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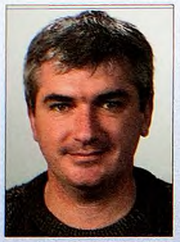

# LITTO$_3$D - A Seamless Digital Terrain Model

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**Abstract**

*The French National Geographic Institute (IGN) and the French Naval Hydrographic and Oceanographic Office (SHOM) were tasked by the Prime Minister to combine efforts to produce a seamless, precise topographic and bathymetric model, of the entire French coast. The Litto$_3$D project was then created to meet more than one hundred requirements expressed by coastal managers and by users of geo-referenced data. An initial laser survey was conducted in the Golfe du Morbihan, Brittany and was used to generate a precise DTM. This experiment enabled SHOM and IGN to develop a methodology applicable everywhere and by everyone.*

**Résumé**

*L'Institut géographique nationale (IGN) et le Service hydrographique et océanographique de la marine française (SHOM) ont été chargés par le Premier Ministre de mettre en commun leurs efforts pour produire un modèle continu, à topographie et bathymétrie de précision, de l'ensemble des côtes de la France. Le projet Litto3D a donc été mis sur pied afin de répondre à plus d'une centaine de demandes formulées par des gestionnaires côtiers et par les utilisateurs de données géo-référenciées. Un premier levé laser a été effectué dans le golfe du Morbihan, en Bretagne, et a servi à produire des DTM précis. Cette expérience a permis au SHOM et à l'IGN de mettre au point une méthodologie appliquée partout et par tout le monde.*

**Resumen**

*El Primer Ministro encomendó al Instituto Geográfico Francés (IGN) y al Servicio Hidrográfico y Oceanográfico de la Marina Francesa (SHOM) la tarea de combinar sus esfuerzos para producir un modelo topográfico y batimétrico uniforme y preciso de la totalidad de la costa francesa. Fue creado entonces el proyecto "Litto3D", para satisfacer más de un centenar de requerimientos expresados por los administradores costeros y por los usuarios de datos geo-referenciados. Se efectuó un levantamiento inicial por láser en el "Golfe du Morbihan", en Bretaña, que fue utilizado para generar un DTM preciso. Este experimento permitió al SHOM y al IGN desarrollar una metodología aplicable en todas partes y por cada persona.*

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## 1 Introduction

During a preliminary study (Allain S., Grateau C., 2004). in March 2003, SHOM and IGN evaluated various issues to resolve in order to produce a seamless database with continuous relief between water and land.

The study noted that the inter-tidal area is not well-described as it is difficult to conduct surveys in very shallow water (i.e. not enough water, too many rocks and breakers) and to obtain good photogrammetric restitution (wet and flat areas especially). That is why, in many places, there is limited data and limited continuity of description between the sea and the land (Figure 1).

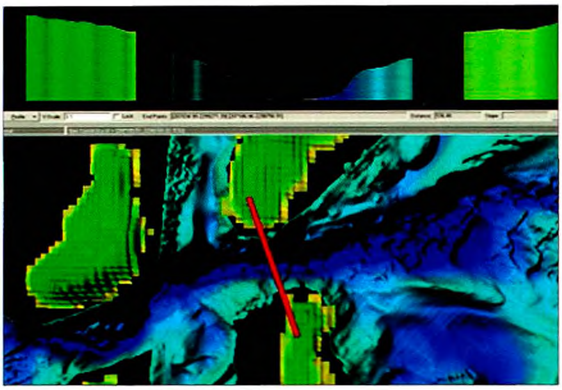


*Figure 1: Fusion of altimetric data from BdAlti IGN (green), multibeam survey SHOM (blue) The cross section makes it appear as a large gap between data (black area ~50m large).*

Fortunately, it appears that there is no difficulty merging information as SHOM and IGN data can in, most cases, share the same geodetic vertical reference level (FIG, 2006). Thus, there are known correspondences between sea chart datum (LAT) and land datum (Bruce Parker, 2002).

These first results were reported to CIMER (Comité Interministériel de la Mer) on 14 September 2004. Within their present responsibilities, SHOM and IGN have all the necessary skills to contribute to this project, including bathymetric, geodetic and cartographic expertise. Notably, a French tide model has been implemented with a precision compatible with Litto$_3$D requirements. An initial stage was to promote and to provide existing digital information through a new product called Histolitt (2007). Thus, a part of the littoral requirements will be rapidly satisfied. Since a commercial policy is not yet defined as to the ownership of the data (SHOM, IGN and others organisations) future agreements must be made before these data is made universally-available.

