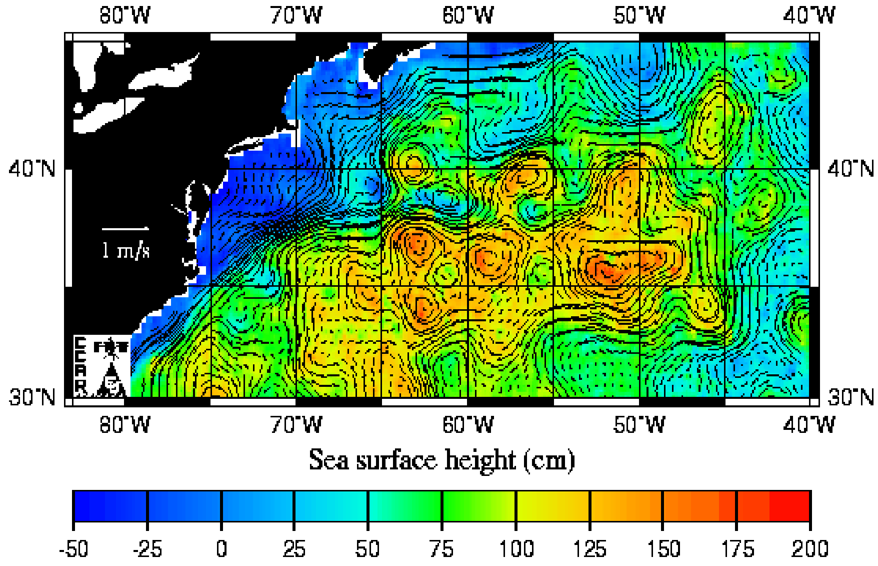
BNSC Service Mission Support (SMS) Programme

Ocean Currents from space



Report for WP4: Systems vs. requirements, product delivery approach and outline business plan.

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Executive summary

The project “Ocean Currents from Space” has been carried out under the BNSC Service Mission Support programme. The first phase of the project consisted of an assessment of user requirements for information on ocean currents, both from the point of view of commercial marine operators and of the research community. The second phase consisted of a technical evaluation of various existing or proposed satellite systems that measure, or have the potential to measure, ocean currents. The final phase of the project contained three parts that are reported here.

Part 1, Matching systems to requirements, summarises the user requirements and candidate systems before selecting which systems are suitable .for meeting the requirements. As a result there are four recommendations for further investigation, as follows:

- Cheaper altimeters. The possibility of increasing altimeter coverage by launching additional but cheaper altimeters should be investigated. Technical development is required to ascertain which instrumentation can be discarded while still providing the measurement accuracy of conventional altimeters.
- GPS reflectometry. There is much technical development to be done, but the attractiveness of a very low-cost system means it is worth pursuing this as a means of ocean height measurements as well as sea state.
- RAR ATI (Along-Track Interferometry of Real Aperture Radars). This is the most attractive new concept for measuring global currents and further investigation into this technique is the primary recommendation of this study. In addition to current measurements, a RAR system could provide wind information to supplement existing and planned scatterometer missions.
- SST (Sea Surface Temperature) exploitation. Further development in the use of SST measurements for retrieving currents and their combination with altimeter measurements is recommended. The possibility of using a geostationary SST system, giving frequent updates in shelf sea areas, should also be investigated.

Part 2 develops a product delivery approach for information products derived from the ocean currents measurement system, segregating the supply chain into different stages. Part 3 develops an outline business case, looking at the market for currents information (in both the commercial and public sector) and expanding the product delivery approach into an outline business model. The key indication here is that envisaged commercial and public revenues from the sale of ocean currents information are not sufficient by themselves to fund a satellite measurement system. However, a significant amount of business activity would be generated at the product delivery stage provided it is not impeded by up-front data costs.

Finally, part 4 reiterates the project conclusions and recommendations and gives plans for exploitation. This and other reports generated during the project have been made available on the web at http://www.satobsys.co.uk/Projects/OceCurr/.

Part 1 - Matching systems to requirements

1. Introduction

The first part of WP4 brings together the findings of WP2 (user requirements) and WP3 (technical evaluation of candidate systems) in order to make recommendations as to which systems are likely to best meet user requirements both now and in the future. Section 2 summarises user requirements, section 3 summarises candidate systems and section 4 makes a selection of candidate systems according to user requirements.

2. Summary of user requirements

Operational requirements

In WP2, operational requirements for information on ocean currents were studied by industry sector, focusing on the following:

- Offshore oil and gas
- Shipping
- Fishing
- Search and rescue
- Leisure
- Naval
- Cable laying

The work consisted of a mixture of direct contact with end users and a review of previous studies and reports that have looked in some way at the requirements for information on currents in marine operations. The overall findings can be summarised by the following table:

Industry	**General requirements**	**Spatial resolution**	**Temporal resolution**	**Max delivery time**
Offshore oil / gas operations: Design:	Local current profiles Statistics	2-10 km 2-4 km	<1-3 hours 1-6 months	<1-6 hours 3-6 months
Shipping	Surface currents along route	10 km	1 day – 1 month	1-7 days
Fishing	Surface / coastal currents	1-12 km	1 day (hourly for tidal)	1 day (hourly for tidal)
Search and rescue	High resolution Surface currents	1 km	< 1 hour	< 1 hour
Leisure	Tidal currents, offshore currents for racing	1-10 km	1 day (hourly for tidal)	1 day (hourly for tidal)

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Naval	Surface and subsurface currents	1-10 km	6 hours – few days (hourly for tidal)	hours - days
Cable laying	Surface and subsurface current forecasts	1-10 km	6 hours – few days	hours - days

Table 1 – Summary of operational requirements for information on ocean currents.

In all cases an accuracy of 10 cm/s (and 20 degrees in direction) is required although this can be relaxed slightly for shipping operations.

It is clear that marine operations have a broad range of requirements for information on ocean currents ranging from the stringent requirements for search and rescue (1km resolution information at least hourly) to more relaxed requirements for shipping (10km resolution, daily - weekly updates). Where a range of requirements are specified, the larger figure can be considered the minimum requirements for information to be useful and the smaller figure the ideal requirements. There is some consensus on the spatial resolution in that between 1 and 10km is suitable for all operations, but distinct differences in the update requirements. The reason for this is largely the area of application. If operations are being carried out in tidal regions then currents will be changing on an hourly basis so information needs to be provided that often. Offshore operations, undertaken by shipping and oil and gas industries, are much more susceptible to ocean current systems, which change more slowly over periods of days. Operational requirements can therefore be split into two categories, nearshore and offshore, and this same distinction is found in the research requirements.

Research requirements

The requirements for measurements of ocean currents in scientific research were broken down into four areas as follows:

- Ocean circulation and climate
- Coastal processes
- Shelf sea processes
- Short-term forecasting

The material was compiled by experienced oceanography researchers at the Southampton Oceanographic Centre and Proudman Oceanographic Laboratory.

Ocean circulation and climate

The large-scale ocean circulation is fundamental to Earth's heat budget and climate variability. It is therefore a hot research topic in the present drive to understand climate change more fully. In the open ocean currents are quasi-geostrophic with an additional wind-driven component at the surface. Spatial scales vary from 10-100km in the western-boundary and equatorial currents to 50-200km for the mesoscale eddy activity that represents 98% of oceanic kinetic energy.

Research is based primarily on numerical models that are run at resolutions down to 1/12 or 1/16 degree, sub grid-scale processes are parameterised. Satellite and *in situ* measurements (such as SSH, winds, temperature, salinity) are assimilated during the model run. The requirements for currents data are both for assimilation purposes and validation of model output. Measurements to 0.1m/s are required at a spatial resolution of 50km, and with updates at least every 2 days.

