

A Framework for the Uptake of Satellite Derived Bathymetric Data Services in Coastal Zone Management

A. Houghton†, R. Whitehouse‡, C. Calcoen‡ and F. Wouters∞

†HR Wallingford Ltd
Howbery Park, Wallingford
Oxon, OX108BA, UK

a.houghton@hrwallingford.co.uk
r.whitehouse@hrwallingford.co.uk

‡ ARGOSS
Geomatics Business Park
Vollenhove, Holland

calkoen@argoss.nl

∞ Geoserve
Geomatics Business Park
Vollenhove, Holland

wouters@geoserve.nl



ABSTRACT

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The uptake of novel coastal management tools is often restricted by a lack of interaction between service providers who develop the techniques and Market Player organisations providing services to end users. HR Wallingford (UK), ARGOSS (NL) and Geoserve (NL) have undertaken a collaborative study to determine how an Earth Observation based bathymetric charting technique could be integrated into existing coastal engineering and management services, thereby providing added value to end users. During the initial phase of the study a number of trial cases were carried out to identify sectors of the Coastal Zone Management market where the Special purpose Large Area Bathymetry (SLAB) service could be used in favour of traditional bathymetric charts or surveys. The performance of the SLAB service was evaluated against a set of predetermined demand criteria and although a range of potential applications were identified, there were also a number of blockages that would prevent commercial uptake of the service. To combat these blockages, a Value Adding Market Player Integrated Information Service (VAMPIIS) supply chain has been defined comprising Geoserve and ARGOSS as service providers and HR Wallingford as Market Players. The framework of the supply chain will facilitate delivery of a range of bathymetric products based on both Earth Observation and traditional techniques combined with data analysis and numerical modelling. Typical applications include long term assessment of seabed and sandbank mobility for the marine construction industry, coastal impact studies, navigation risk assessments and wave/current transformation studies.

ADDITIONAL INDEX WORDS: *Synthetic Aperture Radar, Integrated Supply Chain, Seabed morphology*

INTRODUCTION

Ready access to coastal bathymetric datasets is essential for many aspects of coastal zone development management and monitoring. Bathymetric data is generally obtained from hydrographic charts, which can be obtained at low cost for the majority of coastal regions throughout the world. However, those areas that are not heavily navigated are not frequently resurveyed and consequently the detailed bathymetry may be significantly different to that displayed on the chart. Up to date information can be obtained by commissioning a ship borne survey for the precise area of interest. Modern survey techniques can provide highly detailed and accurate information; however, ship borne surveys are expensive and can be affected by inclement weather.

The potential for using satellite remote sensing techniques for measuring bathymetry has been investigated over a number of years (HR WALLINGFORD, 1999). GAGLIARDINI *et al.*, (2005) found that the information derived from Synthetic Aperture Radar (SAR) could be useful as a complement to classical acoustic morphology studies of the seabed. An approach to charting the bathymetry of shallow seas has been developed by ARGOSS called the Bathymetric Assessment System (BAS). This aims to provide up-to-date information that can be delivered more quickly, routinely and cheaply than ship borne surveys (CALKOEN *et al.*, 2001).

However, the uptake of novel monitoring and measuring tools within the Coastal Zone Management market can be restricted by the lack of a clear integrated supply chain clarifying the relationships between service providers who develop the techniques and Market Player organisations providing services to end users. As a result, blockages to wider uptake of a proposed tool or service may not be adequately addressed, thus preventing the realisation of its full potential. In order to address these issues, HR WALLINGFORD (UK), ARGOSS (NL) and GEOSERVE (NL) have undertaken a collaborative demonstration study to determine how the Earth Observation based bathymetric charting technique developed by ARGOSS could be integrated into existing coastal engineering and management services, thereby providing added value to end users. This paper is written from the point of view of an end user of Earth Observation services and the approach described can be applied in a generic fashion to other supply chains. The science and the modelling to produce specific BAS products has been described previously (CALKOEN *et al.*, 2001).

METHODOLOGY

This section describes briefly the BAS technology and the criteria by which market applications and performance were gauged.

