EVALUATION OF NERC CENTRES 2013

IMPACT CASE STUDIES: NATIONAL OCEANOGRAPHY CENTRE

Note: confidential aspects of the case studies have been deleted where necessary.

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NOC01: Policy Development: Climate Change Impacts

1. Summary of the impact (maximum 100 words)

Man-made climate change has been estimated to cost the UK economy 5-20% of Gross Domestic Product (GDP)\(^1\) amounting to £80-320 billion for 2011 GDP\(^2\). The National Oceanography Centre (NOC) is providing impartial, independent, world-leading expertise in developing the international scientific consensus that informs the Intergovernmental Panel on Climate Change (IPCC) series of Assessment Reports\(^3\). NOC provides authoritative oceanographic scientific evidence to underpin the assessments, necessary as climate change has enormous economic and societal implications. NOC research is a significant contributor to the international delivery of evidence on ocean circulation, global temperature, sea level and climate.

2. Nature of the impact

The IPCC publishes Assessment Reports (ARs)\(^4\) which are the definitive international resource for understanding the science and impacts of climate change. IPCC Reports underpin UK and global efforts to determine and mitigate the impacts of man-made climate change. Their production relies on impartial, independent advice from world-leading scientists\(^5\). The reports are used extensively by a diverse UK and international community, including policymakers, NGOs, and emerging low-carbon energy innovation industries. They present research evidence that informs policy debate, internationally and within the UK, including, for example, the Climate Change Act 2008\(^6\).

NOC ocean science has impact in four main areas, concerned with sustained ocean observing programmes and ocean modelling. They comprise some of the most iconic and societally important manifestations of climate change: sea level rise, global temperature change and ocean variability. The measurements themselves are important for the detection of change; they contribute to the attribution of change through validation of the performance of climate models, and by challenging model performance, they provoke the development of improvements in climate models, leading to reduction in uncertainty in model predictions.

i) Sea-level rise remains one of the most pressing global societal concerns relating to climate change. A city of cities with populations of more than 10 million. Potential impacts of sea level rise are large with one estimate being that 146 million people globally and about $1 trillion of GDP would be affected by one metre of sea level rise\(^7\). Global sea-level research, data products and expertise stem from the NOC-hosted Permanent Service for Mean Sea Level (PSMSL)\(^7\), which operates under the auspices of the International Council for Science (ICSU). Moreover, PSMSL provides leadership for the Intergovernmental Oceanographic Commission (IOC) Global Sea Level Observing System (GLOSS) programme\(^8\).

ii) Global surface temperature is a fundamental representation of climate change. Ship-based observations of marine near-surface air temperature provide verification of the entire surface temperature (SST) record\(^9\). Climate-quality SST from space supports the evidence of recent change\(^10\). Ocean heat content directly impacts sea-level rise, and measurements from Argo drifting profilers have transformed our knowledge of the temperature and variability of the upper ocean\(^11\).

iii) In the ocean, heat carried by the Atlantic Meridional Overturning Circulation (AMOC) is responsible for the UK’s milder winters. RAPID-WATCH is a NOC-led international program measuring the AMOC\(^12\) which has revealed variability in the AMOC outside the range predicted by climate models\(^13\). Sustained observations across the Antarctic Circumpolar Current at Drake Passage (1993-present) and in the Rockall Trough (1975-present) also give important insights into ocean variability\(^14,15\).

iv) The fourth science area is ocean modelling. A high-quality, dynamically-interactive ocean model is essential to predictive skill in climate models on all time scales\(^16\). Such models must be able to reproduce observed climatically-relevant processes such as the AMOC, and ocean temperature variability. Central to the IPCC process are credible predictions of future climate based on state-of-the-art understanding of climate physics as represented in climate models.

3. How the Centre contributed to the impact

Sustained observations and ocean modelling

i) Sea level rise: The PSMSL, based at NOC, is the global data bank for sea level data from tide gauges. It is
the only source of accurate data concerning sea level changes over a period longer than a decade; some records exceed two centuries. PSMSL data provide a unique perspective on the trends and accelerations of global sea level worldwide that provide the main contribution to IPCC assessments of sea level changes of the past century including in AR4 (2007) and the upcoming AR5 (2013). The PSMSL dataset has been cited in ca. 40 peer-reviewed papers per year in leading journals over the past decade, and AR4 Ch. 5 includes 28 PSMSL references.

ii) Global surface temperature: NOC datasets\textsuperscript{18,19} are used by the IPCC to provide observational evidence for changes in marine surface temperature, humidity and wind speed. NOC is a partner in the International Comprehensive Ocean-Atmosphere Data Set (ICOADS), providing observational metadata\textsuperscript{20}. ICOADS marine observations underpin datasets used in AR4 and AR5.

iii) Ocean variability: As the lead organisation in RAPID-WATCH, NOC scientists have deployed moorings across the North Atlantic at 26\textdegree N to measure, for the very first time, the strength and vertical structure of the AMOC and the amount of heat carried by the ocean currents\textsuperscript{12}, leading to major scientific advances (see below). NOC-led sustained measurements of ocean variability from RAPID-WATCH, Drake Passage and the Rockall Trough provide published observational evidence for changes in the ocean reported in AR4 and AR5, and the context in which climate model predictions and their ability to reproduce observed changes may be tested. This will help improve climate models, and therefore predictions, but will also enable changes to be detected.

iv) Ocean modelling: The Met Office Hadley Centre series of global climate models is among the best in the world, and in collaboration with the Hadley Centre, NOC develops NEMO (Nucleus for European Modelling of the Ocean), the ocean component of the latest generation of Hadley models\textsuperscript{12}. NEMO is a central pillar of the new UK Earth Systems Modelling Strategy\textsuperscript{22}, developed as part of the Joint Weather and Climate Research Programme. NOC is a founder member of the NEMO consortium and, through the consortium’s Systems Team and Steering and Development Committees, sets the strategic direction of the pan-European NEMO framework\textsuperscript{23}. This also impacts both the French and Italian climate model contributions to AR5.

NOC scientific expertise

NOC scientists have contributed to all published ARs\textsuperscript{4} and AR5, at all levels from expert reviewers (Srokosz) to Lead Author (AR5: Jevrejeva, Ch. 13; Josey, Ch. 3) and Review Editor (Woodworth).

NOC and PSMSL sea level scientists have produced over 120 papers\textsuperscript{24} during this period, and continue to provide knowledge and expertise for the international sea level community. PSMSL research focuses on the generation of globally consistent records of sea level variability, corrected for biases including isostatic adjustment\textsuperscript{24}.

NOC expertise generated the design of an effective AMOC monitoring array\textsuperscript{25}. The outcome is internationally acknowledged to be successful\textsuperscript{26}, with high-profile publications\textsuperscript{27,28}. The previously unsuspected nature of AMOC variability revealed by the RAPID-WATCH observations and analysis has highlighted the shortcomings in model representations of the AMOC\textsuperscript{13,29}. NOC contributes to Argo through membership of the International Argo Steering Team, as well as via scientific research.

NOC provides unique expertise in the construction of marine surface climatological gridded datasets with quantified uncertainty. Our research led to a major revision of SST uncertainty, with estimates doubling between AR4 and AR5\textsuperscript{30}. NOC scientists showed that a new climate-quality record of SST measured from space met the stringent stability requirements for inclusion in the AR5 – the first time a satellite SST record has been used in this way\textsuperscript{10}.

Implementation and continued development of the NEMO ocean model is critically dependent on expertise maintained at NOC. Essential to model improvement is the ongoing evaluation of model performance, and NOC scientists have studied (e.g.) regional and temporal biases in SST and AMOC variability. Recent NOC-led NEMO developments include: incorporation of a new eddy diffusivity parameterisation, a non-linear free surface, improved handling of topography, and improvements to the sea ice model. New insights resulting from analysis of NOC ultra-high resolution ocean model output impact our understanding of Arctic Ocean circulation\textsuperscript{31}, AMOC variability\textsuperscript{32} and ocean heat content variability\textsuperscript{33}.

Influencing HMG legislation and policy
In response to research evidence presented by the IPCC the UK parliament passed the world’s first long-term legally binding framework to tackle the dangers of climate change (The Climate Change Act 2008). The act requires Government to set carbon budgets, which are limits on greenhouse gas emissions in the UK for consecutive five-year periods. In addition to IPCC assessments, NOC data and expertise, including sea-level from PSMSL, inform studies of impacts of climate change on both national and international levels [e.g. UK Marine Climate Change Impacts Partnership (MCCIP), UK Climate Impacts Programme (UKCIP), UK Foresight Flood and Coastal Defence Review, Charting Progress and Charting Progress 2] - these studies are detailed in Impact Case study NOC05.

Funding: NOC research in sustained observations is funded directly by NERC, and by other direct and indirect national and international sources.

4. Evidence and sources to corroborate the impact

* indicates NOC-authored publication, included in supporting material.

1 Stern Review: http://www.webcitation.org/5nCeyEYJr
2 http://data.worldbank.org/indicator/NY.GDP.MKTP.CD
3 http://www.ipcc.ch/
4 http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1
5 https://www.ipcc-wg1.unibe.ch/AR5/authorsRE.html
6 http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx
7 http://www.psmsl.org/
8 http://www.gloss-sealevel.org/
10 * Merchant et al. (2012), JGR, doi:10.1029/2012JC008400
11 http://argo.jcommops.org/;
12 * Srokosz et al. (2012), BAMS, doi:10.1175/BAMS-D-11-00151.1
13 * McCarthy et al. (2012), GRL, doi:10.1029/2012GL052933
14 * Cunningham et al. (2003), JGR, doi:10.1029/2001JC001147
15 * Holliday et al. (2008), GRL, doi:10.1029/2007GL032675
18 * Berry and Kent (2009), BAMS, doi:10.1175/2008BAMS2639.1
19 * Kent et al. (2013), JGR, doi: 10.1029/2012JD018611
21 http://www.noco.org.uk/Joint-Ocean-Modelling-Prog.html
22 http://www.nerc.ac.uk/funding/news/documents/nerc_mo_esm_strategy.pdf
23 http://www.nemo-ocean.eu/Media/Files/NEMO_Consortium.Agreement.pdf
24 * List of selected NOC/PSMSL sea-level science publications, 2007-2012
26 "exemplary success ... having an immense impact on modelling, analysis and prediction research and capabilities" (Church et al., 2012, International Review Group Report).
27 * Cunningham et al. (2007), Science, doi:10.1126/science.1141304
28 * Kanzow et al. (2007), Science, doi:10.1126/science.1141293
29 * Cunningham and Marsh (2010), WIREs Climate Change, doi:10.1002/wcc.22
30 Kennedy et al. (2011), JGR, doi: 10.1029/2010JD015218
33 * Grist et al. (2010), Ocean Dynamics, doi:10.1007/s10236-010-0292-4
34 see NOC05, "Sustainability and Health of UK National Seas: now and the future."

5. Contacts for further information

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NOC02: The Marine Renewable Energy Industry

1. Summary of the impact (maximum 100 words)

NOC science has underpinned the assessments of both energy resource availabilities and significance of environmental impacts of marine renewable energy installations, enabling growth of the sector and ongoing cost savings for stakeholders. In particular, NOC’s strength and reputation in tidal modelling and ocean observations have been of particular interest to an industry that, by definition, plans to extract energy from some of the most extreme marine environments in the world where accurate predictions and measurements of tides and waves are essential.

2. Nature of the impact

- **Mapping the UK tidal energy resource for the DTI** (now DECC) Atlas of UK Marine Renewable Energy Resources\(^5\). Originally published in 2004, refined in 2008 to include vertical current profiles, and fronted by ABPmer, the freely available atlas provided an independent energy resource assessment based on best available tidal models developed at NOC. The atlas helped establish the location and extent of energy resources that enabled government, industry and investors to commit to developing areas of UK waters for energy exploitation and develop the technologies needed to achieve this. The resulting atlas has been online since 2008 as an interactive webGIS version freely available to all. Other downloadable outputs include pre-prepared atlas maps in PDF format, a technical report and resource data layers (ArcGIS and MapInfo formats). The atlas has been widely used by government, industry and third sector organisations, for example, in HM Government ‘s Marine Energy Action Plan (2010)\(^2\).

- **Contribution to a feasibility study for a future tidal barrage across the Mersey Estuary**\(^4\). Following the ‘Joule’ (NWDA-funded) study which showed that tidal barrages in the Eastern Irish Sea could contribute 50% of the North West’s present electricity needs, NOC contributed advice on tidal principles, modelled a range of operating options and compiled a “Review of Existing Knowledge of Hydrodynamics and Water Levels in Liverpool Bay and the Mersey Estuary” for Peel Holdings in Liverpool. Peel’s study concluded in 2011 that a Mersey Barrage was technically feasible without significant detrimental effects to the environment\(^5\) and could generate sufficient electricity to power 200,000 average homes\(^8\). However, it was unlikely to go ahead without long term financial vehicles to balance the high up-front construction costs with the anticipated long operating lifetime of 120years and security of supply benefits\(^5\). Wider applicability to other potential tidal schemes has also been cited\(^6\).