Coastal processes

Coastal processes refer to the near-shore region with a water depth less than 10m. This is an area with direct relevance to society through the impact of erosion, flooding and pollution. It is also the home of extensive leisure and other marine activities. *In situ* instrumentation is largely used for research, but because of the hostile environment the lifetime is short, and there is a strong interest in the use of remote sensing techniques. Spatial coverage of 10s of km is required over periods of months to years. There is a requirement for high spatial and temporal resolution of the order of 10m and 10 minutes respectively. An accuracy of 0.1m/s is sufficient, but ideally full 3D currents are required, something unlikely to be achievable through remote sensing.

Shelf seas

The shelf seas lie between the open ocean and the near-shore area, typically extending of the order of 100km offshore. This region is characterised by complex physical processes on shorter time and space scales than the open ocean. Tides, bottom effects, freshwater input and shelf-edge processes all contribute to the velocity field, which is generally not geostrophic. Research in this area is carried out through a wide range of numerical models run at centres around Europe. Requirements for current measurements are mainly for validation of these models. There are also likely to be assimilation requirements, though lack of data to date means this is difficult to assess. Measurements on spatial scales of 1km every 2 hours are required over the shelf seas region.

Short-term ocean forecasting

Ocean forecasting has a strong link to operational requirements as forecast models are developed at research institutes and meteorological agencies for the benefit of operational users. The models are based on the ocean component of coupled ocean-atmosphere models and are typically run at 1-degree resolution with higher resolution in shelf-sea areas. Examples are the SOPRANE model run by the French Navy, and the FOAM model run by the UK Met Office, primarily for the Royal Navy. Data assimilation is carried out using all available datasets, so the principal requirement is for independent measurements for validation purposes. Spatial and temporal scale requirements are a mixture of those for ocean circulation and shelf-sea research according to the specific application of the forecast.

Summary

The following table summarises research requirements for information on ocean currents.

Category	General requirements	Measurement accuracy	Spatial resolution	Temporal resolution
Large scale circulation and climate	Global, synoptic 3D data for validating models	10 cm/s (5 cm/s for monthly averages)	50 km	2 days
Coastal processes	Measurements over 10s km	10 cm/s	10-100m	10 minutes

Shelf seas	Measurements over 100s km	10 cm/s	1km	2 hours
Short-term ocean forecasting	Combination of large-scale and shelf sea requirements depending on the specific application of the forecast			

Table 2 – Summary of research requirements for information on ocean currents.

Discussion

The distinction between research and operational requirements is blurred. It is often the needs of industry and public authorities that provides motivation for research, and conversely the output of research changes the requirements and expectations of industry. It is therefore sensible to lump together all the requirements summarised above into three categories according to the research requirements but linked to operational requirements through numerical modelling. The relationship between research topic, numerical modelling and operational applications is construed as follows:

Research category	**Modelling activity**	**Operational applications**
Ocean circulation and climate	Full ocean models run at high resolution for research (1/16 degree) and lower resolution for forecasting (1 degree).	Offshore operations, especially shipping and deeper oil and gas (not N Sea)
Shelf seas	Regional models developed at research institutes and run operationally at Met agencies.	General marine operations (not offshore), including N Sea oil and gas
Coastal processes	Specific modelling for local areas and statistical anlaysis, not for real-time information and forecasts.	Coastal engineering Pollution dispersion

Table 3 – Relationship between research category, modelling activity and operational applications.

Selection of systems in section 4 is based on the above three categories, which can be applied to all the requirements identified under WP2. Where there is a mismatch between the research and operational requirements under a category, numerical modelling will be able to resolve the differences. For example, the research requirement for ocean circulation is measurements at 50km resolution but offshore operations require *information* at a resolution of 10km. In most cases a numerical ocean model will be able to offer the high-resolution information required by operations with the reduced resolution input that satisfies research. In addition, the numerical models will be able to provide information about sub-surface currents that are required by some operations but that cannot be measured by satellites.

The relationship between research, modelling and operational requirements is discussed further in Part 2, Product delivery approach.

3. Summary of candidate systems

WP3 aimed to consider all systems, whatever their stage of development, which can or have the potential to measure ocean currents from satellites, either directly or indirectly. At the top level, there are two categories of instrument, active sensors and passive sensors.

Active sensors include the following:

- Radar altimeters and LIDARs – both nadir looking instruments giving sea surface height from which currents can be derived.
- Radars – real or synthetic aperture side-looking instruments which can be used for interferometry to give currents directly (in the case of along-track interferometry) or surface height variations (for cross-track interferometry).
- Parasitic radars – receiving reflected signals from other active satellites such as GPS.

Passive sensors include thermal and colour imagers, normally operating at infrared and visible wavelengths.

Radar Altimeters

The radar altimeter is an instrument first demonstrated in space by the Seasat mission in 1978. It makes an accurate measurement of the propagation delay between the satellite and the sea surface, which is translated to a sea surface height (SSH) once the satellite position and propagation velocity through the atmosphere are determined. The difference between the SSH and the geoid is the result of ocean pressure systems and associated geostrophic currents, so where the geoid is known altimetry can be used to retrieve these currents. In practice the geoid is not known on small enough scales to give absolute currents, but this is likely to change over the next few years as a result of the dedicated gravity missions GRACE and GOCE. In any case, altimetry provides most of the available information on ocean currents at the moment and is especially useful for determining variations in currents. There are presently five satellite altimeters operating, which improves on the coverage of a single, narrow-swath instrument.

Some novel altimeter concepts have been proposed in the last few years, aiming to increase the swath of the conventional altimeter. Radically new concepts are not likely to offer significant benefits compared to existing altimeters over the next 10 years, although smaller cheaper satellites with reduced functionality are now feasible.

LIDARs

LIDARs, for LIght Dectection And Ranging, are optical altimeters which have been used by the USA on a number of planetary missions. The advantages over a radar altimeter are a more compact instrument, no ionospheric effects and potentially better spatial resolution by scanning. Disadvantages are problems with refraction, safety issues, lack of European experience in the instrument and the requirement for cloud-free skies.

Radar interferometry

The technique of radar interferometry, when two images of the same scene are taken at slightly different times and / or from slightly different positions, can be used to infer currents directly or indirectly. Real and synthetic aperture radars are side-looking instruments that can cover swaths of 100s of km. The advantage of the synthetic aperture radar (SAR) is the high spatial resolution (10s of metres) at the expense of a high-powered expensive instrument. Two types of interferometry are possible, along-track interferometry (ATI) and across-track interferometry (XTI).

Along-track interferometry (ATI)

ATI is given by the phase difference between two images taken from the same position at slightly different times, corresponding to the scatterers' radial velocity. Because of the short time over which the ocean retains a consistent shape, the separation of satellites would need to be about 50m at X-band frequencies. SAR ATI has been demonstrated by aircraft and the principle has recently been demonstrated, fortuitously, using data from the recent SRTM Shuttle mission. There is much interest in the technique and it is expected there will be a dedicated space demonstration in the next few years. Theory suggests that ATI will measure radial velocities of the order of 0.1m/s at 100-400m resolution over 100-500km swath for SAR, and at 20km resolution over 500km swath for real aperture radar.

Across-track interferometry (XTI)

XTI is given by the phase difference between matched images from different across-track positions taken at the same time. This gives the terrain elevation over the swath width, and is a well-established technique for land applications. In the ocean, however, analysis indicates the height accuracy to be inadequate for geostrophic current calculations.