Bathymetric assessment system

Under normal meteorological and hydrodynamic conditions, Synthetic Aperture Radar (SAR) imagery can be used to map seabed bathymetry. Interactions between currents and seabed topography produce surface current velocity modulations, which cause variations in the surface wave spectrum. These in turn produce modulations in the measured radar back-scatter from which depths are interpolated through inversion techniques. To derive depth data from SAR imagery, wind speeds of $3\text{--}9\text{ms}^{-1}$ and current speeds of at least 0.5ms^{-1} are required in order to detect current velocity modulations. A schematic representation of this technique is shown in Figure 1 below and more details of the method are given in CALKOEN *et al.*, (2001).

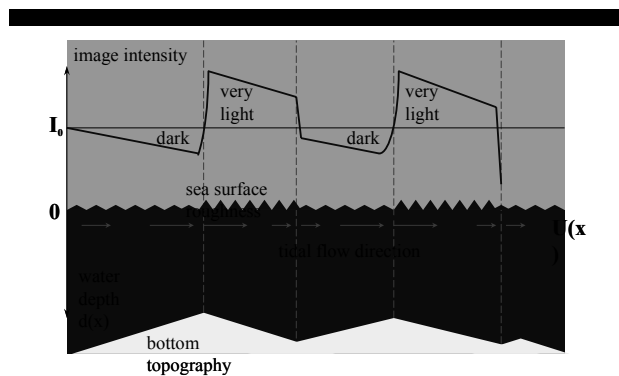


Figure 1. Extrapolation of bottom topography using SAR imagery

Components of the Bathymetric Assessment System

The Bathymetric Assessment System (BAS) comprises a suite of numerical models for calculating the effect on the SAR images of currents modulated by the topography of the seabed. These models are described below.

A current model is employed, which solves the conservation of mass equation together with the two dimensional shallow water hydrodynamic equations. These relate the depth averaged flow u , the surface wind stress t , the reference height of the water h , the local elevation of the water z , relative to the reference height and the Coriolis force, density, gravity and bottom roughness. This system determines the perturbation imposed on the current by the bathymetry.

- The *action balance equation* is used for determining the effect of the perturbation currents in modifying the structure of the sea surface.
- A *backscatter model* is applied relating the modified surface roughness to the observed SAR image. At the present time, there are two mechanisms incorporated within the model:
 - A *Bragg scattering mechanism* for the short wave part of the surface wave spectrum.

- A *long wave contribution* where the water surface is tilted and thus the effective radar incidence angle is modified.

The data assimilation scheme within the BAS aims to select the free parameters of the problem, all related via the models described previously, such that the closest possible correlation between model and measurements is achieved. The following data are assimilated into the Bathymetric Assessment System:

- Tidal data relating to the acquisition time of the SAR image.
- Wind speed and direction relating to the acquisition time of the SAR image.
- Echo sounding data along calibration tracks to allow tuning of the Bathymetric Assessment System.
- SAR imagery of the area of interest.

The BAS is used to produce the so called Special purpose Large Area Bathymetry (SLAB) charts which are delivered to end users through the SLAB Service.

Market Assessment

In order to establish a target market for the service, the customer information requirements for each sector of the Coastal Zone Management market were analysed. Much of this information was obtained from the COASTDRIVE project (HR WALLINGFORD, 2003). As the service can only be provided to those sectors that require bathymetric data, an initial 'yes, no' classification identified six potential markets. These are listed below:

- ♦ Industry
- ♦ Construction
- ♦ Coastal defence
- ♦ Transport
- ♦ Defence
- ♦ Dredging and extraction

These market segments were then subject to a more detailed analysis in order to identify potential customers and to determine their specific requirements for bathymetric data. As anticipated, the customers within each market segment demonstrate a wide variety of working practices and this is reflected in their demands for information.

Performance Evaluation

In order to evaluate the performance of the SLAB service, trial cases were carried out (HOUGHTON *et al.*, 2004). These served not only to identify potential applications for the service but also to assess how well the BAS system performed compared to traditional data sources. The SLAB charts were to provide the bathymetric data input to each trial case and a quality assessment was completed for each application. In addition to the data evaluation, the performance of the supply chain was assessed. This focussed primarily on how well the customer information demands were met but also highlighted any advantages or disadvantages of the SLAB charts compared to other data sources. Both evaluations were based on a set of predefined demand criteria (DYER and MILLARD, 2002) that are described in Table 1. The results were used to identify potential blockages to commercial uptake and to highlight other potential applications for the service.