## 2 Demonstrator in the "Morbihan Gulf"

Working together, SHOM and IGN wanted to show that it is possible to achieve a continuous altimetric model in a small area, combining different, old and new acquisition methods.

A bathymetric laser airborne system was chosen since it provides an accurate, rapid, safe and cost effective method of surveying coastal areas. This system has been used by governments and commercial organisations over the last decade to conduct surveys for nautical charting and coastal zone management. It seems particularly suited to fill the gap between former sea charts and Litto$_3$D (Figure 1 – cross-section).

Key objectives of the laser demonstration are to:

- Examine the performance and the limits of airborne laser survey
- Compare and merge MBES (multi-beam echo sounder) and laser data
- Comply with the highest hydrographic and cartographic standards
- Lay down standards to Litto$_3$D partners in terms of data acquisition methods and qualification rules

The Golfe du Morbihan offers a wide variety of relief and thematic conditions. It is a good location for a demonstrator as it concentrates all difficulties that represent most of the French littoral: 0-50m depths, turbidity, currents, wide inter-tidal area, flat sandy beaches, and rocky coastlines. This is also a much used area for recreational boating in the summer, and there is a need for SHOM to improve the types of nautical charting products.

### 2.1 Survey objectives- Data Acquisition

For the survey of the Gulf, each depth individually fulfils the IHO special publication N° 44 (IHO 1998) Order 1 requirements (absolute accuracy: vertical = 50cm and horizontal = 5m) although the area was incompletely surveyed, as shallow waters were not exhaustively detected. Spatial resolution is 1 measurement every 4m x 4m laser spot spacing and there is 20% of overlap between tracks. Data were processed in batch mode. The survey team was committed to survey the entire area (i.e., full coverage). However, due to turbidity and hazardous meteorological conditions, the team had to make compromises in providing a complete data set.

**2.2 Survey equipment**

A bathymetric laser (SHOALS 1000-T) was mounted in a twin-engine aircraft (CESNA 404). This system operates with a near infrared (1064nm) laser and a green (532nm) laser. There are two distinct working modes:

- Hydrographic and topographic mode at 1 kHz frequency,
- Topographic mode at 10 kHz frequency.

The aircraft position was determined using three methods:

- Real time DGPS - For navigation and data preprocessing, OMNISTAR differential corrections were used. In case of loss of signal, inertial data were also recorded.
- Batch stage KGPS - For data post-processing, both raw GPS data and inertial data were computed in L1/L2 mode to get a Kinematic GPS location.
- Real time GPS-RTK - Ground stations provided differential corrections through a GSM (Global System for Mobile Communication) antenna. This third way is too dangerous for real-time navigation as there are some risks (e.g., data communication losses). But it was very useful for post-processing and quality insurance.

**2.3 Survey strategy**

The survey took place in summer 2005. While many strategies were explored, few of them are optimal. In measurements over water, tide and turbidity influence laser water penetration. On land, it depends on the height of the tide. In all cases weather is a key factor. This includes high-pressure, no rain, and light wind (<15 knots). The best weather period seemed to be summer, although the month of July and August were avoided since there is considerable boating activity in the Gulf.

MBES surveys already existed in the navigation channels, which have the deepest waters of the Gulf. As such, the strategy was to cover the unsurveyed areas rather than to penetrate deep water again. The topographic laser mode was used at low water and bathymetric laser mode at high water at springs.

Turbidity is primarily caused by three factors: chlorophyll content, organic materials content and suspended sediments. The best periods for minimising the chlorophyll and organic materials are summer and winter. The optimal period for sediments is the less turbulent current periods (e.g., slack water at neap tides).

The general strategy was:

- Bathymetric surveys were carried out during slack water at high water springs. Turbidity is not optimal but is lower at slack tide. Deep water depths cannot be reached with LIDAR, but MBES surveys can fill in these gaps.
- Topographic surveys were carried out during slack water at low tide.
- Flights took place during night and day in order to obtain the best laser measurements (i.e., no sun interferences), and not to waste slack water periods.

**2.4 Flight logistics**

Flight tracks were oriented perpendicular to tidal current direction into the Gulf and followed the slack water. There is a tidal model of the Gulf with 143 tide harmonics every 200m (Lucia Pineau-Guillou, 2005). It was used to get predicted tide information all along entire tracks, and to follow the tide with the aircraft in real time (Figure 2).