Parasitic radars

Parasitic radars are systems that rely on third-party transmissions, of which the most promising concept is the use of reflected GPS signals for altimetry. The theory is well developed, and with the number of GPS satellites in operation there is potential for good spatial coverage. The technique has been demonstrated once in space, from a shuttle mission in 2001, but there are several technical issues to be resolved if accurate ocean heights are to be retrieved in this way. More test measurements are planned by JPL and in the UK by SSTL, with an experiment on the BNSC Disaster Monitoring Satellite.

Passive sensors

The most useful passive sensor for ocean current applications is the radiometer, designed to measure sea surface temperature (SST). Passive imagers are, of course, very well established instruments and have the advantages of flexibility with regard to resolution and the ability to cover wide swaths. The major limitation of SST methods is the lack of measurements in the presence of cloud.

Four different methods are used for retrieving information on currents from SST measurements. The first, subjective feature tracking, is a manual method where the progress of distinct features is analysed from a sequence of images. An enhancement to this is the maximum cross-correlation method, a more automated and robust way of tracking features. The third method, inversion of the heat equation, uses the physics of heat flow by looking at temperature gradients and neglecting diffusion over short timescales. Finally, SST measurements can be combined with altimetry measurements to improve coverage and help resolve eddy features. Assimilation of SST into circulation models shows comparable results to the assimilation of sea surface height information, and improves the definition of major fronts.

4. Selection of systems

In this section, candidate systems are selected in terms of their suitability, or potential suitability of meeting user requirements. As discussed in section 2 and addressed in part 2 of this report, the requirements of marine operators are most likely to be met by the output of operational ocean models and the consequent generation of dedicated ocean current products. The systems will therefore be selected on the basis of research and modelling requirements.

Following the investigation of candidate systems summarised in section 3, the following systems will be considered as suitable or potentially suitable for measuring ocean currents from space:

1. Conventional large altimeters
2. Low-cost altimeters on small satellites
3. LIDARs
4. Along-track interferometry using synthetic aperture radar (SAR ATI)
5. Along-track interferometry using real aperture radar (RAR ATI)
6. GPS reflectometry
7. SST methods

The following table summarises the timescale for development, risk of development and approximate cost of development for these systems.

	Timescale	**Risk**	**Cost**
Conventional altimeters	5 altimeters flying at present. New build time 2 years.	No risk, fully mature technology.	Additional satellites ~100Meuro.
Small satellite altimeters	Constellation build time 2 years.	Fairly low risk, technology demonstrated but quality of measurements not certain.	Low cost, ~30Meuro first platform but cheaper subsequent build (e.g. 100Meuro for 6 satellites).
LIDARs	Significant development required, timescale ~10 years.	High risk, safety and technology issues to overcome.	High cost, ~200Meuro.
SAR ATI	Development required, timescale ~5 years.	Medium risk, technology has been demonstrated from aircraft, formation flying issues in space.	High cost, ~200Meuro for X-band SAR
RAR ATI	As for SAR ~5 years	As for SAR, medium risk, poor resolution may compromise applications (and maybe the fundamental principles?)	Low cost, ~50Meuro first platform, cheaper subsequent build.

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GPS reflectometry	Significant development required, timescale ~10 years	High risk as yet to be demonstrated. Very low signal strengths. The theory is there but technology not certain.	Very cheap. ~10Meuro first platform, decent constellation for ~50Meuro.
SST methods	Systems already in place, new build time 2 years.	No risk, fully mature technology.	Additional satellites ~100Meuro.

Table 4 – Summary of timescale for development, risk and cost for candidate systems.

The scene is now set for matching these systems to requirements. Table 5 presents suitable systems against each of the three requirement categories.

Requirement category	**Requirements**	**Suitable systems**
Ocean circulation and climate modelling / offshore operations	10 cm/s 50 km 2 days	Altimeters. Large altimeters already provide the best information on currents in the open ocean, and as our knowledge of the geoid improves over the next few years this will be an increasingly valuable source of information. In order to meet the full spatial and temporal resolution requirements, twenty altimeters are required.
		LIDARs. Provides same information as altimeters only much development required and does not work through cloud. Therefore not recommended.
		Radar ATI. Development is required and any system would have significant data processing requirements, but ATI makes a direct measurement of currents and due to the broad swath of the instrument the resolution requirements are met by a single formation of two satellites (for both SAR and RAR).
		GPS reflectometry. Potentially provides same information as altimetry but lower cost. Long-term solution as much development to be done.

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		SST methods. Provides useful information on ocean currents that complements altimetry, but does not work in the presence of cloud. Microwave SST methods were considered but are not able to offer the required measurement accuracy.
Shelf seas modelling / general marine operations	10 cm/s 1 km 2 hours	SAR ATI and SST methods meet the spatial resolution requirements, but meeting the temporal resolution would require several satellite systems at great cost[1]. Also SAR ATI has yet to be demonstrated using unmanned satellites. Long-range HF radar is the best solution for local areas.
Coastal processes / coastal engineering	10 cm/s 10-100m 10 minutes	Satellite methods are not suitable due to the requirements for spatial and temporal resolution. Land-based methods, such as HF radar, or airborne methods (such as ATI from aircraft) are the best options for remote sensing of currents on these scales.

Table 5 – Suitability of candidate systems to meet requirements.

As expected, due to the global nature of satellite observations, the satellite systems are most suited to ocean circulation and offshore requirements. In this category all potentially suitable candidate systems have been selected, though some are more viable than others on technical grounds. Recommendations on which of these systems merit further investigation are given in section 5 below.

In addition to measuring currents the following spin-offs add to the commercial viability of the systems:

	Spin-off	**Applications**	**Importance**
Altimetry	Wave heights, wind speeds	Storm monitoring, assimilation into wave models, statistics for offshore / renewables industry, climate monitoring	Very important, comparable to currents (height) information.
LIDARs	None	-	-

(cont'd)

[1] As an approximate rule of thumb, one LEO (Low Earth Orbiting) system with a swath width of the order of 500 km can provide about 1 image per day on average over the globe, and guaranteed coverage of any point within about 6 days.

SAR ATI	SAR imagery	Directional wave information and statistics, oil spill detection, ocean processes, land applications.	Very important, as useful as currents information.
RAR ATI	Scatterometry for wind vector measurements. Maybe rainfall over the open ocean.	Weather nowcasting and forecasting + as for altimetry.	Very important, as useful as currents information.
GPS reflectometry	Wind speeds, sea state.	Storm monitoring	Important, comparable to currents (height) information.
SST methods	Sea surface temperature, cloud cover.	Weather / climate monitoring, ocean modelling.	More important than currents information (primary mission objective)

Table 6 – Spin-off information from the candidate measurement systems.

5. Conclusions and recommendations

From the analysis above it is clear that altimetry and radar interferometry, with support from passive imagery, represents the best solution to measuring currents in the open ocean, both now and 10 years into the future.

Altimetry already offers useful measurements for assimilation into ocean circulation models, and with 5 altimeters in operation the present coverage is moving towards meeting requirements. Once the GRACE and then GOCE gravity missions have been undertaken, over the next few years, we should have sufficient knowledge of the geoid to retrieve absolute geostrophic currents from altimeter height measurements. Ideally 20 altimeters are required to fully meet the requirements for 50km resolution measurements every 2 days. In order to achieve this at reasonable cost it will be necessary to investigate the use of cheaper technology than has been used for altimeters up to now. This has been done for altimeters designed to measure wind and waves, but for height (and hence current) measurements it is the additional requirements for orbit knowledge and atmospheric corrections that add to the overall cost. There may be ways of eliminating the need for full instrumentation on each satellite, however, by using intersections with hi-spec altimeters to give the required information. This is one of the concepts being looked at by the EC funded GAMBLE (Global Altimeter Measurements By Leading Europeans) project. While 20 altimeters would be the ideal number, this represents a maximum as satellites additional to this would not add significantly to the amount of information (due to the natural scales of geostrophic current activity). Any number of altimeters more than the 5 flying at present would be of benefit (providing the orbits are designed appropriately) up to this recommended maximum of 20. In addition to conventional altimetry, if the technology can be proved then GPS reflectometry could offer a very cheap substitute.