Demand Criteria	Description
CONTRIBUTION	<i>What impact the data have on solving the problem.</i> Fundamentally the data must contain the required parameter that is complete and accurate to be of value. This is clear for single variables, but has more meaning when applied to groups of data.
LOCATION	<i>Where the measurements have been taken and at what time.</i> The spatial and temporal distributions of the data are critical as most data are required for a particular site and/or time frame.
PRICE	<i>Where the measurements have been taken and at what time</i> The spatial and temporal distributions of the data are critical as most data are required for a particular site and/or time frame.
ATTRIBUTES	<i>Fitness for purpose.</i> This covers a number of factors concerning the data such as accuracy, precision and spatial and temporal resolution. In addition, it also embraces quality control parameters such as metadata and the tracability of processing applied to the data.
DELIVERY	<i>Can the data be supplied in time.</i> Delivery is important in time critical applications. This is particularly the case in emergency operations such as monitoring oil spills. This may also encompass the continuity issues of data.
USABILITY	<i>How easy is it to use the data</i> This covers such factors as the ease of visual presentation or ease of extraction to provide input to a model. Clearly, the demand will be greater for data that can be readily consumed by the customer.

Table 1. Description of the Demand Criteria

TRIAL CASES

Two trial cases were completed to evaluate the performance of the product within the supply chain.

Trial Case 1. Brass River Morphology Study

The objective of this trial case was to undertake a seabed morphology assessment at the mouth of the Brass River in Nigeria. The most recent UK Admiralty survey for this area was carried out in 1904 but additional survey data collected during 2003 was made available for evaluation purposes. The following SLAB charts were requested for the study:

- February and December, 2003 – to assess annual seabed variability
- March/April 2003 – to investigate seasonal variations induced by river outflow during the wet season.

The products delivered comprised:

- 1 SAR image (1995)
- SLAB chart showing seabed elevation of Brass River mouth derived from SAR image.

In order to evaluate the SLAB chart, a comparison was made between this (1995 data) and both the 1904 and 2003 data as shown in Figure 2.

Summary of Trial Case 1 Evaluation

The SLAB chart supplied provided bathymetric data for the Brass River entrance that was comparable in format with the Admiralty Chart and sounding data. It was possible to use this data to carry out a seabed morphology assessment. However, SLAB charts were not provided for the dates originally specified due to a lack of available SAR images. It was therefore not possible to assess annual or seasonal seabed variability. The metadata supplied did not contain any information on resolution or accuracy as had been requested. Additionally, the data files supplied were not easy to manipulate. The data was easily imported into a numerical model but not into a GIS. Finally, the data was not delivered within the required time frame due to problems with image acquisitions and modifications to the model to account for low current speeds at the site.

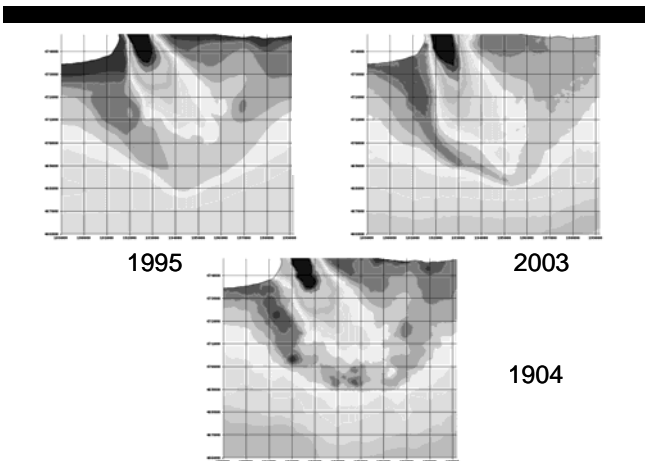


Figure 2. Comparison of SLAB chart of Brass River with measured data

Trial Case 2 – Thames Estuary Integrated Flood Risk Assessment

The objective of this study was to assess the feasibility of using a SLAB chart as input bathymetric data for a morphological assessment that will form part of a flood risk assessment. The following data was requested:

- One morphology map covering a 20km by 20km area of the Thames Estuary in the UK.
- One accuracy map covering a 10km by 10km area of the Thames Estuary.

The time frame for the data required was between 1987 and 2005 and the most appropriate SAR images were obtained from 2002. In order to create the accuracy map, some calibration data was required for ground truthing and some lines of echo sounding data collected during 2004 was provided for this purpose.

In order to evaluate the 10x10km precision SLAB chart, the data was compared to a detailed set of sounding data from the area of interest.