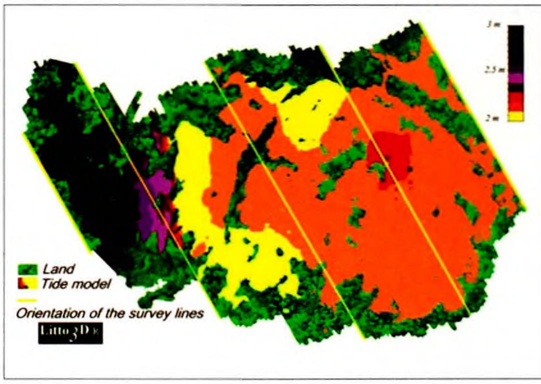



*Figure 2: Evolution of tide height along flight tracks (heights in metres).*

Ten percent of the tracks were flown perpendicular to regular survey tracks allowing error detection and S-44 qualification.

**2.5 Quality insurance**

Throughout the survey, quality insurance has taken into account the different aspects:

- The results of the laser calibration was controlled in static mode and on the fly;
- Ground Control Point and levelling data were used during the data post processing;
- Tide monitoring operated by SHOM allowed flight plan modification in real-time and is used for levelling laser data to the lower astronomical tide level.

Each day, environmental information, geometric calibration measurements and laser data were downloaded to a ground control system (GCS). GCS includes a signal processor to discriminate sea or land surface and sea bottom from the different signals. It contains automatic algorithms that calculate the exact location of laser signal from GPS and inertial attitude data X Y Z and a confidence interval is given for each measurement.

Doubtful signals are underlined and submitted to manual inspection. Some video camera information was helpful for eliminating artefacts in the signals (e.g., birds, boats and breakers on shore).

At the end of the process, data was converted into XYZ format and related to RGF93 datum. The same tidal model used for the previous flight plan was re-used in order to convert laser data into depths. For the first stage, depths were referenced to lowest astronomical tides (LAT), then to chart datum (CD) and finally to land survey datum (IGN69). The tidal model makes this possible as it contains difference models between all these vertical references (Fig. 3).

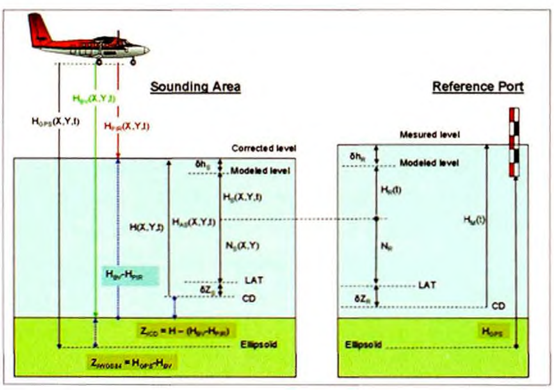



*Figure 3: Propagation of tide observations at depth sounding area throughout model application.*

Laser data were compared to land surveys (e.g., laser and GPS levelling) and MBES surveys. Data were merged in accordance with the different accuracy and uncertainty of these different surveys. Many methods could be applied: GIS methods or geo-statistical criteria; CUBE (Brian Calder, 2003) algorithms for instance.

### 2.6 Products

If hazards to navigation were detected during the laser survey, they were automatically reported to SHOM and issued as Notice to Mariners.

The results acquired within this demonstration allow SHOM and IGN to have a good idea of the feasibility, the costs and the real utility of laser systems. Results may be extrapolated to other metropolitan parts within the Litto3D project.

Validated data will be stored in SHOM and IGN databases for general public use. Most likely, the first customer of these data will be the different littoral agents of the Golfe du Morbihan and the SHOM cartographers. As soon as these basic products will be distributed, many modern and accurate by-products could be produced (Figure 4).

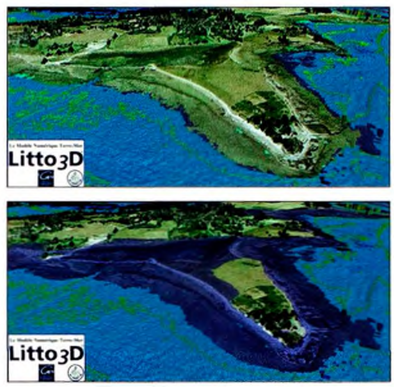



*Figure 4: Sea flood scenario. On left the tide at the mean sea level. On right the dark blue is the sea at high water during spring tide with 1m more due to flood conditions.*

## 3 Some Experiences

### 3.1 Should we fly at high or low tide?

A critical issue of the bathymetric laser is its ability to provide precise measurements in very shallow water. The measurement of depths between 0 to 1m is problematic due to the difficulties in distinguishing the surface from the seafloor. A strategy had to be found to avoid this blind area. The purpose was not to measure the very deep bottom but to have a seamless digital model between the land and the sea with many overlapping areas. Two flights were organised: bathymetric laser at high tide and topographic laser at low tide. This strategy has the advantages of having high precision measurements of the intertidal area and overlapping with the bathymetric measurements providing quality control.