Radar interferometry (ATI) is the most promising alternative concept to altimetry for measuring currents at present. SAR ATI has the unique potential for producing high-resolution measurements of currents from space but cost is a major drawback. Perhaps the most affordable option would be to fly a second X-band TerraSAR alongside that already planned, but the cost would still be high and this approach would be difficult for the UK to pursue. RAR ATI, however, might deliver global information meeting the resolution requirements for offshore applications at a lower cost. It is therefore recommended that the RAR ATI approach, detailed in appendix A of the WP3 report OC-REP-3/03, be seriously considered as a future service mission. An additional benefit of this method is the spin-off measurements of wind vectors, which are of considerable importance to meteorological and wave modelling. A high-frequency RAR might also have a rainfall-monitoring capability over the open ocean.

SST measurements, although affected by cloud, will continue to offer useful information on ocean currents that should be used alongside other measurements. There is scope or further investigation into the relationship between SST and ocean currents, and it is anticipated that future missions designed to observe ocean salinity will be of benefit here.

In the shelf seas the stringent requirements for spatial and temporal resolution mean that satellite systems are less suitable for monitoring the currents. Both SAR ATI and SST methods provide sufficient spatial resolution, however, the number of satellites required for 2-hourly updates is prohibitive. Despite this, both methods (providing SAR ATI from space becomes proven technology) would provide useful information for validation of the shelf sea models. SST methods could overcome the temporal resolution problem if measurements were made from a geostationary system. This has not been considered in the past and it is a recommendation that the concept be investigated further. Regular SST measurements could also be used for meteorological purposes in the presence of cloud. Unfortunately SAR relies on motion for operation and would not work in a geostationary arrangement.

For coastal processes and applications, where information on scales of minutes and metres is required, it is unlikely a satellite system could be any use. HF radar is a land-based technique for measuring currents and is by far the best solution for local coastal areas. Also aircraft-based SAR ATI could provide good detailed measurements, but only for short times and at significant cost.

In summary there are four overall recommendations from this study into measuring ocean currents from space:

- Cheaper altimeters. The possibility of increasing altimeter coverage by launching additional but cheaper altimeters should be investigated. Technical development is required to ascertain which instrumentation can be discarded while still providing the measurement accuracy of conventional altimeters.
- GPS reflectometry. There is much technical development to be done, but the attractiveness of a very low-cost system means it is worth pursuing this as a means of ocean height measurements as well as sea state.
- RAR ATI. This is the most attractive new concept for measuring global currents and further investigation into this technique is the primary recommendation of this study. In addition to current measurements, a RAR system could provide wind information to supplement existing and planned scatterometer missions.

- SST exploitation. Further development in the use of SST measurements for retrieving currents and their combination with altimeter measurements is recommended. The possibility of using a geostationary SST system should also be investigated for frequent updates in shelf sea areas.

Whether there is a business case for pursuing these recommendations is looked at in part 3.