Summary of Trial Case 2 Evaluation

The SLAB data supplied appeared to provide a plausible bathymetric dataset for the specified area of the Thames Estuary. However, the BAS method had a tendency to smooth the amplitude of bed features (sandbanks) resulting in an unrealistic representation of slope gradients. Whilst this was not a major issue in this particular study, it did restrict the accuracy of the data provided and highlight the need for an enhancement of the BAS system for similar applications. The data was supplied as requested in the study brief and within the specified time frame, following provision of the calibration data. The issues raised during Trial Case 1 relating to the usability of the data were resolved and the data was easily imported into a numerical model and a GIS. The cost of producing a morphology chart and accuracy chart is around €15,000 (at 2006 prices). This is likely to be prohibitively high for a study of this nature unless no other suitable data is available, but does have the advantage of a wide area coverage.

Overall Summary of SLAB Performance

From the Trial Cases, the following summary of performance was made:

Strengths

The SLAB charts provide bathymetric data which is both easy to manipulate and can be readily imported in to other applications. Although the SLAB data was provided for the correct locations in both Trial Cases, it was difficult to determine whether hydrodynamic conditions at other sites were suitable to generate SLAB charts. This has since been rectified through the creation of a tool that allows potential users to see immediately whether SLAB products can be obtained for their area of interest. The main strength of the SLAB charts is the potential to provide a broad overview of the seabed in cases where no survey data is available and existing hydrographic charts are outdated.

Weaknesses

Throughout the trial cases there was some uncertainty as to the cost of the various SLAB charts. The overall cost of the products comprises image acquisition, processing and modelling and is therefore not standard. However, for many bespoke applications, the cost of the charts would prove too high for the service to be commercially viable. The problems with delivery encountered during Trial Case 1 were largely resolved but issues such as image acquisition meant this was still a potential blockage to commercial uptake of the service. Also, some conventional survey data is required to produce accuracy maps. It was not possible to fully evaluate the accuracy of the charts as neither of the SAR images used to create the charts corresponded temporally with the available survey data. Based on the tool developed by ARGOSS to indicate locations where SLAB charts can be produced, there are areas worldwide which do not have suitable hydrodynamic conditions to permit the use of this service.

Establishment of the Integrated Service Chain

Following the trial cases and performance evaluation, it was clear that although in certain cases, the SLAB charts could provide a viable alternative to other sources of bathymetric data, there

were a number of blockages that would severely limit or even prevent sustainable commercial uptake of the service. It was found that several of these blockages related to the delivery of the service rather than the technical capabilities of the products offered. In order to combat these issues, an integrated supply chain (ISC) was defined that combined the expertise of the Market Player (e.g. HR WALLINGFORD) with that of the data providers (e.g. ARGOSS and GEOSERVE) to deliver value adding services to end users in the coastal zone management market. The ISC is presented schematically in Figure 4.

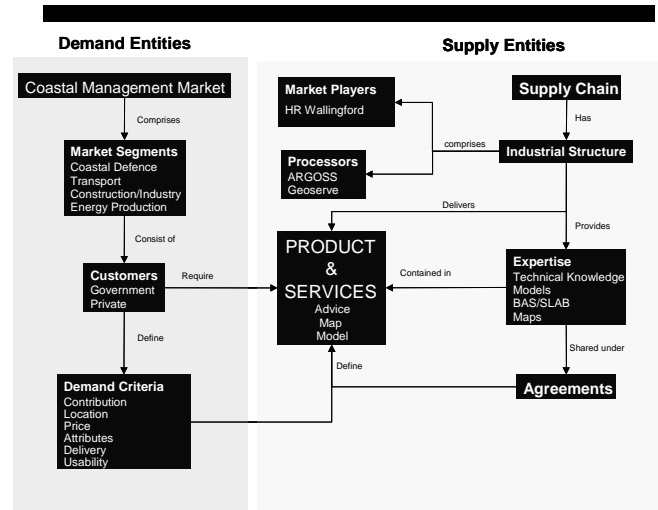


Figure 4. Overview of the Integrated Service Chain

The ISC has been designed around the Five Principles of Information Management developed by the London School of Economics in conjunction with HR WALLINGFORD (DYER and MILLARD, 2002). The five principles are intended to serve as guidelines for information management. By bringing together the high-level internal policy issues and the operational levels of any business, the principles provide a framework within which managers can develop detailed operational procedures. Essentially, supply and demand linkages exist between the various members of the ISC and the five principles represent the operational procedures needed to manage these supply and demand activities. The Five Principles of Information Management are listed below:

1. Recognise and understand all types of information
2. Understand the legal issues and define the roles and responsibilities
3. Identify and specify business processes and procedures
4. Identify enabling technologies to support business processes and procedures
5. Monitor and audit the performance of the ISC.