- **Development of a globally applicable, robust algorithm for wave energy resource assessment**. Skills were successfully migrated from NOC and University of Southampton into Pelamis Wave Power Ltd, adding increased levels of awareness of the use and importance of statistical techniques. The Knowledge Transfer Partnership project\(^7\) developed resources and software to assess the wave energy resource at potential sites for wave energy farms equipped with wave energy converters for any location in the world. Energy productivity can now be assessed at any location in the world, a unique selling proposition, providing a significant competitor advantage. Pelamis Wave Power is recognised as being the industry leader in developing wave energy technology, with the world’s first grid connected wave energy converter and the world’s first multiple machine wave installation.

- **Assessing impact of offshore wind farm (OWF) monopiles on constructive/destructive interference patterns of waves – concluded no need for monitoring**. This study resulted in direct cost savings for the industry by removing the requirement for the monitoring for the effects of wave diffraction/interference effects. The final report prepared by CEFAS advised\(^3\): “Defra’s Marine Consents and Environment Unit (MCEU) are advised not to require developers of OWFs to monitor waves for diffraction/interference effects under a FEPA licence.” Before and after installation studies by radar could be expected to cost upwards of £100k per wind farm (NOC estimate of radar deployment cost, the figure of £50k per deployment also ageed as a reasonable figure by Dr Jon Rees,
3. How the Centre contributed to the impact

- **Increased stakeholder-researcher collaboration in marine renewable energy (MRE) Sector.** NOC hosts the NERC Marine Renewable Energy Knowledge Exchange Programme which is actively facilitating collaborations between NERC funded researchers across the UK and MRE industry, test centre and stakeholder groups. The small KE team have facilitated a range of workshops, meetings, conferences and demonstrations of NERC-funded science. They are taking advantage of existing focus points for the sector such as the European Marine Energy Centre Developers Forum and the National Renewable Energy Centre (Narec) to bring researchers together with industry to help solve sector issues such as impacts of underwater noise, cost effective monitoring, and population consequences of disturbance to marine mammals amongst others. The catalytic effect of these activities is enabling the sector to access the state of the art in all aspects of marine environmental science although it is too early to cite direct industry impacts.

- **Mapping the UK tidal energy resource for the DTI:** NERC has invested in and developed numerical modelling expertise and tidal science capabilities at NOC over many years. NOC’s Marine Systems Modelling group are world-leaders in numerical modelling of the global oceans and shelf seas. The NOC Applications Team contributed tidal data from the POLCOMS high-resolution Continental Shelf Model developed by the modelling group. NOC models are also used by the UK Met Office as part of the National Storm Surge Warning System and maintained by NOC, a pedigree which made NOC the ideal partner to produce the data for the resulting tidal energy atlas.

- **Contribution to a feasibility study for a future tidal barrage across the Mersey Estuary:** NOC scientists together with University of Liverpool’s Department of Civil Engineering contributed to a feasibility study into options for tidal power schemes using the Mersey Estuary. Input included advice on some tidal principles, calculations using ‘0D’ model of the Mersey Barrage with a range of operating options, a ‘Review of Existing Knowledge of Hydrodynamics and Water Levels in Liverpool Bay and the Mersey Estuary’ and various other tidal modelling studies.

- **Development of a globally applicable, robust algorithm for wave energy resource assessment:** NERC has invested in and developed expertise in Satellite Altimetry and Marine Energy capabilities at the NOC. Over the years more than one funding mechanism has supported such work. The Pelamis project was developed as a Knowledge Transfer Partnership (KTP), backed by the then Department for Trade and Industry with the aim to provide academic know-how to commercial enterprises. The project focussed on the specification of the wave power resource, including extremes for survivability, from a variety of sources including satellite, in situ and modelling. Specific outputs of the project included: computed climatologies for offshore and near shore locations, wave energy maps, analysis of extreme waves, and assessment of open data sources to determine their predictive capability.

- **Assessing impact of offshore wind farm (OWF) monopile on constructive/destructive interference patterns of waves:** NOC work with marine radar imagery was recognised as one of the only ways in which the spatial variations in nearshore wave behaviour could be monitored to investigate the possibility of interference patterns impacting on the shore as a result of the installation of wind turbine monopiles on offshore sand banks. Deployments of the NOC marine radar system were made before and after monopile installation at the Scroby Sands Offshore Wind Farm and the dominant wave patterns filtered and mapped in the stretch of water between the wind farm and Great Yarmouth beach. These radar observations along with numerical modelling (Halcrow) found no evidence of constructive/destructive wave patterns at the shore.
### 4. Evidence and sources to corroborate the impact

4. [http://www.merseytidalpower.co.uk/](http://www.merseytidalpower.co.uk/) Reports and summaries of the feasibility study may be downloaded here [http://www.merseytidalpower.co.uk/sites/default/files/MMTP%20FS%20Stage%203%20Development%20of%20Scheme%20Options.pdf](http://www.merseytidalpower.co.uk/sites/default/files/MMTP%20FS%20Stage%203%20Development%20of%20Scheme%20Options.pdf) A number of journal papers and reports by NOC staff are listed in the references sections of this report.
6. [http://www.bbc.co.uk/news/uk-england-merseyside-13875032](http://www.bbc.co.uk/news/uk-england-merseyside-13875032) Mark Atherton, head of energy and environment at the NWDA, said: "The feasibility work has provided a valuable insight into how tidal energy schemes could be operated in the future to deliver wider economic impact, whilst minimising the potential environmental impact. Some of the lessons learnt from the work undertaken are applicable not just to the Mersey Estuary, but to other estuaries in the North West and UK."
8. Journal papers detailing the wave resource estimation techniques (NOC author: Peter Challenor):
9. [http://www.cefas.defra.gov.uk/media/49662/sid5_ae1227.pdf](http://www.cefas.defra.gov.uk/media/49662/sid5_ae1227.pdf) Assessment of the significance of changes to the inshore wave regime as a consequence of an offshore wind array. Final Report including recommendation to DEFRA not to require monitoring for wave diffraction effects at future wind farms.
11. [https://ke.services.nerc.ac.uk/Marine/Pages/Home.aspx](https://ke.services.nerc.ac.uk/Marine/Pages/Home.aspx) NERC Marine Renewable Energy Knowledge Exchange Programme Portal.

### 5. Contacts for further information

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NOC03: NOC Satellite Oceanography supports growth of the UK Space sector

1. Summary of the impact (maximum 100 words)

NOC Satellite Oceanography (NOC-SO) delivers research, consultancy and training in ocean remote sensing techniques relevant to monitoring the ocean, shelf seas and coastal regions globally. NOC has developed close relationships with key stakeholders in the UK space sector such as Surrey Satellite Technology Ltd (SSTL) and Astrium, leading to significant opportunities for economic growth. Its unique position and long-term outlook allows NOC to define and develop new satellite missions, sensors and Earth Observation products that address the needs of operational users, enhance the international competitive advantage of the UK space industry and are of benefit to science.

2. Nature of the impact

1) Working with Surrey Satellite Technology Ltd since 2004, NOC contributed to significant economic growth for SSTL in the field of GNSS-Reflectometry. NOC demonstrated in 2009 the scientific value for sea state monitoring of reflected signals of opportunity from Global Navigation Satellite Systems (e.g. GPS, Galileo). Co-funded by the UK Centre for Earth Observation Instrumentation and the European Space Agency (ESA), NOC research guided hardware developments at SSTL, leading to the innovative GNSS-R SGR-ReSI receiver to be flown on the TSB-funded TechDemoSat-1 mission in 2013. This international leadership has led to SSTL being awarded the contract to procure eight SGR-ReSI receivers as the main payload of the NASA-funded US$151.7M CYGNSS Hurricane monitoring mission due for launch in 2016. With growing interest from ESA and EUMETSAT for an equivalent European mission, SSTL are in a leading position to procure further GNSS-R sensors for a possible bilateral ESA-NASA CYGNSS-2 follow-on mission, which could include as many as 48 satellites in the constellation.

2) Working with Astrium UK since 2008, NOC provided ground-truthing opportunities for Astrium’s proof of concept airborne trials of the PARIS and the Wavemill instrument concepts. In the case of Wavemill, this has lead to further projects of increasing size with ESA, that have placed Astrium UK in a lead position for the Wavemill Mission study and ultimately the implementation of the full mission. Wavemill provides detailed high-precision maps of ocean currents, offering a major advance in satellite observation of ocean eddy dynamics in the open-ocean and coastal seas. Wavemill will benefit ocean forecasting and operational users of ocean current data (e.g. to minimise the cost and risk of offshore operations). NOC will raise the opportunity of a full mission by providing the scientific lead PI for a UK-led Wavemill proposal as a Core mission (200-300 MEuros) to the ESA Earth Explorer 9 call in 2014.

3) Working with SSTL, the Met Office, Thales Alenia and SatOC Ltd since 2011 in the ESA Fine Scale Altimetry study, NOC has raised opportunities for SSTL to procure a possible future constellation of small satellites for a global ocean altimeter mission. Both ESA and the Centre National d’Études Spatiales (CNES) recognise the advantages of constellations of low-cost satellites to provide improved sampling of the ocean mesoscale with a more robust observing system than can be achieved with a single satellite. NOC is supporting SSTL by providing the science lead and defining the mission requirements on the number of satellites needed in the constellation to achieve the scientific objectives for ocean mesoscale sampling.

4) Working with SatOC Ltd since 2007, NOC contributed to economic growth and competitive advantage for UK research and development by developing new capability in SAR altimetry over ocean, leading to new funding opportunities for the UK from ESA and EUMETSAT in relation to GMES Sentinel-3 and Jason-CS. The guaranteed 15 years of continuous SAR altimeter data from the GMES Sentinel-3A/B missions will revolutionise the exploitation of Earth Observation data, with the long-term availability of satellite data stimulating new operational and commercial services, particularly for coastal applications. NOC also advise the UK Space Agency and the Met Office on SAR altimetry and on UK needs regarding the provision of future altimeter missions (e.g. Jason-CS)

5) Working with Logica UK Ltd, NOC contributed to the European Space Agency (ESA) Data User Element (DUE) GlobWave (2010-present) and ESA eSurge (2011-present) projects to develop new tools and
products for satellite ocean wave and sea level data. These new satellite products are relevant to improve wave and storm surge forecasts and open up opportunities for operational forecasting services (e.g. Met Office) and down-stream commercial services (e.g. HR Wallingford Ltd).

6) Knowledge Transfer Partnership with Pelamis Ltd in 2008 led to global maps of ocean wave power based on satellite altimeter wave period data. Ocean wave power maps are used by renewable energy companies to characterise wave resources worldwide (e.g., see NOC Impact Case Study 02). This allows manufacturers of wave power devices (e.g. Ocean Power Technologies) to optimise the design of wave energy converters to minimise the risk of infrastructure loss or damage in extreme sea states and thus produce commercially competitive devices, and b) to select suitable wave farm sites that maximise power generation and income from electricity production. Global maps of wave power benefit renewable energy companies all over the world, which otherwise have to rely on short-term in situ buoy deployments or expensive numerical model output to estimate wave power resources.

3. How the Centre contributed to the impact

Paragraph numbers refer to paragraph numbers in Section 2

1) GNSS-Reflectometry with SSTL: NOC developed and validated the theoretical inversion algorithms needed to retrieve directional sea state information from ocean reflected GPS signals measured by SSTL on UK-DMC. This provided the scientific advance and initiative for hardware development of GNSS-R receivers for ocean roughness at SSTL.

2) Wavemill with Astrium UK: NOC provided ground-truth data and interpretative skills to validate ocean surface current data for the Astrium UK proof-of-concept flights of the Wavemill airborne demonstrator in the Irish Sea. NOC coordinated the (successful) proposal to ESA for the Wavemill Product Assessment Study, and will provide the scientific lead PI to propose Wavemill as a Core mission to ESA Earth Explorer 9.

3) Fine Scale Altimetry with SSTL: NOC designed and developed specialised software to quantify the mapping error for altimeter sea level for different orbital and satellite constellation configurations. The output of the NOC software will define the requirements for a constellation of small satellites to achieve scientific objectives for ocean mesoscale mapping.

4) SAR altimetry over ocean with SatOC Ltd: NOC was first to demonstrate an almost two-fold improvement in altimeter sea level accuracy with SAR mode altimetry from Cryosat-2 compared to sea level data from Jason-2, as well as excellent performance of SAR altimetry in coastal regions to within 1 km of land.