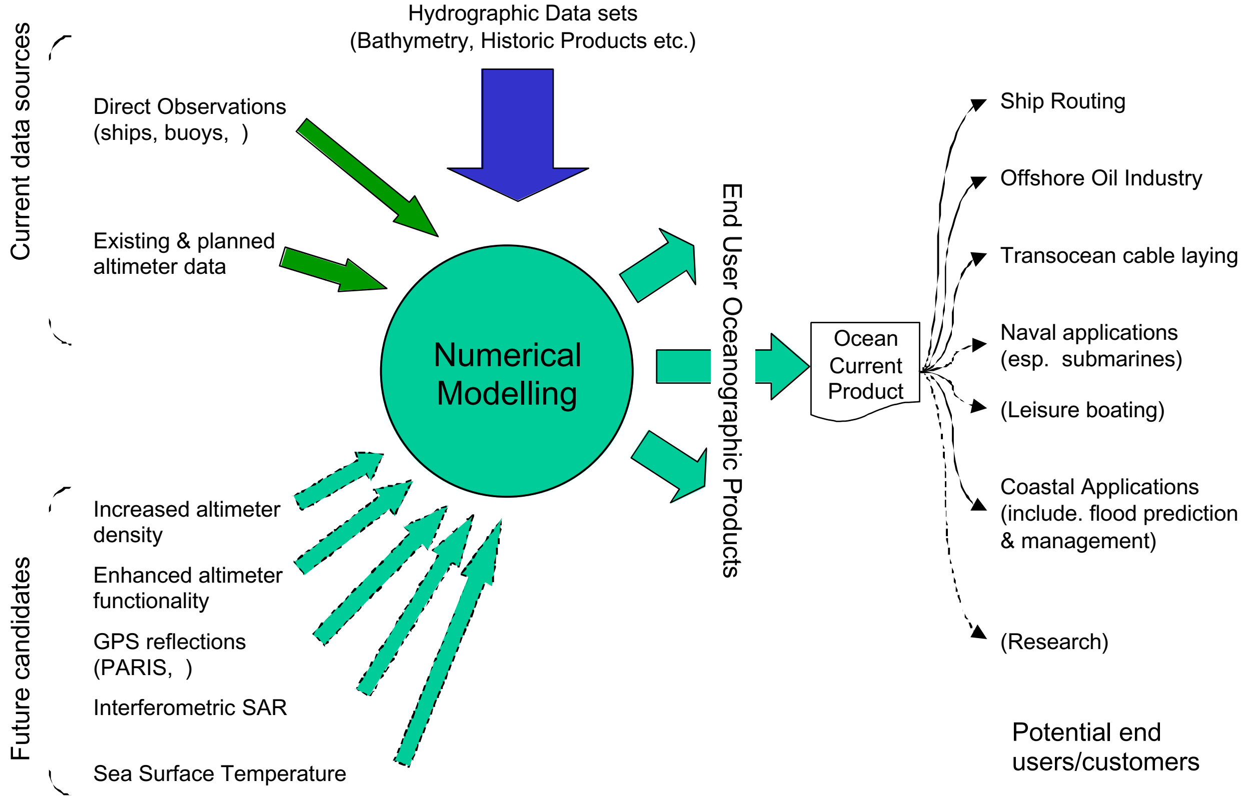
Part 2 – Product delivery approach

1. Introduction

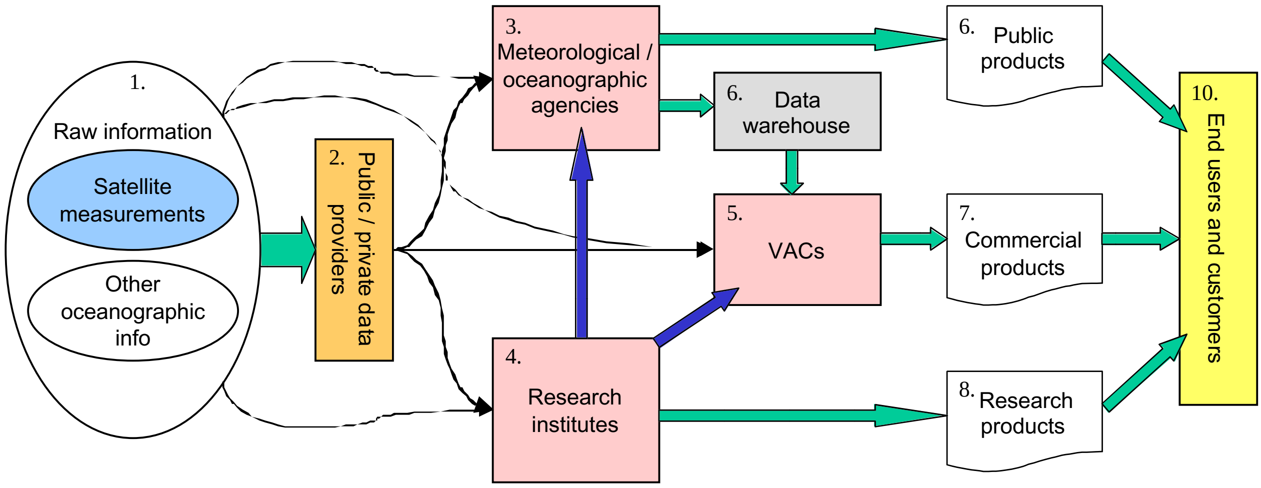
The second part of WP4 looks at the information supply chain, from raw measurements to products for the end user. The operational concept presented in the original proposal is developed into a service model based partly on the existing set-up and partly on recommendations resulting from discussion at the WP4 workshop.

2. Operational concept

A provisional operational concept for delivery of currents information was laid out in the proposal as follows.



Here the main focus is numerical modelling and it is still recognised that this is the central mechanism for bringing together raw measurements in order to deliver information products. Following discussion at the WP4 workshop, the Ocean Currents team has expanded on this provisional approach and agreed a complete operational service model for delivering currents products, in terms of the stages and players involved:



The system begins with raw information (1.) consisting of satellite measurements (as described in Part 1) as well as other oceanographic information such as *in situ* measurements. These are likely to be processed to give the basic data products and distributed via public and private data providers (2. – e.g. owners of satellites and licensed distributors). Data are then provided to the meteorological / oceanographic agencies (3.), research institutes (4.) and value added companies (VACs – 5.), collectively 'data users' as opposed to 'information users'. In some cases direct provision of data to these bodies will be possible and desirable. For example altimeter data from the Jason-1 satellite is now available via very low-cost ground stations direct to data users, and the Met Office receive the majority of their data direct. Data from any system with expensive ground station requirements (such as SAR / RAR) are likely to be controlled by specific data providers.

It is at the 'data users' stage that numerical modelling is carried out. The greatest modelling capability is likely to be at the Met agencies, especially for analysis and forecasting purposes. There will also be extensive modelling facilities at research institutes, but less of a focus on operational modelling. However, through developing the modelling skills required for research, the best technology for operational models is likely to emerge from the research institutes. It is therefore important that technology transfer takes place between research institutes and the Met agencies and VACs (blue arrows). VACs are included here as they may also have a modelling capability requiring the input of raw data. This is likely to be on a smaller, cheaper scale than the Met agencies for local areas. In addition VACs may see value in delivering information based on the actual measurements, and so perform a data visualisation role. The primary function of VACs, however, will be as providers of commercial products based on the output from the operational forecasting models of the Met agencies.

In order to achieve the best efficiency and meet the specific requirements of individual service providers, it is recommended that output from the Met agencies is handled by a 'data warehouse' (6.). This is because there is a vast amount of output from operational models and handling this information and distributing it according to customer needs requires a specialist capability that may not be held in-house (particularly for the latter function). The data warehouse need not be physically separate from the Met agencies, and indeed it will be desirable if it is situated on the same premises, but it should be a distinct entity (possibly a private company) with a sole function to manage and distribute model output. A suggested business mechanism for this approach is given in part 3.

Model output provided to VACs will then be packaged and tailored to meet user needs, and for currents information this will almost certainly mean integrating with other parameters of interest to the user, such as weather information which may also originate from the met agencies.

As well as providing model output to VACs via a data warehouse, met agencies have a role in producing products for the public sector, and in the UK example the most important customer for currents information is the Royal Navy.

Finally, the output of research will also be required by certain end users and customers, and will be provided by the research institutes as research products.

3. Discussion

The approach described above suggests separating the met agencies from the provision of information products to the commercial market. The reason for this is to promote maximum competitiveness in the market place. The Met agencies may of course have their own application division, but this should operate under the same terms as other VACs so as not to introduce unfair competition. The key feature is that model output should be provided free in the first instance, with revenue to the data warehouse and met agencies generated from royalties payable on subsequent sales of commercial products. In this way there are no up-front costs prohibiting the development of products, as is the case for some model output at present.

It is proven that when data is made freely available, then commercial companies will add value to it to provide services that generate wealth, both directly and indirectly. In the USA, companies such as WSI and Accuweather started as pure data warehouses, providing packaged data services to added value companies, such as TV stations and meteorological consultants. They have also developed their own value added products and services, based on the data being “freely” available from the NMS and other sources. Revenues of these companies is around $30-$50m.

The approach suggested here for information on ocean currents could equally be applied to other parameters such as the output from wave models and met models. Commercial aspects of the product delivery approach are discussed further in part 3.

Part 3 – Outline business plan

1. Introduction

In part 3 the issues that would enable a business plan to be constructed are considered. To facilitate this, target market segments have been identified and analysed to assess the potential global market size. Issues relating to development of business in the identified target markets have also been addressed.

The business plan has to consider, for each stage of the supply chain, the capital and operating costs, likely revenue flows, and other issues relating to development, marketing and delivery of information and services based on the ocean current measurements.

The situation is complex as we are considering a global market. Within the global market, business factors (political, legislative, technological, social, and economic factors) vary greatly, from industry to industry, and on different geographical scales, and this will impact in various ways on each stage of the supply chain.

2. The market for currents information

An important part of any business plan is to attempt to define the total market size and potential sales to that market. It is not a simple task to define the demand for ocean current measurements, as much of the demand is hidden within the demand for systems and services of which ocean current measurements is only a component. A useful exercise however is to consider the present market for similar or related services, and make some assumptions based on this.

For example, the total global market for marine information systems was estimated in a report to BNSC prepared by British Maritime Technology (BMT) in 2001[2]. This total market, including both the commercial and public sector, was projected to be ~$2 billion in 2002, with growth at least 7% a year. A large percentage of this will be related to hardware and software, leaving an estimated 5-10% for actual information. If a suitable measurement system were in place then perhaps 10% of this information would be related to currents giving a market size of $20 million.

In order to assess the potential market, the first step is to divide the market into meaningful parts or segments. Our segmentation is based on the following:

1. the source of revenues (or funding): public or commercial, with the commercial segment being further split into vertical industry e.g. Oil & gas, Shipping, etc.
2. the primary use to which the data is being put: research or operational.

Based on this segmentation, we can then make some assumptions about each industry sector, in terms of their requirements, their accessibility, their business environment, and other factors, in order to assess market size and potential.

[2] BNSC report no. 16400/02, Developing the market for EO data in the marine information systems sector, November 2001.

Commercial sector

The primary requirement for ocean current measurements in the commercial sector is to support operational activity. This requirement may also be for data as input into design, for example in the Oil & Gas industry, or may be realised by expenditure on research to obtain the necessary understanding of an operating environment, such as research into the Atlantic margin funded by the oil & gas industry. For the sake of this business plan, all revenues from the commercial sector are deemed to be for operational purposes.