### 3.2 Should the multi-beam survey be done before or after the bathymetric laser survey?

In the Morbihan Gulf, a multi-beam survey was first conducted in order to have a flat area well-described to be used as a depth check (ground truth). In hind-

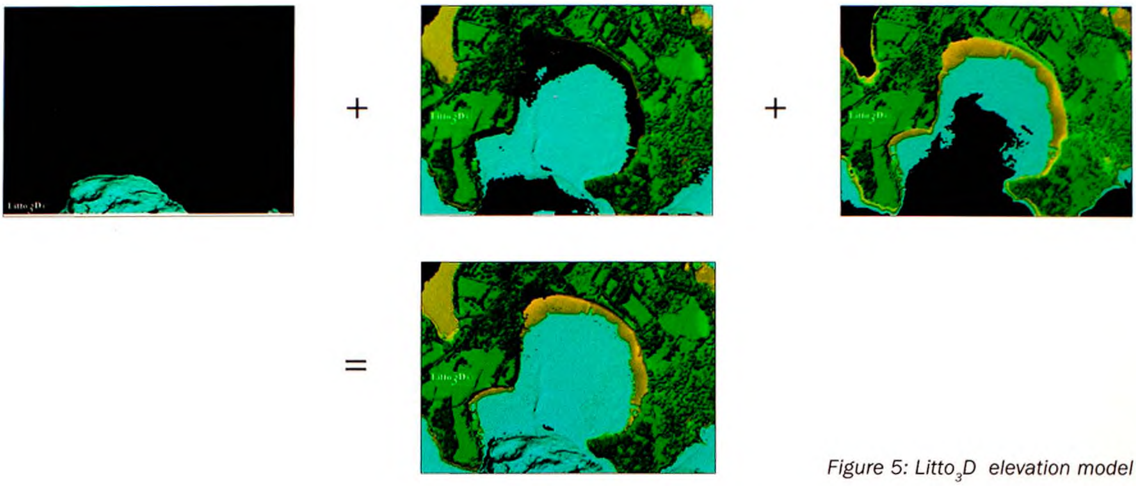


Figure 5: Litto$_3$D elevation model

sight, it seems that it might have been better to do the multi-beam survey after the bathymetric laser survey. At the end of the bathymetric laser survey, some areas (Figure 6) were not detected (i.e., too deep, too turbid, boats, etc.). Thus, the strategy would have been better to conduct first the multi-beam survey of the calibration (control) areas, then the bathymetric laser survey and finally the multi-beam survey of the areas not covered by the laser. In addition it will be more efficient for the hydrographer if the dangerous areas were known prior to the ship survey as the shallow water limits will be well-delimited. In this manner, one has the capability to survey the entire area with fewer risks.

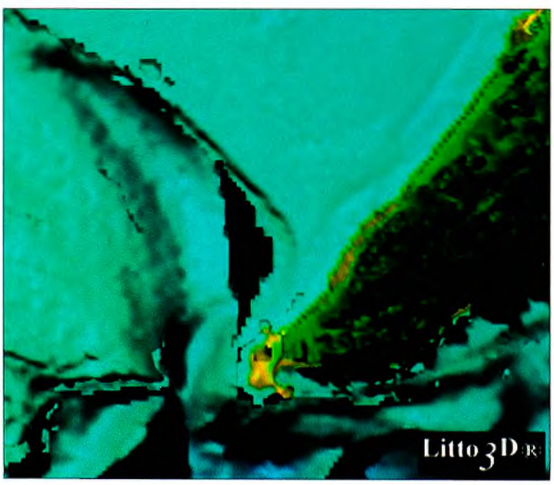


Figure 6: Areas not detected between the bathymetric laser and the MBES survey.