5) ESA Data User Element (DUE) Globwave and eSurge projects with Logica: NOC developed advanced processing methods and data products to improve satellite altimeter data of sea level and waves in coastal regions within 10 km of land.

6) Ocean wave power maps from satellite altimetry with Pelamis Ltd: NOC pioneered the algorithms to retrieve ocean wave period from satellite altimeters, from which global maps of ocean power resources are derived.

4. Evidence and sources to corroborate the impact

Numbers refer to superscript numbers in Section 2 and Section 3

1 Statement by CEOI Director on Future of NOC Satellite Oceanography, 19 October 2012 (see file attached: CEOI_Support_for_NOC_SatelliteOceanography_Oct2012.pdf)


3 Letter of support by SSTL for NERC Impact Case Study, 19th October 2012 (see file attached: SSTL Letter
4 Statement by Astrium on NOC & Astrium economic impact, 19 October 2012 (see file attached: Astrium_Support_for_NOC_SatelliteOceanography_Oct2012.pdf)
5 SAR Altimetry MOde Studies and Applications project page (SAMOSA), http://www.satoc.eu/projects/samosa/
6 Cryosat Plus For Oceans project page (CP4O), http://www.satoc.eu/projects/CP4O/
8 ESA Data User Element eSurge portal, http://www.storm-surge.info/esurge

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Prof. Meric Srokosz, Senior scientist, mas@noc.ac.uk, 02380 596414
### NOC04: NOC Public Outreach and Media Engagement

#### 1. Summary of the impact

NOC has an active programme of public outreach and media engagement through websites, media releases, requested commentary on new items, twitter, contributions to television productions, and school resources that supports NOC and wider marine community in engaging with the public to highlight the importance of marine science to the global environment\(^1\). This activity is aligned with UK’s Concordat principle for Engaging the Public with Research to “enhance research so that it contributes positively to society and results in greater relevance, accountability and transparency”\(^2\). NOC is the preferred commentator within the UK for marine news in both broadcast and print media.

#### 2. Nature of the impact

NOC supports public outreach/media engagement through sustained media engagement, development of online platforms/social media channels, face-to-face public engagement and support for a range of other knowledge exchange activities:

**Media engagement**

NOC as a national centre is a default source of comment on marine science issues. NOC carefully targets news releases (~50 a year, on average, since 2007\(^4\)) to ensure maximum reach to key target audiences and stakeholders. These include national and international publisher-broadcasters, UK national broadsheets, science and technology sector titles, and regional media. The penetration of news releases is high. For example, in 2011 the majority of targeted NOC press mentions featured on mainstream, multi-platform news titles outside the UK (820) with over half of these appearing on North American sites (429) and “one-third on European sites (294). Mentions in mainstream UK media totalled 252. The number of non-multi-platform/online-only news sources was greater\(^5\). The potential online viewership of NOC-generated news releases for a typical quarter (e.g., Q4 2011) indicates that there were in excess of 110 million opportunities to see a story featuring NOC, equating to around 440 million potential views per annum\(^5\). On the science media portals to which NOC posts its news releases, up to 1,500 science/environment journalists typically view each release\(^6\). NOC stories feature across a broad range of mainstream national and international media. Notable appearances in UK broadsheet and middle market tabloids since 2008 include:

- Geopolitics - NOC’s advisory role to the Foreign and Commonwealth Office on seabed territorial claims (The Guardian\(^7\))
- Climate and mitigation - the debate on geo-engineering (The Telegraph \(^8\)); the role of the oceans in changeable climate (The Guardian\(^9\))
- Marine hazards - NOC wave expertise in widely covered book on surfing (Sunday Times\(^10\))
- Biogeochemistry - the Cayman hydrothermal vents expedition (The Daily Mail\(^11\))
- New species - NOC’s role in Census for Marine Life (The Telegraph\(^12\)).

Features in sector-leading science and technology journals / magazines have been equally as diverse:

- the centre’s autonomous underwater vehicles (Nature\(^13\))
- the excavation of the Pavlopetri archaeological site (New Scientist\(^14\))
- funding for AUVs in mapping and monitoring seas around Britain (The Engineer\(^15\))
- NOC’s leadership role in the RAPID project (Nature\(^16\))
- The debate around geoengineering (The Economist\(^17\)).

NOC provides expertise or participates in numerous broadcast documentaries; examples include:

- Coastal: The Nature of Britain with Alan Titchmarsh – BBC\(^18\) (2007)
- Mapping the ocean floor: Draining the Ocean – NatGeoTV\(^20\) (2009)
- Historic sea level: City Beneath the Waves - Discovery Channel\(^21\) (2011)
- Climate: Is our weather getting worse? – Channel 4\(^22\) (2012)
• Marine Hazards (storm surges) - BBC Countryfile \(^{23}\) (2012)
• Inspiring the marine scientists of tomorrow is a key communications objective and NOC supports material in relevant fora such as:
  • the popular Classroom@Sea initiative\(^{24}\)
  • Royal Society sponsored collaboration between NOC and Liverpool’s Childwall School\(^{25}\)
  • a feature on the TeachersTV professional resource.\(^{26}\)

Comment and expertise

NOC scientists are frequently called upon to comment on topical marine science issues, such as the impact of geo-engineering solutions to mitigate atmospheric carbon levels, habitat destruction, or the environmental impact of oil spills. The tsunamis of 2009 and 2011 generated a huge demand for NOC spokespeople who were interviewed by over 30 national and international broadcasters, with many carried out from the centre’s own broadcast studio.\(^{27}\)

Example target media – BBC online

The BBC is a core media target for NOC. As a trusted global media brand, and the UK broadcaster of record, it exerts a high level of influence over policymakers and other key stakeholders, as well as being a primary source of news and information for general audiences\(^{41}\). In the period January 2007 to December 2012, 107 news stories\(^{39}\) on the BBC website featured or mentioned NOC(S) – a rate in excess of one per month. This is in addition to appearances on various television documentaries (e.g., Coast, Countryfile, Horizon) radio programmes (e.g., Material World\(^{30}\) or The Infinite Monkey Cage\(^{31}\)). Again as an example, in 2012, NOC science and technology, ranging from the Autosub PAP Survey\(^{32}\) or the Cayman vents to the Lake Ellsworth mission featured in 24 individual science stories (an average of two per month) on the BBC news website – principally in the Science & Environment section. The majority of these online stories were also broadcast in at least one of the network’s radio and/or television news programmes or documentaries, widening the potential audience considerably. To give an idea of the scale of the audience for BBC online: in January 2010 alone the BBC generated 35 million unique users, achieving a total 313 million visits.\(^{28}\)

Online and social media

The NOC website provides a comprehensive overview on NOC science and technology impacts. From October to December 2012 it received 46,290 page views of the homepage – the repository of latest news, events and academic publications information. It also feeds social media platforms, including:

  • Facebook, Twitter (2,500 followers) and YouTube (32,000 video views at January 2013) that are all growing our audience, with our target groups (e.g., early-career scientists, research peers, learned institutions, science journalists) well represented in our following.
  • a system allowing scientists to blog in real time from shipboard science exhibitions.

NOC was also a partner in Google’s launch of the oceans layer of Google Earth and provides ongoing input to Google ocean mapping.

Outreach

Outreach engaging broad public audiences ‘face-to-face’ and online are core to NOC’s agenda:

• Ocean & Earth Day at Southampton takes place during National Science & Engineering Week and attracted 3,200 visitors in March 2012, receiving very favourable feedback.
• other open days and managed visits or academic and interest groups.
• funded outreach such the BG Group Geo and Marine Science Summer School 2012.
• schools education support materials, such as Oceans4 Schools, posters and storybooks.
• partnerships with national museums and learned societies, such as the exhibition, The Deep at the Natural History Museum, or the Oceans on Wheels touring exhibition which featured at the Royal Society Summer Science Exhibition - provide NOC with high-profile, national showcases for its work which attract a knowledgeable audience.
NOC’s role as science adviser to the Cape Farewell project, which unites artists and researchers to consider climate change, opens up oceanography to new audiences.

3. How the Centre contributed to the impact

As a world leading marine institution, NOC has an established science and technology expertise that is a default commentary source. This expertise is built on a pool of leading scientists that explain and promote NOC science to a range of stakeholders - including policymakers, industry partners and research peers – through external media, online, social media and outreach, the centre’s ensures that research impacts reach as wide an audience as possible, opening up opportunities for more focused engagement. This supports tangible benefits for the centre in targeted recruitment, commercial partnership, funding and acknowledgement of achievements. NOC is involved in various fora, such as the European Science Foundation (ESF) Marine Board Communications Group, the Partnership for the Global Oceans (POGO) and the Marine Science Coordination Committee’s (MSCC) Communications Working Group, to improve ocean literacy so that marine science is better understood by stakeholders and the wider population.

4. Evidence and sources to corroborate the impact

1. Setting Course – A community vision and priorities for marine research developed by the National Oceanography Association. Measuring Success (p.14) http://noc.ac.uk/f/content/downloads/2012/Setting-Course.pdf
5. Analytics report on online media traffic generated by NOC CPE, provided by Meltwater Group.
6. Eurekalert/Alphagallileo analytics.
10. http://www.thetimes.co.uk/sto/culture/books/non_fiction/article401140.ece
17. http://www.economist.com/node/13013035
19. http://www.bbc.co.uk/programmes/b0087fg0
24. BBC Online news web search
25. http://www.bbc.co.uk/programmes/b01ljkwk

5. Contacts for further information

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### NOC05: Sustainability and health of UK national seas: now and the future

#### 1. Summary of the impact (maximum 100 words)
NOC was pivotal in providing advice and evidence feeding into UK assessments on “clean, healthy, safe, productive and biologically diverse oceans and seas”. These underpin legislation aimed at achieving this vision, specifically the EU Marine Strategy Framework Directive. In the UK this took the form of the report: “Charting Progress 2: The State of UK Seas”, and the on-going Evidence Groups. Alongside this, the Marine Climate Change Impacts Partnership (MCCIP) and UKCP09 provide assessments of potential future conditions. NOC is the leading UK organisation for providing this evidence, advice, information and future projections for physical oceanography. Its scientists were lead / co-authors for CP2 “Ocean Processes” chapter, most MCCIP science reviews, and the UKCP09 Marine Section.

#### 2. Nature of the impact

- **The UK vision for “clean, healthy, safe, productive and biologically diverse oceans and seas”** (Defra, 2002) is reinforced by international obligations, e.g. the Oslo-Paris Convention. Especially, the EU Marine Strategy Framework Directive (MSFD, 2008) lists 11 aspects of “Good Environmental Status” (GES) to be achieved by 2020, and monitored on a six-yearly cycle. Costs of neglecting such Directives can be severe but avoided through good scientific knowledge; NOC’s role has been to provide this knowledge in appropriate and timely forms.

- In pursuit of the UK vision and more recently the implementation of MSFD, Defra leads the UK Marine Monitoring and Assessment Strategy (UKMMAS), a “community” of more than 40 member organisations. Through UKMMAS Defra sponsored “Charting Progress 2: The State of UK Seas” (CP2, 2010)¹, a comprehensive report on the state of the UK seas. CP2 “provides a considerably improved assessment of the productivity of our seas, and the extent to which human uses and natural pressures are affecting their quality – addressing the specific species, habitats and economic issues of the eight UK Marine regions. It helps to show whether current environmental protection measures are working, and aims to provide policy makers, planners and the public with a clear evaluation of our progress towards the vision” (Defra introduction therein). CP2 forms the primary evidence base for the Defra 2012 UK Initial Assessment of the state of UK seas under MSFD; this Initial Assessment needed little other evidence than that in CP2 (2010)¹. The CP2 experience has enabled the UK to take the lead across Europe in many aspects of MSFD refinement of GES, defining indicators and targets.

- **Annual gross value added by UK marine economic activity** is estimated as £47bn, including £37bn oil and gas extraction (CP2, 2010)¹. MSFD poses a challenge to sustain this activity while achieving and maintaining GES. An aspect of this challenge is delivering science to distinguish human from climatic factors in change. The distinction helps to develop an effective Programme of Measures for GES, saving UK plc and Government money. An example is the successful defence of Infraction Proceedings under the Urban Waste Water Treatment Directive. Science refutation of this alleged eutrophication in nearshore UK waters (due to nitrate etc. in waste-water) avoided a cost to the UK water industry of £6 bn⁷ (of ineffective measures).

- **The UK Marine Climate Change Impacts Partnership (MCCIP)** brings together scientists, government, its agencies and NGOs to provide co-ordinated advice on climate change impacts around our coast and in our seas³. The UK marine science strategy states that “Ocean information will be essential and integral to the development and continual improvement of climate information. In this context, MCCIP, in which many organisations contribute to regular assessments of current and future changes, is an example of good practice that the Strategy will seek to support and encourage”⁴. Beneficiaries include all those handling marine impacts of climate change. These include Defra and “UK plc”: UK business performance vis à vis environmental sustainability and environmental operating conditions.

