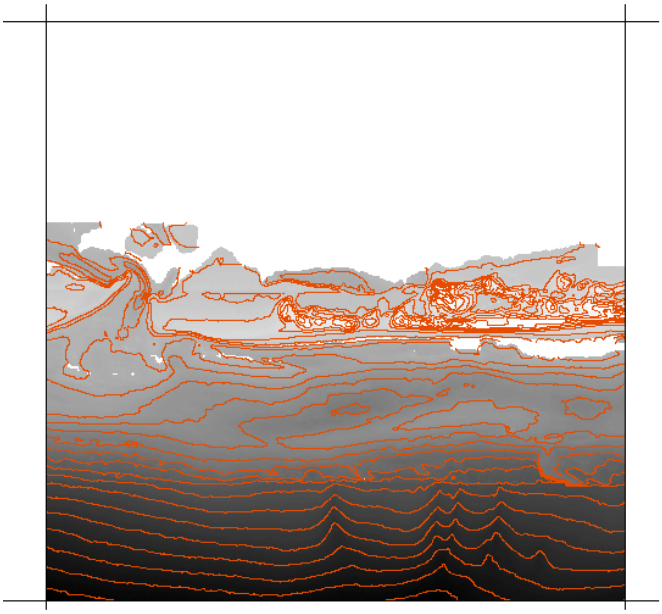
Several steps are taken to create the DEM file. To begin with, the LADS Mk II x,y,z export was used to generate a file of elevation mass points in ArcGIS. This is then used to create break lines, which are a calculation of areas of 'no data'. This is essential as areas containing 'no data' should not be interpolated across.

For data from Hawk Eye II (x,y,z,I) and topographic lidar (LAS files), the full data sets were imported into CARIS Bathy Database and a shoal-biased 5-m true position grid was created to reduce the data volume, which was exported as a x,y,z file. A polygon created for the voids in the LADS data was then used to cut out the required areas from the Hawk Eye II and / or topographic lidar 5-m gridded data set. This data was then cut in 2km tiles in ArcGIS and then merged with the LADS Mk II 2km tile data.

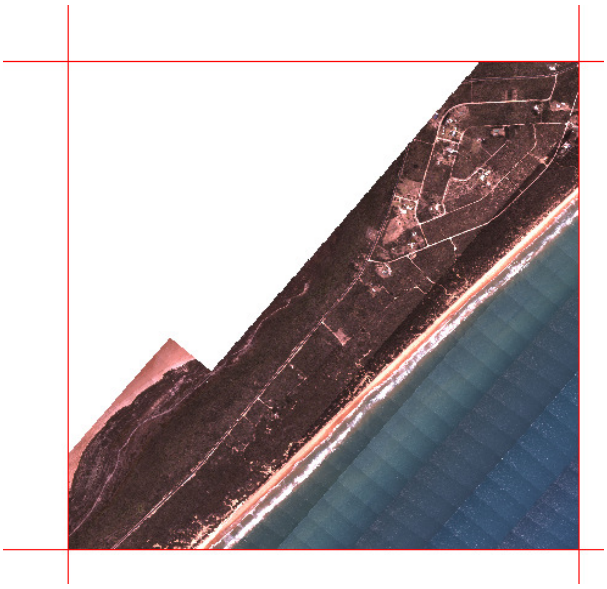
A TIN was then populated using the combined data set and the break lines created to mask blank areas. The populated TIN was then converted to a raster dataset at 2.5 m, using the original boundary coordinates to trim the overlapping 20 percent. The resulting raster grid was then converted to an XYZ text file. The following image is of part of the ninety Mile Beach 12km north-east of Seaspray.



Contour files were created by firstly stitching together each 2km tile into an overall area mosaic. This file was subsequently run through three stages of filtering, which smoothes the data by reducing local variation using a 3 x 3 neighbourhood with a mean statistic type. Contours were created for the entire area at a 1m interval, and clipped using the 2 km tile boundaries. The contours were provided to UTM on the AHD. The following image shows the contours at the Snowy River estuary.



A mosaic of each area was created using an internally developed mosaic build tool. The 1-second images captured during sounding were then joined together using a semi-automated processing technique to select appropriate images based on operator selectable attributes of time and heights of tide. This process provided a series of geo-referenced aerial mosaics in 6 x 8 km tiles at a resolution of 25 cm. These tiles where then divided up into 2km tiles to match the DEM tiles in geo-tiff format, and were combined to produce images of the entire area in ECW format using the software Global Mapper. The following image is of part of the ninety Mile Beach 12km north-east of Seaspray.