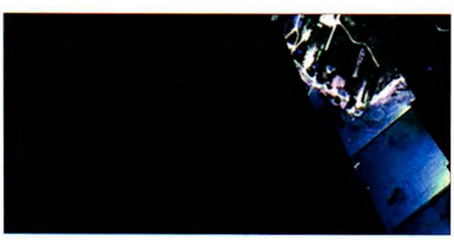
### 3.3 Should we fly by day or by night?

In the Morbihan Gulf, the flights were conducted during both day and night time. This gave more time to do the survey and when the weather was fine the survey could advance very quickly. Although it is well known that laser performs best during the night, the cost is high due to the necessity of having two teams. In addition, when you are flying during the night, you have no photo of the ground. Consequently, it is difficult to choose the valid data and to reject the errors or the artificial objects such as boats. This is especially true in the Morbihan Gulf where there can be more than 6000 anchored boats.

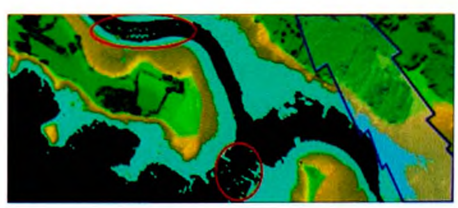
### 3.4 What about the turbidity?

The water in the Morbihan Gulf is very turbid. Many areas are very shallow, but it is tide, river interferences, and human activities that primarily increase the turbidity. As such, the timing of the survey is very important. It is better not to work at spring

Figure 7: The utility of photos to validate data.



Photos (by day), No photo (by night).



In the red circle, spots to be accepted or rejected.

tide. The turbidity increases considerably after bad weather (e.g., due to rain showers and wind). It is also essential to communicate with the sea users. During the survey in the Morbihan Gulf, the fishermen obtained permission to drag for clams. As such it was impossible to find the bottom of the sea in this disturbed area. The programme was communicated to the official administrations but not to the fishermen's associations. Next time the purpose of the survey will be explained to everyone beforehand.

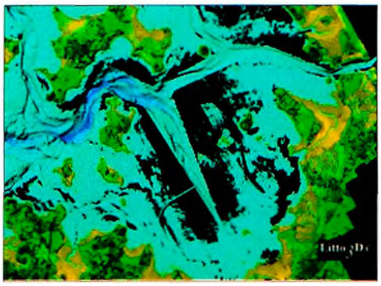
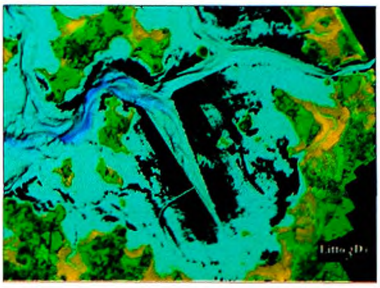


*Figure 8: Turbidity means no data.*



*Less turbidity some days after.*

*Turbidity due to the dragging for clams.*

## 4 Summary

The survey of the Golfe du Morbihan demonstrates the capability of a bathymetric laser survey to improve the knowledge of the littoral. It also provides a means to accelerate the cartographic process, in addition to MBES surveys. With a combination of multi-beam, bathymetric and topographic laser, it is possible to generate a seamless sea/land coastal digital model. A recommendation has been written and will be useful for people who wish to realise such a survey. This experiment enabled SHOM and IGN to develop a methodology applicable everywhere and by everyone.

Within the Litto$_3$D project, coastal managers will obtain more rapidly a detailed and accurate description of the coast: the project has provided dense, precise data everywhere at low cost, open to everybody and fully shared.

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## Biographies of the Authors

**Yves Pastol** is an hydrographer of the French navy (SHOM). He surveyed the north of France, West Indies, Indian Ocean and New Caledonia for 10 years. In 1992, he was in charge of the geodetic office of SHOM and managed hydrographic databases. Since 2003, he is tasked for littoral studies and assists the project manager Litto$_3$D.

**Catherine Le Roux** started her career at SHOM in Toulouse at the operational military centre. She was in charge of the spatial oceanographic real-time products. After five years, she returned to Brest and was in charge of the standard oceanographic products for the Navy. Since one year, Catherine is Litto$_3$D project manager.

**Laurent Louvart** is graduated in computer sciences, developed a specific digitalisation system for survey sheets based on OCR recognition and designed hydrographic databases. In the last 90s, he became an hydrographer of the Navy and surveyed New-Caledonia lagoons, Indian Ocean and Arabic Sea. He started Litto$_3$D project and some other projects in remote sensing thematics (Coastchart with ESA). Since 2005 he is the head manager of the geodetic-geophysics office of SHOM.

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