- **UKCP09** is the fifth generation of climate change information for the UK, reflecting significant advances in climate science and computer modelling. For the first time, marine and coastal projections for NW European Seas are included (for sea level rise, storm surge, sea surface and sub-surface temperature,
salinity, currents, and waves), including freely available model data sets. MEECE\textsuperscript{3} and QUEST\_FISH\textsuperscript{4} projects followed this up by exploring climate and direct anthropogenic effects on planktonic ecosystems and fish/fisheries.

• The potential relevance of climate change impacts on fish production to food security are immense, particularly when considered on a global scale, as in QUEST-FISH: about 400 million people rely on fish for >50% of their animal protein\textsuperscript{7}.

• UKCP09\textsuperscript{8} and MEECE provide a future look at potential changes to GES under MSFD, specifically relevant to the following GES Descriptors: 1, Biological diversity; 3, Population of commercial fish / shell fish; 4, Elements of marine food webs; 5, Eutrophication; 6, Sea floor integrity; 7, Alteration of hydrographical conditions.

3. How the Centre contributed to the impact

• J. Huthnance (NOC) was lead author of Ocean Processes Chapter 2 in “Charting Progress 2” (CP2, 2010)\textsuperscript{1} and lead author/editor of the supporting Ocean Processes “Feeder Report” (279pp)\textsuperscript{9}. Thereby NOC (with partners) has determined how the state of UK seas (temperature, salinity, CO2/pH, circulation, sea-level, waves, suspended matter and morphology) depends on human, climate and other “external” factors. Other NOC lead authors for these components were D. Hydes, R. Sanders, J. Wolf and P. Woodworth.

• Led by J. Holt, NOC has developed and applied shelf sea hydrodynamics, waves, sediments and ecosystem models, and has been central in the deployment of these for climate change studies and the analysis of past and present day change (in UKCP09, MEECE, QUEST-FISH, MYOCEAN\textsuperscript{10}). In parallel, these models have also been developed for operational oceanography (e.g. NEMO). This has been realised through: (a) the use of models (POLCOMS, POLCOMS-WAM)\textsuperscript{11} developed at NOC in the UKCP09 process\textsuperscript{12}, (b) NOC provision of the EC/ESA Global Monitoring for Environment and Security (GMES) Marine Core Services product for long-term hindcast of the North west European Shelf (in MYOCEAN)\textsuperscript{10}, (c) production of the MEECE Atlas and Fact Sheets, and (d) provision of the QUEST-FISH data sets to BADC\textsuperscript{13}, to yield primary production estimates for a future scenario, aggregated by Exclusive Economic Zone they cover ~60% of the global fisheries production.

• For MCCIP (2010)\textsuperscript{14} nine chapters of the underpinning Science Reviews were co-authored by D. Berry, S. Cunningham, P. Holliday, J. Holt, K. Horsburgh, J. Hughes, S. Josey, E. Kent, J. Sharples, C. Wallace and J. Wolf (all of NOC).

• NOC participates in the newly formed ICES-PICES Strategic Initiative on Climate Change effects on Marine Ecosystems (SICCME). This group coordinated the first international symposium on ‘Climate change effects on fish and fisheries’, in Sendai, Japan (2010), organised by ICES, PICES, and FAO, with sponsors including the World Bank\textsuperscript{15}.

4. Evidence and sources to corroborate the impact

Regarding CP2 as a basis for the UK 2012 Initial Assessment under the EU MSFD: from paragraphs 154 and 157 of the Defra MSFD Consultation Document, March 2012: “Gathering together existing knowledge on the state of these varied seas represents a formidable challenge, which has been tackled through the development of Charting Progress 2 and its peer-reviewed feeder reports by the UK Marine Monitoring and Assessment Strategy (UKMMAS) community. The underlying evidence compiled to support the UK’s Initial Assessment for the MSFD represents the most comprehensive assessment of the current status of UK’s seas to date, and provides a framework which we will look to build on in our future management of the seas.” And: “The assessment of the current environmental status of UK waters and the use of those waters by different economic and social sectors is based on the Charting Progress 2 assessment of the state of UK Seas, which was published in 2010. Charting Progress 2 was a milestone evaluation prepared by the UKMMAS community which has over 40 member organisations. It was based on a robust, peer-reviewed evidence base and provided key findings from UK marine research and monitoring for use by policy makers and others, as we move towards the UK vision of clean, healthy, safe, productive and biologically diverse
Minister for the Marine Environment, Richard Benyon, said of the MCCIP 2010 Report Card: “For hundreds of years our seas have supported our fishing industry that provides us with food and coastal communities a way of life, as well as the vital marine ecosystem that is home to half the world species and habitats. But the seas and oceans are changing and we are only just starting to understand what this means. Scientific studies through partnerships such as this provide the research and knowledge that we need to understand how climate change is affecting the world’s waters and what action we need to take.” - http://www.mccip.org.uk/

1 Charting Progress 2 (CP2, 2010); http://chartingprogress.defra.gov.uk/.
3 http://www.mccip.org.uk
5 http://www.meece.eu
6 http://www.quest-fish.org.uk/
7 FAO 2012
8 http://ukclimateprojections-ui.defra.gov.uk/ui/admin/login.php
9 http://chartingprogress.defra.gov.uk/ocean-processes-feeder-report-download
10 http://www.myocean.eu/web/24-catalogue.php
11 Between May and December 2012, 38 downloads of the POLCOMS and ERSEM 40yr NWS hindcasts product were logged (data has been available from 2010 but earlier figures are not available).
12 As of November 2012: 1478 data requests from the UKCP09 user interface for the POLCOMS hydrography data have been made.
13 http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_12233057258726774
14 Baxter JM, Buckley PJ, and Wallace, CJ (Eds.) Summary Report, MCCIP, Lowestoft, 12pp
15 http://www.pices.int/meetings/international_symposia/2010/cc_effects_fish

5. Contacts for further information

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Jason Holt, Associate Head Marine systems Modelling Group, jholt@noc.ac.uk, 0151 795 4853
NOC06: Training the next generation of the UK’s skilled workforce in ocean science and technology

1. Summary of the impact (maximum 100 words)
The UK Government has a core policy of developing a skilled workforce to improve public policy, and underpin an innovating and expanding UK economy (especially in emerging low carbon and innovation technologies). NOC is a key partner in training postgraduates in STEM subjects within the Graduate School of the National Oceanography Centre, Southampton (GSNOCS)\(^1\), and universities of Liverpool\(^2\) and Bangor\(^3\). Within the 2007-2012 period NOC has contributed to the training of >150 PhD graduates\(^4\) that are contributing to UK economic / societal benefit.

2. Nature of the impact
At a macro-economic scale, the impact of highly-skilled postgraduate students to UK economic growth and innovation is well established with (1) postgraduates as “key drivers of growth, innovation, entrepreneurship, management, leadership, and research and development”\(^5,6\), (2) enterprises that are “innovation active” have nearly twice the number of graduate or postgraduate employees\(^7\), (3) enterprises that employ highly qualified staff are more productive\(^8\), (4) typically 94% of postgraduates gain employment\(^9\), (5) postgraduates have additional lifetime salary benefits of >£70,800,000\(^10\). Additionally, new emerging industries (e.g., offshore carbon capture and storage, marine renewables) are constrained in development by the lack of appropriate supply of skilled STEM postgraduates\(^11\). GSNOCS (and to a lesser extent the universities of Liverpool and Bangor) are key training institutions to develop postgraduates across solid earth geology and geophysics, observational and modelling oceanography, marine biology and biogeochemistry, and ocean technology and engineering sciences. Postgraduates from GSNOCS are gaining employment in oil and gas exploration, offshore oil service industry, marine renewable industry, offshore wind power industry, climate service consultancies, marine environmental consultancies, and maritime defence industries.

Similarly, NOC is directly training and educating the next generation of earth system researchers and academics to maintain the UK’s world-leading environmental science and technology research base.

3. How the Centre contributed to the impact
The GSNOCS has been a joint and collaborative activity for NOC (and its predecessor institutes) with the University of Southampton since 1998, and has been jointly funded since 2002. Over the period 2007-2012, the GSNOCS (and postgraduates at Liverpool and Bangor) has grown by 57% and as of December 2012 comprises more than 200 PhD students. The recent and significant expansion of GSNOCS PhD numbers could not have been sustained by University of Southampton Ocean & Earth Sciences academic staff alone. Currently NOC staff are supervising, co-supervising, or providing independent panel advice to >95 PhD students (at 1 December 2012\(^12\)), and is consequently producing a large cohort of STEM postgraduates for the UK skills and research base. Over the review period NOC has generated 39 PhD studentships through competitive funding success (where NOC is the institutional lead), and directly funded a further 100+ PhD studentships from its own funding resources over the review period\(^13\). Additionally, NOC staff are regularly involved in the co-supervision of PhD students hosted in other research organisations and universities overseas.

The research and training of these postgraduates has been enhanced by working within NOC research programmes, where students have been exposed to multidisciplinary, long-term environmental change and world-leading science and technology projects that provide a global perspective to PhD research projects. Additionally, the contribution of NOC “activity” to the GSNOCS provides PhD graduands with training opportunities and experiences not usually offered at other UK academic departments, including:

- training on the use, application, and code development of high-performance cluster computing
(including access to national facilities e.g., HECTOR / MONSOON), with specific application to ocean / atmosphere modelling;

• opportunities for extensive at-sea training in shipboard data acquisition/processing for world-leading marine geophysical, marine biogeochemical and oceanography research;

• extensive access to unique UK research infrastructure (e.g., Autosub AUVs, ISIS and Hybis ROVs) that is not routinely accessible to most UK postgraduates;

• extensive access to unique NOC laboratory facilities including high pressure test facilities, high pressure rock physics laboratories, micro-sensor fabrication facilities, and aquaria;

• easy access to national facilities and long-term sustained observing datasets directly funded by NOC (e.g., BOSCORF core repository\(^1\), Permanent Service for Mean Sea-Level\(^2\), Discovery Biological Collections\(^3\), and RAPID project\(^4\)) that encourage research on fundamental science questions requiring decadal observation.

4. Evidence and sources to corroborate the impact

1. http://noc.ac.uk/gsnocs
2. http://noc.ac.uk/education/postgraduate-studies/phd-opportunities-noc-liverpool
3. http://www.bangor.ac.uk/oceansciences
4. Prof. Paul Wilson (Head) GSNOCs paul.wilson@noc.soton.ac.uk
   Prof. Damon Teagle (Head of Recruitment), GSNOCs damon.Teagle@southampton.ac.uk
12. GSNOCs Graduate Office, University of Southampton, Southampton.
13. GSNOCs Graduate Office, University of Southampton, Southampton.
17. http://www.noc.soton.ac.uk/rapidmoc/

5. Contacts for further information
   Professor Ian Wright, Director of Science & Technology, jan.wright@noc.ac.uk, 02380 596017
1. Summary of the impact (maximum 100 words)

NOC science in the areas of sea level study, modelling of storm surges, waves and tsunamis, and the statistics of sea level extremes, underpins many aspects of government policy on coastal defence and the mitigation of risk. The science forms the basis of mature operational partnerships with the Environment Agency and with the Met Office. Through the Natural Hazards Partnership, NOC reviews coastal hazards for the National Risk Assessment (NRA) and advises the Government Chief Scientist on this issue.

2. Nature of the impact

Coastal floods affecting the UK represent a threat to life as well as to economic and environmental assets. Around £150 billion of assets and four million people are at risk from coastal flooding in the UK. Irrespective of any future change in storm climate, mean sea level rise will result in more instances of extreme sea levels. NOC plays a central role in the UK Coastal Monitoring and Forecasting (UKCMF) partnership, developing and maintaining the operational storm surge models as well as managing the network of UK tide gauges. The UKCMF system delivers improved coastal flood warning systems to the Environment Agency (EA). The coastal flood warning system for the UK was established as a direct result of the 1953 North Sea storm surge, which is still the worst natural disaster to affect the country in modern times.

These flood warning systems safeguard lives, property and economic investment in the Thames area. Predictions for the November 2007 storm surge allowed agencies to operate the Thames Barrier and evacuate areas of Norfolk, avoiding fatalities and financial loss (307 lives were lost in the 1953 storm surge). Analysis by the Environment Agency shows that 500,000 homes are at risk of flooding in the Thames floodplain. The estimated value of property protected by the Thames Barrier is £200 billion. If predictive modelling safeguards only 1% of these assets then it protects property to the value of £2 billion per annum. Preserving Foreign Direct Investment to the London economy by alleviating concern of flood risk is also valued at £2 billion per annum; furthermore, the direct economic costs of any flood event in London would cost £94 million per flood day.