In the US, the annual revenue from commercial meteorology is put at $400-700 million of which $20 million is from the marine sector[3]. This will be mostly conventional meteorology, but an estimated 10% or $2 million would be spent on currents information if it were available. In contrast, the annual revenue from commercial meteorology in the EU is put at just $30-50 million. Given that the economies of the US and EU are of a similar size, and are surrounded by a similar amount of water, the revenue from the EU has the potential to increase to the US level.

Oil and Gas

In the oil and gas industry the following costs were reported during the research carried out for WP2 of the project (user requirements):

- General estimates of the costs attributed to currents were between $1 million and $5 million per company per year. Taking there to be 5 major oil companies with costs of $2 million each, these costs total $10 million annually.
- In regions of strong current activity, such as Gulf of Mexico, operational delays of several days are not infrequent and are reported to cost several $100k. Drilling downtime is estimated to be 2-3% per installation at a cost of $1 million per year. There are approximately 100 mobile drilling rigs for deeper water in the Gulf of Mexico so potential costs are $100 million annually.
- In one incident, currents were responsible for a delay of 30 days, with costs at $200k a day giving a total of $6 million.
- Other costs are associated with mooring line failures, frequent delays to the operation of ROVs, and offtake problems, especially with floating platforms.

This limited information gives a baseline for costs associated with currents in the oil and gas industry, with an annual figure between $10 and $100 million. Only a fraction of this could be saved through improved information, however, so the benefits of improved information are likely to total less than $10 million. This is considered a conservative estimate.

Although the potential benefits are large, experience shows that the industry has traditionally not been prepared to spend significant amounts on metocean services for operational purposes. A significant proportion of its spend is for design purposes where the primary interest is for archive and statistical information, and for research (e.g. the North West Approaches Group has reportedly spent in the order of US$10m on developing a 3-D ocean model).

The amount the industry would be prepared to pay for improved currents information can be estimated from the amount it presently pays for weather forecasts, which is $50 to $100+ per day for an installation. We have to take into account that currents information would most likely be

[3] Source US National Weather Service, http://www.ofcm.gov/sai/presentations/02-panel_1-part1/05-p_weiss.ppt

provided as an enhancement to existing services, with service provides only able to increase their pricing by an incremental amount that would not necessarily reflect the true worth of the data.

There are over 10000 offshore installations world-wide. Only a fraction of these would be interested in currents, say 10%. That gives 1000 offshore installations, paying around $20+ per day for additional currents information (on top of the $50-100 they already pay for weather), equating to around $7m per annum. This compares favourable with the conservative estimate for annual potential benefits of around $10m.

This figure of $7m assumes 100% market penetration. It would take some years to achieve, this, but it probably is possible due to the well-developed nature of current metocean services to this industry, with strong competition between suppliers. There is an existing culture of minimising risks and costs by better engineering and procedures. The industry is also dominated by a relatively small number of large wealthy companies, which have a high awareness of metocean issues, so marketing new ocean current products to them would be fairly straightforward using existing marketing and product delivery channels. The market opportunity is also enhanced by the present and predicted future move into deeper waters, further offshore, where offshore ocean currents become more significant to operations.

Shipping

With shipping, potential savings rather than costs have been reported during the research carried out for WP2 of the project.

- One estimate of savings from improved global wind, wave and currents information was $95 million per year. If 20% of this is attributable to currents the corresponding savings are about $20 million.
- Improved observations of wind, waves and currents in the Gulf of Maine are estimated to save 5% of commercial shipping costs equating to $500k per annum for that region. If 20% is attributable to currents the saving is $100k annually, consistent with the above global figure.
- Improved routing using currents information could produce fuel savings of about 10%, which for larger ships amounts to $1k a day. There are approximately 1000 larger ships in operation say 50% of the time, giving a potential annual saving of $200 million.

For shipping the range of potential benefits spans $20 to $200 million annually. Here improved information has a greater impact compared to the oil and gas industry, as ships are able to change position accordingly. If the benefits of improved information are 50% of this figure the range becomes $10 to $100 million, greater than that for oil and gas

However, unlike the oil and gas industry, which are willing to spend on improved information, shipping tends to be a conservative industry, with relatively slow acceptance of new technology. The industry is also much more fragmented, with a large number of shipping companies, of varying types, all operating to different procedures and objectives. Although there are established suppliers of commercial services to the industry, the information sources used by the industry is far more diverse that say the offshore oil and gas industry. Public services that are available free of charge are considered by many to be a reasonable alternative to commercial services. Perhaps the best opportunity in this sector is the enhancement of existing weather routing services with improved currents information, for example, the transmission of additional information (both observational data and model output) to on-board software systems. The industry would only pay a small premium on existing charges for such data, and new customers would be found only slowly.

The potential for fast-growing significant revenues from products based on ocean current measurements sold to the shipping industry is relatively low. It would take years to fully realise the potential in this market. Daily expenditure on weather services per vessel would be around US$25, and only a fraction of this, say 20%, would be attributable to currents. The industry is very large, with global merchant fleet including 9,000 tankers alone, so a realistic estimate for annual revenues would be around $5m based on assumption that 2000-3000 vessels use commercial services.

Other industries

Other industries reported the following costs associated with currents:

- In one incident a fish farm lost over $1 million worth of fish when cages broke free in unexpected strong currents.
- Cable laying is very sensitive to currents, albeit full current profiles, and downtime costs $100k a day. There are about 60 specialist cable laying vessels, so assuming a downtime of 2% (as for drilling operations) and 50% in operation at any one time the annual costs amount to $20 million.

There will also be costs to other industries associated with currents, but often near shore and so less relevant to the delivery of offshore currents information that is the main focus of any satellite system and associated modelling activity.

There is also potential market in the leisure industry, although much of this industry would relay on public services. Specialist provider area already providing weather and oceanographic services to fishing, yachting and cable laying industries, and these would be able to enhance their services with the new current measurements. This would lead to increased revenues through incremental fee increases and perhaps growth their customer base.

However, total annual revenues from these other industries is considered small when compared with potential from shipping and oil and gas, but could grow to around US$1-2m per annum after a few years.

Summary

Potential global revenues from the commercial sector resulting from improved measurements of ocean currents have been estimated, and are summarised in Table 7 based on growth over a period of 5 years.

Year:	1	2	3	4	5
Oil and gas	$2m	$4m	$6m	$7m	$8m
Shipping	$0.5	$1m	$2.5m	$3.5m	$5
Other	$0m	$0.5m	$1m	$1.5m	$2m
Total	$2.5m	$5.5m	$9.5m	$12m	$15m

Table 7 – estimated total annual expenditure on currents information by industry

Public sector

It is anticipated that the major market for information on currents is the public one, consisting of research, defence expenditure (in this case for navies), and expenditure on public services, such as search and rescue. There are already considerable public funds spent on oceanographic research and products, to realise benefits to the “public good”.

In developed economies there is significant spending on national meteorological and oceanographic agencies. For example, the proposed annual budget for the US National Weather Service (NWS) for 2002 was $727.6 million, whilst the UK Met Office accounts for 2000/2001 report a total turnover of £154 million, of which only £21 million was generated from commercial services. A proportion of this spending will be on oceanographic research and operational meteorology/oceanography for public services.

Any satellite system measuring currents would in some ways be in competition with other global, public funded programmes to improve current monitoring, such as the Argo project. There would have to be a clear illustration of the likely benefits resulting from the improved data.

While it is not possible to provide a justified estimate of the likely revenues available from the public sector, it is thought that a global figure of $10-50 million is the right range for research and operational modelling relating to currents.