A number of additional products were also produced:

- CAF files were created to provide additional attributes, for example, line number, tide, frame, row column, time of acquisition, etc ...
- Flight Runs in ArcGIS Shape file format Run lines shape files were also created including line number and start and end date and times.
- Tile Indices in ArcGIS Shape file format, Tile index – shape file in ARC showing every file delivered from the area.
- Metadata in Word format

All digital data was provided on DVD and USB Hard Disk for Aerial Imagery.

An error has been detected on the export of the first and last return data on the GRS80 height datum due to a software error. This data has yet to be provided and will be exported when this problem has been solved. The affects the first and last return data on the GRS80 datum.

10. COVERAGE

In general very good results were achieved with depths down to the required 20 m obtained.

Some localized gaps in the coverage occurred as described below:

- Persistent turbidity in Hobsons Bay in the northern part of Port Phillip due to dredging operations near the mouth of the Yarra River and in Corio Bay near Geelong, within parts of Western Port, offshore from Portland Harbour due to dredging and in the vicinity of Cape Conran east of the mouth of the Snowy River meant that coverage

within these areas was reduced. Operations within these areas were attempted throughout the survey, however conditions in these areas remained marginal.

– White water in the surf zone created some gaps in the coverage. Whilst every effort was made to under take the flying operation in all areas during periods of minimum surf, white water still created some gaps along the more exposed parts of the Victorian coastline.

– Rock and kelpy areas tend to generate a lower return due to the low reflective quality of the kelp and the rocky seabed. These areas were generally flown at least twice due to overlapping sub areas or through the use of refly lines, however only sparse coverage was achieved in some of these areas.

An example of the data merged from the LADS Mk II and Hawk Eye II system in Area 7 - Wattle Island (Wilsons Promontory) to McLoughlins Beach (including Corner Inlet) is provided in the following image.

In this image, the offshore data from the coastline to seaward of the 20 m isobath and deeper areas within corner inlet were collected using the LADS Mk II system. The data within Corner Inlet to a depth of approximately 10 m was collected using a combination of LADS MkII and Hawk Eye II systems.

11. VICTORIAN DSE BATHYMETRIC DATA QUALITY ASSURANCE, INTEGRATION AND RELEASE

VicDSE has performed a number of quality checks on the bathymetric lidar data once it is received from FLC. For the vast majority of Victorian survey the LADS Mk II system achieved thorough coverage with only Western Port failing the coverage requirements due to turbidity issues. The accuracy of the lidar bathymetry was checked against existing multi-beam data in the marine environment and overlapping topographic lidar in the terrestrial environment. In both cases the data met the vertical accuracy requirement of IHO Order 1. The differences between the bathymetric and topographic lidar along the coast were generally less than 0.40m.

The Victorian seamless coastal DEM is composed of both topographic and bathymetric lidar data. Within the coastal DEM the topographic lidar defines the ground surface more accurately, so its values were retained in all areas above the vegetation line. The foreshore zone is supplied as a seamless composition of both bathymetric and topographic lidar. All data below the waterline at the time of topographic lidar data capture is composed of only bathymetric lidar data.

The bathymetric and topographic lidar data has been released in their native resolutions. The integrated foreshore area is supplied twice. At a 1m resolution within the topographic DEM which extends down to the water line, and at a 2.5m resolution within the bathymetric DEM which extends up to the vegetation line.

As a seamless product the Victorian coastal DEM will provide a major contribution into assessing the vulnerability of Victorian coastal assets. The data will improve the planning and management of coastal areas by providing the base data for information products, including generating an assessment of the Victorian coast's physical vulnerability to climate change impacts. Data products and associated guidance and interpretation packages will be designed to help coastal decision-makers develop adaptive responses to climate change in planning and policy decisions.

12. CONCLUSION

This significant project involved two ALB and topgraphic lidar sensors operating over a 4-month period in exposed and difficult survey areas. The data collection, processing and creation of products were all significant tasks. For example, in excess of 15,000 files of data tiled in 2x2 km areas were produced involving seven different data formats. The success of this project is a testiment to the robust systems and procedures employed and the quality of the staff.

The data received by VicDSE exceeded expectations in its quality and vertical alignment to exisiting coastal topographic lidar data. The robust methodology for the collection of

bathymetric lidar data has enabled an accurate datum definition for the bathymetry across the whole project. The close alignment between the topographic and bathymetric LiDAR datasets has eased the integration process. This particular feature has enabled the release of a seamless coastal bathymetric and topographic lidar dataset for Victoria.

BIOGRAPHICAL NOTES

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.

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