The expected annual damages to properties in England at risk of flooding from rivers and the sea is estimated at more than £1 billion. Over 25,400 miles of flood defences help reduce the risk by a factor of four, and in 2008-2009 the budget for flood defences in England was £427 million. Coastal protection is designed using statistical methods, and the Environment Agency funded NOC scientists to work with university and engineering partners to provide the most reliable estimates of extreme water levels in a consistent way around the entire UK coastline.

Through the Natural Hazards Partnership (NHP), NOC science relating to coastal hazards is translated into products and information in support of government. The NHP is a consortium of public bodies that provides information, research and analysis on natural hazards for the development of more effective policies, communications and services for civil contingencies, governments and the responder community across the UK.

Following the devastating Indian Ocean tsunami in 2004, Horsburgh and Wilson provided the tsunami wave modelling expertise for two Defra-funded studies. These studies assessed the risk to the UK of tsunamis from several plausible sources. NOC scientists and engineers (Woodworth, Holgate, Foden) also contributed towards international efforts to deliver a more effective tsunami warning system in the Indian Ocean, resulting in the saving of thousands of lives. Although the risk to the UK from tsunamis is extremely small, it is important to engage with international warning system initiatives: Horsburgh advises the Cabinet Office on how the UK should receive operational alerts from the Intergovernmental Oceanographic
Commission’s (IOC) North East Atlantic and Mediterranean Tsunami Warning System (NEAMTWs).

More recently, the Sendai earthquake off Japan in March 2011, and the resulting disaster at the Fukushima nuclear power plant, prompted a further review of risk to the UK’s nuclear infrastructure from tsunamis. NOC were solicited to provide advice on tsunami risk to the UK to HM Chief Inspector of Nuclear Installations.

3. How the Centre contributed to the impact

NERC scientific expertise: NOC scientists develop the operational models for waves (Wolf) and storm surges (Horsburgh, Wilson) that are the core of the coastal flood warning service. Woodworth and Horsburgh work with university statisticians to develop the statistical methods for the reliable and consistent calculation of extreme sea level statistics. The same tools are used to interpret the results of climate model simulations and thus advise the government on sea level extremes in future climate scenarios; this influences policy on coastal defence and investment therein. NOC also advises the insurance and reinsurance industry on coastal hazards. NOC is a member of the Willis Research Network (WRN), and Horsburgh holds the Chair of the Scientific Steering Group of the Lloyds Register Educational Trust project, “Global networking to improve prediction of extreme maritime events”.

New tools and understanding: The UKCMF operational modelling systems combined with the NOC-managed tide gauge network are a critical forecasting service and provide the Environment Agency with a platform to warn the public; their upgrade and improvement involves NOC scientists (Horsburgh, Wilson) funded by the EA on an ongoing basis, and working in collaboration with the Met Office.

The latest estimates of extreme sea level characteristics provide the basis for the design of seawalls and other defence assets around the entire UK coastline. As a result of these figures, the government can maintain the level of protection where policy demands, and also ensure that public spending for expensive coastal engineering has a rigorous basis.

Scientists from NOC (Woodworth, Foden, Holgate) designed new telemetry technology for the Indian Ocean tsunami monitoring system. The work resulted in an agreement between the Intergovernmental Oceanographic Commission (IOC) and Inmarsat to provide BGAN satellite transmission service for 50 sea level stations in the Indian Ocean, to improve the speed of tsunami warnings and save lives. Those involved were awarded the IMarEST Denny medal for their paper describing the work.

Influencing HMG legislation and policy: The sea level team within NOC is world-leading in every aspect of coastal extreme water levels. NOC science in the areas of sea level rise, storm surge and wave forecasting, and shelf sea modelling formed the basis of marine projections in the UKCP09 climate projections. This study influences planning policy for coastal defence and – in tandem with the EA’s Thames Estuary 2100 programme –provides the decision framework for replacing the Thames Barrier.

The Natural Hazards Partnership advises the Civil Contingencies Secretariat (CCS) of the Cabinet Office annually on the risks contained in the National Risk Assessment (NRA), and also provides the scientific advice briefings required by SAGE for each hazard. The key coastal flood hazard in the NRA is the so-called ‘scenario H-19’ major East Coast Flood. Letters of support for the work of NHP have been received from the Cabinet Office; its work has been put forward by the government Chief Scientist as an excellent model for a risk expert group to consider emerging international risks and disasters resulting from natural hazards.

Wolf, Huthnance, Horsburgh and Holt all contribute to the Marine Climate Change Impacts Partnership (MCCIP) annual report card that is widely disseminated across UK marine stakeholder organisations and is used by decision makers within government. Horsburgh consistently provides lead authorship on the MCCIP annual reports for sea level extremes and coastal flooding. MCCIP Chair Philip Stamp says ‘The expertise of NOC scientists on a huge range of topics was invaluable and the comprehensive nature of the scientific reviews provided were particularly impressive’.

At the request of HM Chief Inspector of Nuclear Installations, NOC supplied the oceanographic input to his
report\textsuperscript{15} in 2011 to the Secretary of State for Energy and Climate Change. In a letter of thanks from HM Chief Inspector\textsuperscript{16}, he states that, “...the final report was widely praised for its clarity and content”.

\textbf{4. Evidence and sources to corroborate the impact}


\textsuperscript{2} http://www.environment-agency.gov.uk/research/policy/116129.aspx


\textsuperscript{4} Economic estimates are from DTZ report: www.nerc.ac.uk/business/casestudies/.../storm-surge-report.pdf


\textsuperscript{6} http://www.cabinetoffice.gov.uk/content/natural-hazards-partnership

\textsuperscript{7} http://archive.defra.gov.uk/environment/flooding/risk/tsunami.htm

\textsuperscript{8} Holgate, S., Foden, P., Pugh, J. and Woodworth, P. 2008. Journal of Operational Oceanography, 1, 3-8


\textsuperscript{10} Thames Estuary 2100. Analysis of future extreme sea levels in the southern North Sea, based on coupled climate-surge models (collaboration with the Met Office). http://www.environment-agency.gov.uk/homeandleisure/floods/104695.aspx


\textsuperscript{14} Letter to Prof Ed Hill from MCCIP Chair Philip Stamp following publication of the 2010-11 MCCIP Report Card.

\textsuperscript{15} http://www.hse.gov.uk/nuclear/fukushima/final-report.htm

\textsuperscript{16} Letter to Dr Kevin Horsburgh from HM Chief Inspector of Nuclear Installations, Dr Mike Weightman, 24 October 2011

\textbf{5. Contacts for further information}

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**NOC08: Seafloor mapping and monitoring: Marine Protected Areas and policy advice**

1. **Summary of the impact (maximum 100 words)**
   As human activities in the marine environment proliferate, there is an increasing need for high-quality seafloor mapping and monitoring data (the ‘evidence base’) to support integrated marine planning, sustainable resource exploitation, and maintenance of ecosystem services. NOC scientists are meeting this requirement by i) developing new technologies, techniques and products (maps) to improve the quality, coverage and cost-effectiveness of data, ii) providing expert scientific advice to UK and international policy-makers, e.g. Defra, to underpin marine conservation and governance, and iii) leading efforts, through MAREMAP, to improve co-ordination of marine mapping and monitoring activities across NERC and the public sector.

2. **Nature of the impact**
   NOC seafloor mapping and monitoring activities have had significant impact in two key areas:

   **Development and co-ordination of marine mapping to underpin ‘blue growth’**
   Marine activities now contribute >£50bn pa to the UK economy, and employ more than a million people1. Primary activities include leisure, shipping, resource exploitation (fishing, hydrocarbons, aggregates), and development of offshore infrastructure (e.g. marine renewables, oil and gas pipelines). All of these activities require base maps of the marine environment, e.g. seafloor bathymetry, substrate, habitats/species, especially when viewed within a marine spatial planning framework. However, in many areas suitable maps are not available, e.g. less than a third of the UK seafloor is mapped with multibeam bathymetry at fit-for-purpose resolution. This data gap is exacerbated by the rising cost of survey vessels, e.g. the average price of heavy fuel oil increased by 254% in real terms between 2001 and 2011, including an increase of 18.5% since 20102. Therefore, the overall cost to government and industry of ship-based marine mapping and monitoring is rapidly increasing, at a time when increasing human impacts and statutory obligations (e.g. Marine Strategy Framework Directive; MSFD) mean that the requirement to undertake such work is also increasing.

   **NOC impact:** NOC scientists have developed new techniques and technologies to improve data quality and reduce costs of seafloor mapping and monitoring for government and industry. A recent example is a Defra-funded study demonstrating how Unmanned Underwater Vehicles (UUVs) can be used for Marine Protected Area (MPA) mapping and monitoring3. NOC are also Lead Partners in the UK Marine Environmental Mapping Programme (MAREMAP), launched in 2010 with British Geological Survey and Scottish Association for Marine Science and dominantly funded through NERC National Capability. Associate Partners include Cefas, Channel Coastal Observatory, Maritime and Coastguard Agency, and Universities of Southampton and Plymouth, while the Marine Management Organisation and Joint Nature Conservation Committee (JNCC) have seats on the Advisory Panel. The two main aims of MAREMAP are to i) co-ordinate mapping effort between government, industry and academia to ensure maximum coverage and avoid duplication, and ii) generate new seafloor and habitat maps in strategically important areas and make them freely accessible via the programme website4. It costs ~£0.7M to map a 1000 km² area of seafloor on the UK shelf using multibeam bathymetry; avoiding duplication and ensuring effective dissemination of data through MAREMAP will help reduce these costs.

   **Mapping and monitoring of UK and International Marine Protected Areas**
   The UK is committed to development of an ecologically coherent network of MPAs; this network will add to existing MPAs, such as Special Areas of Conservation (SACs). Originally planned for delivery in 2012, the implementation of the network in England has been delayed so that new data can be collected to strengthen the evidence base for decision-making. Marine mapping is an integral part of this process, specifically to aid design of the location, areal extent and management measures for each MPA. Regular monitoring will then be required to assess the efficacy of management measures. Further afield, the UK
Overseas Territories Exclusive Economic Zones (EEZs) cover 5.8 million km², of which >99% is marine. There are huge economic opportunities in these EEZs, and in international waters outside of UK territory. Potentially important activities include deep-sea mining, eco-tourism and hydrocarbon exploration. These need to be balanced against recent establishment of vast MPAs in UK territory, such as the South Georgia and South Sandwich Islands MPA that covers over one million km². Seafloor maps and scientific advice are required to underpin management of these activities, and to inform policy in these regions.

**NOC impact:** NOC has internationally-recognised expertise in the science of benthic habitat mapping, exemplified by leadership of major EU programmes such as HERMIONE (£15.5M) and CODEMAP (£1.4M), and publication of high-profile scientific papers in the review period³⁶. NOC scientists are now applying this expertise to MPA development in UK waters, through i) provision of new data and habitat maps to Defra/JNCC/Cefas to assist with implementation of MPAs in UK waters, and ii) sharing of best practice and resources in marine habitat mapping through, e.g. vessel sharing and technical workshops. At the international level, provision of expert advice by NOC scientists is helping policy-makers determine how best to manage seafloor resource exploitation in the open ocean. This is achieved through contributions to UN fora, e.g. the International Seabed Authority, and delivery of reports to the UN, e.g. on deep-water fisheries impacts⁷.

3. How the Centre contributed to the impact

Within MAREMAP, NOC are responsible for leading many aspects of seafloor and pelagic habitat mapping, and have delivered several reports to policy-makers engaged in UK MPA planning. This includes a strategic study funded by Defra in 2012 on the scientific capabilities of the UK UUV fleet, and how these platforms can be applied to MPA mapping/monitoring; the final report concluded that UUVs can collect data of higher quality and at significantly lower cost in many areas of the UK offshore³ (see Annex 1). Ongoing proof-of-concept studies are now demonstrating to Defra how these platforms can be integrated into MPA and MSFD monitoring (see quote below from Director of Defra Marine⁸). NOC has also been funded by JNCC to deliver broad-scale habitat mapping studies off northwest UK⁹,¹⁰, and in 2010 NOC scientists led an EU-NERC-JNCC-funded research cruise on RRS James Cook to this region (with JNCC staff aboard) to map and monitor vulnerable cold-water coral communities; both studies are now guiding MPA implementation in this area¹¹. Most recently, NOC has been i) funded by Cefas to deliver habitat maps to aid designation of recommended Marine Conservation Zones (rMCZ) in England, ii) funded by Worthing Borough Council to deliver nearshore benthic maps off Sussex to assist with coastal defence and marine spatial planning, and iii) funded by Natural England to map seabird and cetacean foraging distributions off northwest Cornwall in relation to substrate/bathymetry, in order to advise mitigation measures to reduce seabird and cetacean bycatch in commercial fishing gear.