For further analysis the public sector can be split as follows:

- public funding of research
- public expenditure on operational oceanography for the public good (i.e. search and rescue, pollution response etc)
- defence (naval) spend on research and in support of naval operations

Public funding of research

Governments are major funders of oceanographic research, a proportion of which will be spent on observations, and products based on observations, such as ocean models. In the USA, the federal support for ocean research is reported to be about US$600m per year[4].

An estimate of the research market in the UK for information on currents can be made from the annual science budget of NERC. Spending on ocean modelling related activities in research is given in Table 8, with a total of £7 million. It could be assumed that of this 15% say £1m is attributable to currents.

Research item	**Expenditure £k**
Coupled ocean-atmosphere processes and their effect on climate	688
Oceans, climate change and consequences for the coastal zone	1,322
Seasonal to decadal ocean variability	825
Large-scale long-term ocean circulation	1,172
Associated infrastructure	~3,000
Total	~7,000

Table 8 – Annual expenditure on modelling related activity by NERC during 2000-2001

Although this figure is fairly low, oceanography is currently the focus of increased research due to the recognition of the impact on the oceans on the atmospheric circulation, and response to

[4] Source: Economics of a US integrated Ocean Observing System. J. Kite-Powell, et all Draft. 27 Feb 2002.

global warning issues. It can therefore be assumed that public funding of oceanographic research is likely to increase over the next five years, and a part of this funding would be spent on observational systems and data. Also the value to society of better understanding of the circulation of the oceans is considerable.

Public expenditure on operational oceanography for the public good

Public services in oceanography focus on operational requirements such as search and rescue, public weather and tidal information services. Much of the requirement here is for coastal information, with only a small fraction for ocean areas. However, pollution response and some search and rescue activities would benefit from improved current measurements offshore so it can be assumed that a proportion of public expenditure would be available for improved current measurements.

Defence (navy) expenditure

The naval defence forces of developed countries are major spenders on both research and operational oceanography. For example, UK Royal Navy is the major funder of the UK ocean model FOAM, and operates a meteorological/oceanographic service at Northwood to meet the operational metocean requirements of UK fleet world-wide.

As defence remains a high priority in the current world political climate, it can be assumed that the navies, especially those of the USA and western Europe, would provide a significant revenue source for any ocean current measurement programme, and related activities, such as ocean modelling. Of course, they would have to be convinced of the benefits of further investment.

3. Business model

Each part of the supply chain adds value to its inputs to produce its outputs. The table below consider each phase of the supply chain, as already specified in part 2, to identify the inputs and functions to which costs need be assigned.

Supply chain stage	Input(s)	Function(s)	Output(s)
Satellite measuring system	satellites, ground stations	develop and managing data collection system	basic data
Public & Private data providers	basic data	process and deliver data	basic data products
Meteorological/Oceanographic agencies	basic data products	develop and operate numerical models, develop and deliver public services	model output, public products

(cont’d)

Data warehouse	basis data products; model output;	collate, package and deliver	customised data sets, added value products
Research institutes	basic data products, model output	research	improved models, other research products
Commerical service providers	basic data products, customised data sets	develop and deliver services to end users	customised products and services

The function, where value is added, is essentially the business model, to which costs and revenues are assigned. Cost items, both capital and operational, are identified for each stage of the supply chain, along with potential customers and revenues sources from those target customers.

In reality, the supply chain has a complex structure, with many different types and size of company. This results in a wide variety of cultures and accounting structures making it difficult to precisely model each and provide quantitative analysis. Vertical integration is common, with some companies playing more than one part. For example, a national meteorological agency could be running models, providing data warehouse services, undertaking research, and providing of commercial services. The analysis that follows is therefore by necessity a simplification.

Supply chain stage	**Capital Costs (investment)**	**Operational cost items**	**Source of revenues (customers)**
Satellite measuring system	Design, build, and launch of satellite system $100m	Operation of ground stations, for monitoring and maintenance of satellite system, and processing data $5m per annum	1. Public funding 2. Public & private Data providers
Public & Private data providers	Limited, as likely to be currently processing data, so infrastructure in place.	Processing and delivering data.	1. Public funding (NMSs) 2. Research agencies 3. Commercial companies 4. Data Warehouse

(cont'd)

Meteorological/ Oceanographic agencies (National Meteorological Services – NMS)	Limited, as infrastructure already in place to receive, process and use satellite observations.	Developing, marketing and delivering new ocean current products; Developing and running operational models	1. Public funding for public services 2. Naval spending 3. Data warehouse 4. Commercial companies
Data warehouse	Limited, if present data provider, but may require new entity.	Marketing and delivering product sets	1. Research agencies 2. Commercial companies 3. Public funding (Smaller NMS) 4. Naval spending
Research institutes	Limited, as most will already be undertaking research & have necessary infrastructure in place	Marketing and undertaking research specific to ocean currents; Develop and running research models	1. Public funding 2. Naval Spending 3. Commercial companies
Commerical service providers	Limited, as most will be already providing metocean information services; Perhaps higher for new companies entering market	Developing, marketing, producing and delivering products and services to meet end-user requirements, but, as most will already be providing services to end users, principal costs will be for the data	1. Industry: (a) Oil & Gas (b) Shipping (c) Leisure (d) Fishing (e) Cable Laying (f) Other 2. Public funding for public services (possibly)

Capital Costs

Capital costs are limited for all but the satellite measurement programme as the data, modelling and products, would in most cases be flowing through existing production, delivery and marketing channels. There will be no doubt additional investment in systems, resources and personnel due to the availability of increased observational data, but these costs are not going to be as high as if organisation in the supply chain were starting from scratch. A reasonable assumption would be a 10-20% in capital costs, but it could be argued that these could be met by re-assigning investment resources with minimal impact.

From the information presented in part 1 of this report it is clear that any dedicated satellite system for measuring currents is going to cost upwards of $100 million to develop and launch.

Operating Costs

Again the satellite measurement system is the major operating cost. Then there will be ongoing costs for the ground segment of perhaps 5% of this or $5 million per year. Other parts of the supply chain will have increased operating costs, but these are likely to be incremental, say 10-20% increase, as most organisations will already be functional. For example, the commercial service providers will in most cases existing service providers, such as met-ocean service providers to the oil and gas industry and ship routing companies.

The incremental costs would be due to the cost of developing and then producing new products, whether it is an ocean model or added- value products such as charts, would be an additional operating cost. Marketing costs are likely to be proportionally higher, especially in the early stages of the project, as programmes to build awareness of the new products are implemented.

Revenues

The whole supply chain is driven by revenue inputs from the following sources:

- Revenues from the commercial sector for operational products.
- Revenues from public funding of public services.
- Revenues from public funding of research
- Revenues from pubic defence (naval) spending on research and operational oceanography.

Revenues from the commercial sector is estimated to be around US$15m per annum, after 5 years, whilst minimum revenues from pubic funding is estimated to be around US$10m, totalling around US$25m per annum. In addition there would be revenues from spin-off data (see Table 6). It would of course take time to grow these annual revenues. This revenue is calculated for the “end product”, and not just pure data output from the satellite measurement system, and so would have to cover the increased operating costs, and also make a contribution to the source data (the satellite measurement programme).

For a feasible business, each stage of the supply chain would generate profits (excess of revenues over operating costs) that would either directly or indirectly enable a flow of funds back through the supply chain. The final revenues that would flow into the satellite measurement system is not easy to estimate as it is not possible to account for the additional operating costs of the various types of organisation and activities in the supply chain.

However, this direct flow of revenue would not be the only measurable on which the feasibility of the programme should be assessed. There will be hidden benefits to the economy and the public good, which will be impossible to quantify or even in some cases identify. The “revenues” should therefore consider such benefits. This indicates that public funding will be essential to cover the capital costs of the programme.