The benefits of formalising such a supply chain led, in this instance to the creation of a Value Adding Market Player Integrated Information Service (VAMPIIS), which has started to operate as follows:

Requests for a coastal engineering or management service will arrive at the Market Player (HR WALLINGFORD), who will determine the nature of the bathymetric data required and then submit a data request to the data providers (GEOSERVE and

ARGOSS). GEOSERVE will check the availability of any satellite data whilst ARGOSS will verify the feasibility of the proposed activity. Following confirmation of the order and funding with HR WALLINGFORD, a SLAB chart will be produced and supplied. The chart will then be used to complete the application and the end user product delivered to the client accordingly. The information flow through the supply chain is presented in Figure 5.

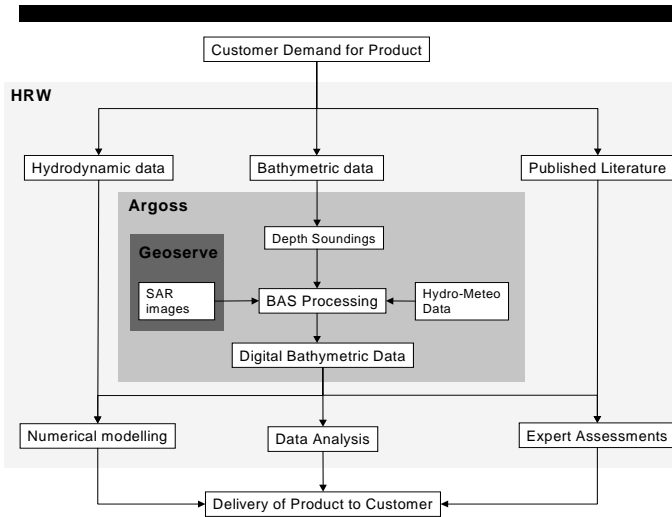


Figure 5 VAMPIIS information flow

In addition to the creation of the VAMPIIS, it was necessary to address the limitations of the SLAB charts themselves. It was concluded that the VAMPIIS could not provide a viable commercial service based solely on SLAB charts derived through the BAS. Therefore the VAMPIIS will offer a range of standard and bespoke products to satisfy end user demands. Given the reluctance to rely solely upon satellite image availability, the products offered will be based on the following data sources:

- Digitised Admiralty Chart (DAC)
- Gridded Admiralty Chart (GAC)
- Gridded Enhanced Admiralty Chart – GAC extended with satellite data (GEAC)
- BAS Chart + Survey lines (BASC)
- Full Survey – Note, the availability of this service component will depend on the availability of existing information or the client commissioning a dedicated survey.

The demand criteria described in Table 1 are used to evaluate which products are required.

CONCLUSIONS

This study has shown how a method for providing bathymetric data based on satellite imagery can be incorporated into the existing services of Market Player organisations. Through a series of pre-commercial trials, the strengths and weaknesses of the product and supply chain were identified. It was concluded that although potentially useful in certain applications, the SLAB charts alone would not provide a commercially viable alternative to traditional sources of bathymetric data. To combat these blockages, an integrated service with the acronym VAMPIIS has

been created that will deliver a range of products based on both satellite based and non satellite based bathymetric data. The target market for this data will be the Coastal Zone Management sector whilst typical applications include long term assessment of seabed and sandbank mobility, coastal impact studies, wave/current transformation studies and navigation risk assessments. It should be noted however that the SLAB charts should not be used for navigational purposes.

Although this study focussed on a particular data source (namely bathymetric data derived from satellite images), the generic framework used to facilitate collaboration between data providers and market player organisations could be applied to other coastal management tools. It is anticipated that by developing integrated services of this kind, some of the difficulties faced by the developers of new coastal management techniques may be resolved whilst Market Player organisations are able to enhance their existing capabilities, thereby providing added value to end users. Additionally, interoperability between organisations providing services to the Coastal Zone Management market is of paramount importance to the future success of sustainable coastal development.

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