At an international level, NOC sits on the Legal and Technical Commission of the UN International Seabed Authority (and hosted the Chair in 2011), and on the British Indian Overseas Territory (BIOT) Science Advisory Group. NOC scientists made presentations to the UN General Assembly in 2009 and 2011 on the results of the HERMIONE project and the impacts of fishing in the deep ocean (partly based upon a high-profile scientific paper published in PLoS One⁵); NOC subsequently delivered a report to the UN on how to mitigate seafloor impacts of deep-sea fisheries⁷. Other specific deliverables include preparation of seafloor maps for the UN South East Atlantic Fisheries Organisation (SEAFO) to support implementation of fisheries management measures on seamounts¹², and contribution to a Convention of Biological Diversity workshop in autumn 2011 on establishment of Ecologically and Biologically Significant Areas (EBSAs) that resulted in a commentary published in Nature¹³.
4. Evidence and sources to corroborate the impact

4. http://www.maremap.ac.uk
8. Quote from John Robbs, Director, Defra Marine and Natural Environment Programme: “This is the first time that autonomous underwater technology will use novel sensors such as echosounders and Passive Acoustic Monitoring instruments to assess fish and cetacean abundance in dynamic frontal regions in UK shelf waters. These are important sites for commercial pelagic fisheries but are difficult to monitor using conventional means. The project will provide an innovative proof-of-concept and could significantly influence the nature of future marine monitoring in UK shelf waters”.
11. http://jncc.defra.gov.uk/page-5903

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1. Summary of the impact (maximum 100 words)
NOC is a strategic partner with the MoD in supporting technology, innovation, and scientific advice, particularly in areas of “marine environmental battlespace” and unmanned maritime systems. The UK Ministry of Defence Strategic Defence and Security Review (SDR)\(^1\) sets clear targets for national security and defence capabilities, and a clear objective of this strategy is greater focussed science and technology capability provided by strategic partners. NOC is a strategic partner in providing specialised capability in technological innovation and application of autonomous surveillance systems, ocean environment and counter-detection of submarines, and operational oceanographic modelling to the MoD and associated defence industry.

2. Nature of the impact
The beneficiaries of NOC defence-orientated research application include the Royal Navy, Defence Science and Technology Laboratory (Dstl), Ministry of Defence, and defence industries comprising BAe, Thales, QinetiQ, Atlas, and SEA. NOC is providing expertise in three key areas (see below). In each area, NOC has provided crucial underpinning technological innovation risk, cost benefit analysis, legal and design studies, and translational research.

Unmanned maritime systems (UMS): The Royal Navy (RN) is increasingly turning to UMS to both characterise the battlespace and fight within it. UMS offers a number of advantages over conventional platforms - cheaper capital and operating costs, removal of personnel from the threat environment, potential to operate more covertly, and ‘force multiplier’ as a consequence of ‘swarming’. NOC development of underwater vehicles has lead to a world-leading position in marine geospatial intelligence acquisition from UMS, including sensor integration, data handling, autonomous intelligent mission tracking, and de-risking of operations. As a consequence, NOC is an important contributor in the Mine Counter Measures, Hydrography and Patrol Capability (MHPC) programme, which incorporates significant use of unmanned surveillance and battle systems, and is fundamental to the RN’s future capability in the underwater battlespace. This work has either been directly funded by Dstl or through consortium structures such as OSPREY and its successor MarCE set up by the MoD to fund defence science and technology. More recently, NOC has provided advice on defence applications of non-powered and surface wave glider vehicles. Such advice also includes strategies for maritime autonomous vehicle mix, a modular approach to sensors to be carried on vehicles, and the legal and policy approach adopted during operational use during both peacetime and armed conflict.

Ocean environment: Various ocean parameters including bioluminescence, biogeochemistry, underwater acoustic, turbulence, and radionuclide emissions are potential signatures of UK SSN and SSBN submarines. NOC is providing critical insight into the distribution and natural variability of these parameters to improve the tactical awareness of UK SSN and SSBN submarines to minimise their counter-detection by enemy submarines and other anti-submarine warfare assets. This work has proven sufficiently important to lead to follow-on classified work being undertaken by Dstl and defence companies. MoD has funded a number of NOC scientists to work on defence science at the highest levels in this field.

Ocean modelling: NOC science (particularly ocean modelling) has a clear global reach. With reducing number of UK naval assets but potentially greater ‘operational space’, the use of high-resolution oceanographic modelling (especially in waves, currents, turbulence, seasonal temperature variability, seasonal salinity range and bioluminescence) for physical and environmental / biological parameters is critical to guide and prepare for future defence operations. Such work is also underpinning naval equipment procurement with expected service for at least 20 years, an example being the NOC research relating to the planned Mine Counter Measures, Hydrography and Patrol Capability (MHPC).

Wider NOC engagement with the NOC UK Defence community is maintained via a web-based newsletter (see [http://noc.ac.uk/pios](http://noc.ac.uk/pios)) that is circulated to highlight unclassified work from NOC’s defence research activities. Dstl recently noted that MoD will in future, “have to rely on certain [scientific] knowledge being supported” by NERC.
3. How the Centre contributed to the impact

NOC expertise and leadership in autonomous vehicle technology and synthesis of global oceanography observation datasets has been fundamental to the impacts described above. Since the first Autosub vehicle went to sea in 1996, NOC continues to be a centre of expertise in autonomous vehicles and has successfully completed extensive scientific programmes under both Antarctic and Greenland ice shelves. Within the review period NOC has developed the Autosub6000 and Autosub Long-Range vehicles, consolidated its 14 vehicles and expertise into the Marine Autonomous and Robotic Systems (MARS) Facility, and increased development of marine sensors. This continued and sustained activity is the building block upon which UK defence UMS applications have been developed, especially over the last five years where NOC innovation is making a step change in capability including an evolving autonomous surface vehicle capability. Similarly, NOC capability in multi-parameter observations, insight into physical and biological processes, and associated assimilation into global ocean models provides the scientific basis for being tactically aware and prepared within the ocean environment.

The entire scope of the defence related impact and associated supporting evidence cannot be fully described due to the classified nature of the work being undertaken.

4. Evidence and sources to corroborate the impact


Below are some of the key reports and science papers that reflect the significance of the impact of the NOC presence as a strategic partner to the UK Defence and security communities:

Underwater Maritime Systems


Ocean Environment and Modelling

Luminescence And Marine Phytoplankton - LAMP


a review, National Oceanography Centre, Research and Consultancy Report No. 05, pp. 106.


Operational Biogeochemistry for Submariners - OBS


Legal Regime of Naval Sonar


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NOC10: Deep water frontier hydrocarbon exploration

1. Summary of the impact (maximum 100 words)

Until new energy sources can be developed, the world economy and human wellbeing remains dependent on hydrocarbons, many of which are in subsea reservoirs found in increasingly deep waters or extreme conditions (e.g. West of Shetland & Arctic Oceans). NOC has made a significant contribution to economic growth through its delivery of scientific results in the areas of crustal geophysics, rock physics and seafloor environmental observatories for deep-water frontier oil and gas exploration. Example studies include: geological crustal scale analysis of seismic refraction data in the Arctic Ocean; environmental observatories in deep water frontier and mature exploration areas; and fundamental rock physics studies for improved geophysical imaging and quantification for reservoir exploration, characterisation and monitoring.

2. Nature of the impact

The impact has a global reach as it affects the activities of nation states, serviced by the oil and gas industrial sector, seeking to secure hydrocarbon resources to provide the energy needed to sustain increasing standards of living through economic growth. Apart from developed nations wishing to maintain living standards, the need to secure increasing energy resources is particularly acute for rapidly developing nations with large populations such as China, India and Brazil. Beneficiaries fall into three main categories:

1) Oil and gas companies who need state-of-the-art knowledge to assess the hydrocarbon resources in deep water frontier areas such as the Arctic, offshore Africa and Brazil;

2) Regulatory authorities such as sovereign states, the EU and the UN who wish to control the environmental impacts of offshore hydrocarbon exploration and production for sustainable economic growth, including the mitigation of anthropogenic climate change;

3) Consumers of goods and services provided by high-energy-use societies, underpinned by hydrocarbon fuels and petrochemicals for domestic use, manufacturing, materials, agriculture, transport and defence.

Specifically, NOC activities have benefitted oil and gas companies, such as BP, seeking new resources in the Arctic frontiers by providing basin-scale geological interpretations of seismic refraction data, and service companies (e.g. Offshore Hydrocarbon Mapping plc, now Rock Solid Images plc) to develop new marine geophysical exploration capabilities. NOC activities have also benefitted companies such as Statoil, Chevron, Total, BP, Hurricane, OMV, Shell, Guardline, and Fugro through the provision of long-term environmental impact monitoring around drilling and production platforms. Moreover, much of this research is done via a special model whereby industry donates robotic survey infrastructure through an international effort coordinated by NOC - the Scientific and Environmental ROV Partnership using Existing iNdustry Technology (SERPENT). The resulting datasets on impacts and scientific results are published openly and are informing debate on industry best practice for sustainable economic activities.

Overall, NOC activities have helped to reduce costs and increase efficiency of deep water offshore exploration and production, while minimising impacts on the marine environment in often sensitive frontier areas, as well as helping to secure jobs in this competitive market sector. Apart from contributing to short-term economic gains by commercial operators, NOC activities are likely to have their greatest impact in the medium to long term as new information is absorbed into exploration culture and regulatory authorities role out exploitation plans for frontier areas.

3. How the Centre contributed to the impact

**Crustal geophysics**: As hydrocarbon exploration moves into ever deeper water, industry faces new challenges for both exploration and recovery of resources. NOC has assisted oil companies to reduce risk in deep-water exploration through the analysis of long-offset seismic refraction data, (a niche scientific
geophysical technique not common within oil exploration) which provides additional control on crustal geology not otherwise obtainable from conventional seismic methods. Seabed receivers (Ocean Bottom Seismographs) record seismic energy to offsets of tens of kilometres, providing key insights to determine crustal type and thickness, both of vital importance for understanding thermal histories and oil maturation within a sedimentary basin. Such surveys are acquired as low cost add-ons to standard seismic reflection surveys.

Adoption of this “scientific” technique by BP has significantly increased their regional understanding in frontier areas worldwide. Long-offset seismic data also play a key role in the accurate prediction of fluid pore-pressures within deep sedimentary basins, and in particular the detection and measurement of overpressures. Pore pressures play a role in both basin evolution and hydrocarbon migration, and quantification of overpressures from geophysical data is of vital importance prior to drilling exploration wells (especially in frontier areas with little record of drilling conditions) to prevent potentially catastrophic well blow-outs.

Rock physics studies: Since September 2007, NOC has worked closely with former University of Southampton spin-out company Offshore Hydrocarbon Mapping (OHM) plc, now Rock Solid Images (RSI) plc, to generate novel laboratory geophysical datasets on the joint elastic and electrical properties of reservoir rocks (with OHM providing funding of £300k). The work is providing experimental validation data for interpreting co-located, marine controlled source electromagnetic (CSEM) and seismic surveys in terms of hydrocarbon fluid detection and quantification of reservoir capacity. NOC regularly reported science results to the WISE (Well-driven Integration of Seismic and EM) consortium of oil industry companies led by RSI. RSI implemented the new experimental data within their state-of-the-art commercial geophysical interpretation software to win new contracts from client oil companies and increase market share. RSI currently captures about 4% of the $250 million global reservoir characterisation market and is one of the few oil service companies that can jointly invert seismic and electrical resistivity data (because of the NOC contribution) into an enhanced reservoir interpretation. Initial results were published in leading exploration journals to benefit the wider geophysical community.

Additionally, NOC has been collaborating with the BGS Edinburgh Anisotropy Project (BGS-EAP), which has about 20 oil industry sponsors who have benefitted from the latest multicomponent seismic data interpretations, especially for hydrocarbon detection and reservoir fracture network characterisation. NOC has acquired novel laboratory elastic wave measurements on synthetic fractured sandstones that are used to validate theoretical models, developed by BGS-EAP and published in leading geophysical journals. BGS-EAP were recently awarded the 2012 Society of Exploration Geophysicists Distinguished Achievement Award, to which NOC can claim a contribution.