The supply chain is not linear, and there are revenue inputs at various stages. As an example, the national meteorological agencies would be receiving revenues from government and navies for modelling products and other operational products, as well as receiving revenues from the data warehouse for sales of modelling products (that used the ocean measurements). Additional to its operating costs would be the cost of the satellite measurements. It is unlikely that any organisation would want to pay for the ocean current data set up front. Therefore, the pricing and charging structure for the data needs to be considered.

Pricing and charging structure

Each stage of the supply chain could be viewed as a value-added reseller of the ocean data, with a proportion of revenues generated by products based on ocean current measurements being returned to the ocean current programme.

Any charging structure for the data needs to be simple to avoid high administration overheads, which in turn could lead the data being priced too high for the market to bear.

The pricing of the data is critical to the success of the programme. The cost of the data is an additional cost for businesses, as are the operational and capital costs identified above. For companies (and government) to invest in the data, they need to see a reasonable return over an acceptable period, with a level of risk they are comfortable with. The more this risk can be reduced, and the more competitively the data can be priced, the more chance that organisations will be attracted to use and exploit the data, and the higher the chance that the identified benefits will be realised. These realised benefits, both economic or non-economic, such as reduced loss of life or reduced environmental damage, will find their way back into the system, either directly in increase revenues, or indirectly through taxes and reduced government expenditure.

It is worth noting here that the philosophy of using public spending to facilitate commercial exploitation would probably be the key to ensuring commercial success of an ocean current measurement system. Proof of this would be the parallel experience of the commercial meteorological industries in the USA and Europe. In USA, where all data from the National Weather Services flows free of charge to commercial service providers, the market is estimated at $400-700m with over 400 companies. In Europe, where access to the data is restricted by unrealistic (from the customer's viewpoint) pricing policies, only commercial revenues of around $30-50m are generated from 30 companies.

4. Summary and conclusions

Providing a business plan for the exploitation of ocean current measurements from space is a difficult task due to the complexity of the supply chain that will deliver to market products based on the measurements. To provide a fully detailed and costed business plan is seen to be outside the scope of this project.

What we have attempted to do is provide a structure of a business model, describe its components, and to detail the issues that would need to be addressed to fully develop a detailed business plan.

The presented outline business plan illustrates that there is a potential market for improved ocean current measurements from space that could generate commercial revenues of around $15 million and public funding of at least $10 million a year. The exploitation of this market to its full potential requires a wide variety of organisations working in partnership to ensure the diverse user requirements, both for research and operational purposes, are met.

The principal costs associated with the business plan are the development and operation of a space system for the measurement of currents. This involves significant capital investment (estimated at $100 million), and it is envisaged that this could only be met by public funding.

The operational costs of the measurement system could be met by revenues if the view of revenues is seen in a wider sense. The potential revenues that would be generated from investment and operation of such a system would arise from a wide range of activities and diverse sources. Some of these revenues would be directly accountable and some would not. For example, accountable revenues would include payments made for data or services based on the measurements. More indirect, and less accountable, revenues would arise from taxes on the profits of commercial providers using the measurements to enhance their services, and from cost savings and intangibles, such as increased safety and “the public good”. It is difficult to put a value on the benefits of better informed decisions on environmental issues that affect government and commercial policy, global warming being a major and most relevant example of one such issue.

Finally, as any satellite measurement system for ocean currents would be global in scale, political, economic and technological factors would greatly influence the chance of commercial success.

Part 4 – Conclusions, recommendations and exploitation

1. Introduction

The final part of this report reiterates the conclusions and recommendations for the project as a whole, provides a statement of compliance with SMS Programme objectives, and describes plans for exploitation.

2. Conclusions and recommendations

The main conclusions and recommendations result from the matching of various candidate systems with user requirements in the latter part of the project. They were presented in part 1 of this report and make recommendations for systems warranting further investigation as follows:

1. Cheaper altimeters. The possibility of increasing altimeter coverage by launching additional but cheaper altimeters should be investigated. Technical development is required to ascertain which instrumentation can be discarded while still providing the measurement accuracy of conventional altimeters.
2. GPS reflectometry. There is much technical development to be done, but the attractiveness of a very low-cost system means it is worth pursuing this as a means of ocean height measurements as well as sea state.
3. RAR ATI (Along-Track Interferometry of Real Aperture Radars). This is the most attractive new concept for measuring global currents and further investigation into this technique is a primary recommendation of this study. In addition to current measurements, a RAR system could provide wind information to supplement existing and planned scatterometer missions.
4. SST (Sea Surface Temperature) exploitation. Further development in the use of SST measurements for retrieving currents and their combination with altimeter measurements is recommended. The possibility of using a geostationary SST system, giving frequent updates in shelf sea areas, should also be investigated.

From the outline business case presented in Part 3 it is clearly not viable for satellite measurement systems to be funded based on projected revenues, with science benefit and public good remaining the primary motivation for new systems. However, estimated revenue figures exceeding £10 million could meet operational costs and enable a significant amount of business activity to be developed, provided it is not impeded by up-front data costs.

3. Compliance with SMS objectives

In making these recommendations, *Ocean Currents* has met the long-term objectives of the BNSC Service Mission Support Programme, which are concerned with the '…selection of emerging technologies and techniques to meet potential user needs on future missions…'.

In respect of this there are 2 examples of possible future missions worth noting, both addressing the first recommendation for cheaper altimeters. One is the GANDER concept for microsat altimeters, proposed by Satellite Observing Systems (SOS) and Surrey Satellite Technology

Limited (SSTL) and discussed further under exploitation below. The other is a French concept known as AltiKa, also a constellation of microsat altimeters but operating at the higher Ka-band frequency. This removes the requirement for an ionosphere correction at the expense of greater sensitivity to rain.

4. Exploitation

Measurements of currents is fundamental to the future of oceanographic research and the provision of useful information to operational users, and remains less well measured than other physical parameters. The prospects for improved measurements in the near future are promising, and the *Ocean Currents* consortium would encourage BNSC to support technical development in this field.

Of the four recommendations above, members of the *Ocean Currents* consortium are well placed to exploit three of them. For the first recommendation, the GANDER concept for a constellation of microsat altimeters (http://www.satobsys.co.uk/GANDER/) has been developed SOS and SSTL over recent years and shown to be feasible for wind and wave measurements through a previous study funded by BNSC. There are now plans to investigate an upgrade to the concept for height measurements as well as wind and waves. The value of this has been reinforced by discussions at a recent workshop of the EC GAMBLE project (Global Altimeter Measurements by Leading Europeans), a thematic network to plan the future of altimetry in Europe (http://www.altimetrie.net). Here the consensus of opinion was that a constellation of perhaps eight altimeters could provide a suitable measurement system in support of ocean modelling activities. SOS and SSTL have begun talks with Systems Engineering and Assessment Ltd (SEA) to seek funding opportunities to further investigate the GANDER concept in this context.

GPS reflectometry is a concept of great interest to the remote sensing community. SSTL and Astrium were both key participants in a proposal for an Earth Explorer Opportunity mission that was submitted in early 2002, and there is likely to be a further attempt at the next round. SSTL is aiming to fly a demonstration experiment on a satellite within the next year. This is a real opportunity for the UK space industry and they would welcome further support from BNSC. The success of a trial mission will very much determine the prospects for this technology.

Rutherford Appleton Laboratory are interested in investigating the technology for a geostationary system for the measurement of SST, and would take this further if the appropriate framework or opportunity became available.