Seafloor environmental monitoring: Since 2002, the SERPENT (www.serpentproject.com) project has taken advantage of remotely operated vehicles (ROVs) used by the hydrocarbon industry to undertake biological research during stand-by time. This has resulted in 92 scientific visits to exploration rigs, drill-ships, and survey vessels working in depths of 100 to 2800 m, mostly by NOC researchers, and funded by major oil and gas companies including Statoil, Chevron, Total, BP, Hurricane, OMV and Shell, with “in kind” support from Transocean, Subsea 7, Oceaneering and Fugro. Yielding c.350 offshore days, NOC scientists have unparalleled access to the seabed to study and monitor the effects of local scale disturbance on benthic communities in deep water (worth over £6 million in equivalent vessel costs). Large data sets are now available in the Faroe-Shetland Channel and Norwegian Sea in the North East Atlantic, where 25 sites have been studied, and two studies have been published at sites in the deep North East Atlantic. Such access has allowed the collection of substantial imagery, along with specimens, for the first ID guide to this exploration area. SERPENT data has resulted in 27 peer reviewed publications on biodiversity and impacts. Reports provided to the companies inform future license applications and allow operators to quantify seabed impacts. The SERPENT archive database details nearly 2000 observations from deep-water drilling locations globally and is seen as the ‘go-to’ resource by industry to identify deep-sea life encountered in their operations. About 200,000 people have been reached in 5 high profile outreach events, and media outputs
include 7 television programmes and numerous magazine and web articles.

Also, since 2002, the DELOS partnership has developed new understanding of deep-water biodiversity, ecology, and the effects of energy industry activities. Since 2009, the project has operated two observatories offshore Angola at 1,400 m depth; BP has invested more than £5 million in capital and operating expenses allowing the DELOS community to gain access to the data from these observatories, expected to remain in place lifetime of the field. Improved understanding is leading to the responsible use of deep-water resources. Furthermore, NOC has led a review (via a six-month staff secondayment to BP) of deep-water environmental practices including the design, tender and execution of analyses, quality control and sample and data curation. This effort is producing standardised streamlined guidance for BP and its contractors. Future work includes potential collaboration with BP on exploration of biodiversity in offshore East Africa, Trinidad & Tobago. BP could save £30 million in survey costs in the next 5 years, while delivering scientific data and samples that are of a great science value.

Arctic Climate Change, Economy and Society Study (ACCESS): This is an ongoing €11 million EU funded multi-disciplinary study of the socio-economic effects of climate change on marine eco-systems, specific economic sectors and human activities in the Arctic. Recent estimates suggest that 13% of the world’s undiscovered oil and 30% of its undiscovered natural gas are Arctic, while melting there makes exploitation of these resources increasingly attractive. ACCESS addresses the opportunities and multiple risks of hydrocarbon extraction within the Arctic. NOC staff contribution to the project has included development of a Marine Spatial Planning tool (MSP), analyses of existing regulatory frameworks and proposal of new options for EU-led policy initiatives in governance and stewardship to ensure future sustainable development of the region during a period of climate change in a resource rich area.

4. Evidence and sources to corroborate the impact

1 BP testimonial letter to Rosemary Edwards, dated 1 October 2012.  
2 Rock Solid Images testimonial letter to Angus Best, dated 12 November 2012.  
8 e.g. Gates and Jones, 2012. PLOS ONE, 10.1371/journal.pone.0044114 and Jones & Gates, 2012. Marine Ecology Progress Series 461,71-82. doi: 10.3354/meps09827  

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1. Summary of the impact (maximum 100 words)

Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS) provides the formulae allowing coastal states to claim continental shelf beyond the 200 nautical mile Exclusive Economic Zone (EEZ), and allows states to exploit the natural resources of the seabed and subsoil of this continental shelf. UNCLOS also contains provisions for the protection and preservation of the marine environment. NOC has led the technical advice to the UK Government on all four UK claims under Article 76, provided advice and services to several overseas governments, and continues to provide advice on several aspects of UNCLOS, including delimitation of the continental shelf beyond 200 nautical miles.

2. Nature of the impact

The United Nations Convention on the Law of the Sea (UNCLOS) conveys sovereign rights to coastal states over the seabed and subsoil of their continental shelf. Article 76 of UNCLOS provides formulae that allow coastal states to claim a continental shelf beyond the 200 nautical mile EEZ where the necessary criteria are met, and allows the state to explore and exploit the natural resources of the seabed and subsoil of this area of continental shelf. The UK has submitted four areas of continental shelf to the United Nations Commission on the Limits of the Continental Shelf (CLCS), which includes 80,000 sq km of continental shelf in a joint submission with France, Ireland and Spain in respect of the Celtic Shelf area\(^1\), some 2.1 Million sq km of seafloor area in the Hatton-Rockall area, Ascension Island, and Falkland Island regions with their associated potential resources submitted to UN for ratification, of which 900,000 sq km within the Falkland Island region could include substantial hydrocarbon reserves similar to the existing UK company exploration within the Falkland Island EEZ. Similarly, seafloor polymetallic sulphides lie within the Ascension Island shelf area on the mid-Atlantic Ridge, near to where Russia and France have been granted exploration licenses by the International Seabed Authority (ISA). China and Korea have similar licenses for mineral exploration along the SW and central Indian Ridge.

In a recent communication released by the European Parliament, which states that "By 2020, 5% of the world's minerals, including cobalt and zinc, could come from the ocean floors. This could rise to 10% by 2030. Global annual turnover of marine mineral mining can be expected to grow from virtually nothing to €5 billion in the next 10 years and up to €10 billion by 2030" re-enforces the importance of securing areas of seafloor with potential mineral resources. The fiscal value of the non-living resources (including hydrocarbons, seafloor minerals, biomedical products from sessile animals) within these areas has yet to be determined, but these UK marine areas may contain oil / gas, mineral rich polymetallic massive sulphides and manganese nodules, which are a source of valuable minerals, including nickel, copper, cobalt, manganese and rare earth minerals.

The ISA is an agency established under UNCLOS to organize and control activities in the Area (i.e. parts of the oceans beyond national jurisdiction), in particular with a view to administering the resources. Applications for such licenses have been sponsored by the UK government, and revenue from these activities will potentially result in UK tax revenue benefit:

- The UK has recently sponsored a UK subsidiary of Lockheed Martin to submit a licence for exploration in the Pacific Ocean.
- Potential revenue from a wide range of non-living resources, both hydrocarbon and mineral.
- Potential benefit to security of UK mineral resource supply.

In addition, NOC has assisted Barbados\(^2\), Vietnam\(^6\), and Yemen\(^4\) in submitting extended continental shelf submissions to the CLCS via commissioned research contracts and has generated considerable goodwill for the UK through capacity building. Over 100 nationals from 40 countries have undertaken training courses at NOC / University of Southampton in UNCLOS application and international maritime law underlining the UK lead is this field.
3. How the Centre contributed to the impact

The UNCLOS Group at NOC led and provided technical advice to HMG for all four UK claims under Article 76; in respect of the Celtic Shelf, Hatton-Rockall, Ascension Island, and the Falkland Islands and South Georgia and the South Sandwich Islands.

• NOC provided the scientific and GIS technical lead to UK submissions, including case preparation and defence at the CLCS at the UN1,3,5,7.

• Research funding by NERC National Capability supported the data analysis of the multibeam bathymetry, seismic reflection, seismic refraction and gravity data into coherent published, peer-reviewed geological interpretations10,11,12 of the boundary between continental and oceanic (the underlying premise of an extended continental shelf), to further substantiate the UK submission to the CLCS technical experts. Acquisition and interpretation of new UNCLOS datasets has led to increased understanding of the UK’s continental margins.

• Our collaborative work with the UKHO also allowed access to the Royal Navy vessel HMS Scott, and HMS Scott was used to acquire data in three of the four UK submissions areas, with plans provided for additional surveying in the Southern Ocean / SW Atlantic.

• The NOC continues to provide advice to HMG on delimitation of continental shelf areas beyond 200 nautical miles, as well as retaining a watching brief of current activity within the UNCLOS community.

Mr Chris Whomersley, deputy legal advisor, Foreign and Commonwealth Office quoted;

"NOC played an indispensable part in the British Government’s programme to make submissions to the Commission on the Limits of the Continental Shelf about the extended continental shelf around the United Kingdom and its Overseas Territories. We were very grateful for their expert and enthusiastic contribution to this programme. NOC are also invaluable in the assistance they provide us on issues concerning marine scientific research."

In addition the NOC provides advice relating to Part XIII of UNCLOS, namely Marine Scientific Research. Exploration of seafloor minerals traverse the varying legal regimes included in the UNCLOS, and use of such research will result in a better understanding of these environments. For example off-shore the Cayman Islands NOC scientists recently discovered one of the deepest but potentially mineral rich chemosynthetic environments yet discovered. Whilst the technology and drivers to exploit such areas are in their infancy, and the environmental impact of such exploitation is currently not well understood, NOC research and marine governance advice is providing a roadmap for future environmental management and exploitation of these resource-rich areas.

Diplomatic clearances for research expeditions managed by the NOC are also processed with an input of UNCLOS relevant information, such as maritime space, environmentally sensitive areas and knowledge of current areas of dispute. Such information has resulted in changes to science plans and potential avoidance of costly seizure of ships.

Two of the current ten Technical Studies commissioned by the International Seabed Authority have been produced by the NOC8,9. The first Technical Study commissioned was awarded to the NOC, which focuses on non-living resources on the continental shelf, as was the fifth Technical Study, which focuses on implementation of Article 82 of the Convention, i.e. payments in respect to the exploitation of resources beyond 200 nautical miles.

Further information relating to UNCLOS work at the NOC can be found at www.unclosuk.org.
4. Evidence and sources to corroborate the impact


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NOC12: NOC science and technology maintaining a competitive advantage for UK marine science industry

1. Summary of the impact (maximum 100 words)
The UK marine science and technology sector in 2012 had estimated turnover of £1.35billion (double the 2010 figure) with exports of £500 million\(^2\). NOC is a world leader in developing new technologies for marine science that are being translated into new products for UK companies. These instruments, conceived by NOC scientists include a range of new platforms, analytical tools and sensors, are internationally recognised as world-leading technology, and in collaboration with industry, are becoming commercial instruments. This world leading technology developed by NOC is assisting the UK marine science industry to maintain a competitive advantage and continue its remarkable expansion.

2. Nature of the impact
NOC-developed technology includes: **HyBIS** - an innovative new robotic underwater vehicle, providing a low cost, versatile solution to deep-water (to 6 km) remote operations including rock, fluid, gas and biological sampling, seafloor instrument deployment and recovery\(^2\). **ITRAX** - an innovative high-resolution non-destructive sediment core scanner for analyzing environmental and chemical records to underpin climate change, sedimentary processes and mapping environmental contamination research\(^3\). **AUTOSUB** - Innovative state-of-the-art AUV’s with two new specific mission-oriented sub-types: 1) Autosub6000 - optimised for deep operations (to 6 km) with sophisticated sensors (including a collision avoidance system to operate in extremely rugged terrain)\(^4\); 2) Autosub Long Range AUV with a unique capability for deep diving (6 km) and long endurance (up to 6 months). **Biogeochemical Sensors** – Innovative state-of-the-art *in situ* (i.e. submersed and autonomous) sensors for precision measurement of biogeochemical parameters including: 1) patented low cost high performance miniature Conductivity Temperature and Dissolved Oxygen sensors (CT-DO); 2) patented high performance and low cost Lab on chip nutrient analysers; 3) other sensors in development in collaboration with industry that are smaller and higher performance than alternative technologies.

These instruments originally conceived for science are providing pipeline on new innovations for the UK marine science and technology sector.

**HyBIS**: HyBIS’s versatility and low cost operation in gas hydrate and methane flux studies in the Arctic Ocean; discovery of the world’s deepest hydrothermal vents at 5000 m in the Cayman Trough\(^5\); and unregulated fishing impacts on an Atlantic seamount and has lead to interest from marine operators. UK SME Hydro-Lek Ltd has made HyBIS a commercial instrument with sales to Germany and China, and interest from the offshore sector. Using a cost-competitive system like HyBIS is highly attractive and will spin out further developments.

**ITRAX**: The ITRAX micro-XRF core scanner acquires and combines sub-millimetric element analysis with high-resolution x-radiography, allowing unprecedented analytical capability to record environmental records at annual (or even less) in sediment cores. ITRAX is being increasingly used to better understand environmental problems, such as climate change, natural hazards (slope stability, earthquakes, volcanism, coastal inundation), marine resource vulnerability and environmental variability. It can rapidly measure anthropogenic heavy metal pollution (e.g. Severn Estuary\(^6\), Venice Lagoon\(^7\)), in the emerging field of environmental forensics, providing essential data to undertake or enforce remedial works. ITRAX is now finding application in mineral and petroleum extraction industries, to rapidly assess drill core and environmental impacts of Ba-enriched drilling mud distribution. This proven analytical capability has developed a market with ITRAX now an established commercial instrument with 25 instruments sold to research institutions worldwide since 2007 and currently three on order.

**AUVs**: Since 2008 the instrument payload of Autosub6000 AUV has been extended to now acquire a wide
suite of sub-seabed, seafloor, and water-column parameters. Increasingly industry and environmental protection agencies see AUV’s as an effective and efficient survey platform. New Defra-funded initiatives (see NOC08) are demonstrating the use of this vehicle for monitoring of MPA’s. Additionally, the Autosub programme has developed an unparalleled expertise in risk analysis for AUV missions and other ocean-deployed systems, and routinely advise major international AUV operators on risk and reliability assessment for their proposed campaigns. Since 2007 the Autosub Long Range AUV has been developed from a concept design vehicle to near completion of a series of sea-trials and will be operational in 2013. Though originally conceived for science missions, NOC have actively engaged with potential industry users since 2010 to use Autosub Long Range endurance capabilities. One recently funded initiative is the monitoring of offshore carbon capture and storage sites. NOC has led initiatives in this field which has led to Autosub Long Range AUV being the designated “survey platform” for the development of a pre-commercialisation prototype marine monitoring system (funded by the Energy Technology Institute) to support the nascent North Sea sub-seabed carbon storage industry.

**Sensors:** This work is recognised as world leading technology. Key advances include low-cost high performance opto-fluidic chips made in low-cost polymers leading to two patents; greater than 100 times reduction in CT-DO technology size and cost; nutrient sensors providing data at previously unattainable accuracy and data rate demonstrate variability not seen by spot sampling; precision pH measurements, capable of resolving anthropogenic ocean acidification on autonomous platforms. Miniature CT-DO sensors have been used to provide satellite salinity sensor validation and next generation devices are much improved leading to commercial exploitation and six patents (funded by industry). Six companies tendered for a licence to manufacture/market the CT-DO sensor technology leading to a signed commercial evaluation agreement, with an estimated >£500M annual market. Commercialisation agreement for CT-DO sensor in negotiation. Commercial negotiations have begun for lab on chip nutrient and pH /carbonate sensors with analytical and offshore energy companies. A pipeline for future exploitation has been established with interest from large multinationals in the instrumentation and offshore energy industries including the largest global players. Potential markets are multibillion and can be accessed because our technology is world beating, but feasible to manufacture, sell and deploy in large numbers. Particular opportunities include drinking and wastewater, offshore monitoring (e.g. hydrocarbons), aquaculture, and regulatory compliance verification in environmental and industrial applications. We are in discussion with MOD/DSI for further applications. At a minimum we expect >3% of >£500 M pa market to return directly to the UK for the CT-DO sensor alone.

**Enabling technology:** NOC has also developed innovative gadgets that have wide application throughout the marine sector, such as Quick-Clamp, a new clamp that allows instrumentation to be quickly and easily attached to, and detached from, towed or moored cables. This has been successfully licensed to a UK-based commercial company, a further example of NOCs collaboration with business to bring innovative products to market.

Beneficiaries of NOC-developed technology include UK offshore technology and engineering industry; UK environmental monitoring industry; UK-listed mining and petroleum industries and public sector agencies tasked with mitigating effects of environmental change, UK defence industry, and we have high support and application from industry (see Annex 1).

### 3. How the Centre contributed to the impact

NOC scientists have conceived the technology innovation (to solve a science question) and then sought the funding (including substantive competitive funding proposals) to progress development.

**HyBIS:** NOC science objectives and technology innovation funding led to initial technological development in 2007 and later fabrication by Hydro-Lek Ltd. in 2008. NOC cruises in 2009 and 2010 led to further technical developments. In 2011 and 2012, it undertook Arctic methane studies, and in 2012 CO2 sequestration studies in the North Sea. NOC-led RM funding in 2009 led to discovery of deepest
hydrothermal vents in the Cayman Trough in 2010. By end 2012 HyBIS had completed over 100 missions.

**ITRAX:** ITRAX was conceived by NOC / UoS scientists who secured Office of Science and Technology funding in 2000 to develop new x-ray analytical capability. Cox Analytical Systems were partnered to build the core scanner in 2003. Take-up by the scientific community was swift, with over 100 scientific papers based on ITRAX analysis published in the scientific literature since 2005. NOC hosts the *British Ocean Sediment Core Research Facility* that facilitates ITRAX use to the UK scientific community.

**AUVs:** The entire technology development of the Autosub AUV and the most of the science application (in collaboration with HEI’s) has been developed by NOC from long-term “core” funding, and numerous competitive proposal submissions to NERC. The technology has also evolved with NOC lead of DEFRA, UK MOD, and European Research Council funding.

**Sensors:** NOC technology innovation funding led to initial developments. NERC core funding followed and 3 co-supervised PhD studentships. In 2008 a £2.2M EPSRC (70%) / NERC research grant to NOC and UoS led to further NERC funding and responsive mode research grants (with UK HEI’s). Currently sensor programme is supported by ongoing projects, with NOC providing laboratories for hosting the *Centre for Marine Microsystems* to further this work.

### 4. Evidence and sources to corroborate the impact


### 5. Contacts for further information

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NOC13: Tidal and wave data applications to support coastal and offshore users

1. Summary of the impact (maximum 100 words)
Physical properties of the oceans, such as tides are key parameters for working in offshore and coastal locations. Understanding how these change and interact is vital information for many disciplines. We use a combination of data processing to convert raw scientific data into more usable forms, then develop commercially available software tools to manipulate and visualise the information into formats that make it more accessible to non-specialists. The NOC ‘Applications Team’ develops these unique added-value products to be harnessed by users generating economic growth impact (sales of tide tables, maximising port vessel operations) and societal benefits (safety at sea, flood defences).

2. Nature of the impact
Knowledge of the tides for ports and harbour operations; knowledge of tidal streams for offshore operations and hydrographic surveys; knowledge of surge levels and extremes for coastal defence. These are just a few examples of how NOC science penetrates various market sectors to provide information critical to their business. The work of NOC’s sea-level research group gives rise to vast data sets, which, if manipulated into an appropriate form or encapsulated within a powerful software application, can be of immense value to these sectors.

Although NOC has hundreds of clients that directly purchase this ‘standard’ software, many choose to come to us to provide them with the bespoke answers they need. For this we often utilise the same software, or develop new programs to create custom-made products meeting their requirements.

As a recognised world leader in tidal harmonic analysis and prediction since the 1920’s, NOC has developed some of the most accurate software available that is sold commercially as well as licensed to the scientific community. For example:

- NOC are the sole suppliers of harmonic analysis services to the UK Hydrographic Office, essential in the production of tidal publications that are vital for safety at sea (SOLAS Ch.5 Reg. 27)\(^1\);
- NOC are the sole supplier of harmonic analysis and prediction services to the UK Environment Agency who would be unable to operate at the coast without tidal data. Information we provide is used in flood protection, beach cleanups, coastal planning, environmental risk assessments, shoreline management etc.\(^2\):

  Environment Agency: “The Environment Agency manages the UK Coastal and Monitoring Forecasting Service on behalf of DEFRA. Part of the remit of this service is to provide timely warnings to businesses and communities to alert them of potential coastal flooding. We rely heavily on accurate tidal data from NOC at key forecasting points around the coastline to deliver this service. The astronomical data is fed into the Surge Model (run by the Met Office 4 times a day) that takes account of weather systems impacting tidal water levels. If we did not have the astronomical data, we would not be able to provide a coastal flood warning service.

  Some of our flood defences, for example the Thames Barrier, are dependent on the tidal predictions to operate effectively. The barrier protects 125 square kilometres of central London from flooding caused by a combination of high tides and surges. As well as coastal flooding, defences like the Thames Barrier are used to regulate flows upstream to protect communities from fluvial flooding and also to maintain higher flows in times of drought. It’s imperative that we receive an accurate tidal prediction so that we close and open the barrier at the right times.”

- One-off consultancy projects (e.g. work carried out for Airbus to assist them in transporting the wings for the Airbus A380 up the River Dee from their factory in Broughton to Mostyn Docks; predicting the times the ships could navigate under low bridges yet not run aground\(^3\));
- Port and harbour operations require accurate tidal data. Tide tables provide port operators with the times that ships of different draughts can safely be brought into harbour, and therefore maximise port utilisation\(^4\);
- NOC tidal data is distributed by the majority of newspapers via Meteogroup (previously the Press Association). Used by the general public for recreational purposes (fishing, sailing, diving etc.)\(^5\);

Meteogroup: “Meteogroup UK has a long-standing commercial arrangement with the National
Oceanography Centre regarding provision of tidal data for 158 coastal locations in the UK and Ireland. The tides are a key piece of information and are published in page-ready weather panels that we produce for various newspaper clients, both regional and national.

- Power station operators for planning their environmental monitoring programme of beach areas local to the site.

Ocean modelling generates large time series data sets, many of which are available through a recently launched British Oceanographic Data Centre (BODC) portal. However the application of harmonic analysis to these data has developed new added-value products which have been used to:

- Provide tidal energy estimates for a BERR (now D-BIS) funded project to look at UK potential for marine renewable energy and to identify the location of ‘hot-spots’ for maximising energy production (and therefore profit);
- Provide a core mathematical engine (Hydro-DLL) for a range of third-party applications relying on tidal streams including those for navigation (vital for safety at sea);
- Provide software for offshore ship operations and planning in oil/gas exploration and hydrographic survey – data is used for risk assessment and identifying windows of opportunity for offshore work including divers that only dive in currents less than 0.8 knots;
- Provide data and advice to the Met Office Marine Business Unit for offshore operations and incident investigation as well as for inclusion on their web services;

Met Office: “The data you provide to us is used for the daily operations of the various oil companies that operate in the North Sea and beyond. We put the data into an Excel spreadsheet and produce daily graphs which are used to determine how drilling is carried out and if there was an emergency how the rescue vessels would be deployed etc. Other customers use it to calibrate sonar studies that they have carried out.”

- Support further research in science institutes and universities, for example custom software to batch process large quantities of data for the purposes of seal-tracking, and biodiversity monitoring around a Wave Hub installation.

When dealing with private companies, our software and/or data have two primary impacts that relate to all organisations: i) increase in turnover/profit, and ii) minimising risk.

Accurate tidal prediction data is increasingly important in many industries and they develop and grow (traffic levels into major ports, large offshore structural developments etc.)

- Number of business customers: 1,400; Number of data licences issued: 478 since FY 07/08
- Number of direct data sales: average: 195 per year (these are in addition to the data licences).
- Number of active royalty agreements: 12
- Income generation from data sales/licences: FY07/08: £235K; FY08/09: £258K; FY09/10: £315K; FY10/11: £267K; FY11/12: £268K.

3. How the Centre contributed to the impact

The physics of the oceans (sea level, tides, currents, surges, waves etc) are key parameters in many areas of coastal and offshore activity. NOC is a leading centre for the understanding of how such parameters change and interact over time. Our aim is to communicate this understanding in the form of products and services based on refined data sets into public and private sector for a wide range of activities from pure research studies through to coastal flood defence, safe port/harbour operations, offshore installations and marine renewables. NOC ocean observing, marine physics and modelling scientists generate large quantities of oceanographic data that form the basis of these products.

The NOC Applications Team develops these into unique added-value products and services making the data more accessible to non-oceanographers, and leading to both economic growth and societal benefit (see section 2 for examples).

The key to the impacts described is the integration of high-level science generating accurate data with the development of innovative software tools to both manipulate and provide easy access to these complex datasets. Making the software powerful yet user-friendly is vital if clients are to maximise their use of the
The Applications Team includes mathematicians, physicists and professional software developers, and we work closely with the scientists in the National Tidal and Sea Level Facility (a group comprising several members of the NOC sea level science group, the British Oceanographic Data Centre and collaborating university departments, and based around the UK National Tide Gauge Network).

The Applications Team has developed a suite of Windows-based products which are available commercially, comprising:

- POLTIPS-3 tidal prediction software (available with UK database of ports, or as an international version) – developed and constantly updated from 2004 to-date. Latest version was released in April-2011 with numerous enhancements over previous versions;
- POLPRED offshore information system provides model based calculations and a range of visualisations of the tidal streams and heights. Latest version Nov-2010, however, development of a new version supporting the latest unstructured grid models is in development;
- Hydro-DLL – a core mathematical library for computation of tidal levels and currents from a database of harmonics. This software has been incorporated into a wide range of third-party applications that are sold by external companies (and for which NOC received a royalty on each sale). Updated with new models as they become available;
- A world-class harmonic analysis suite of software. The commercial version is still under development but the software is currently used at NOC with the commercial version ready in early 2013. The National Tidal and Sea Level Facility will also become key users of this software.

4. Evidence and sources to corroborate the impact

1. A three year contract awarded to NOC in February 2012 to carry out harmonic analysis work; Chris Jones, Head of Tidal Branch, UKHO.
2. 5 year contract 2008–2012, with a two year extension to cover supply of data up to 2014 awarded to NOC; Neil Ryan, FCRM Senior Advisor for Monitoring and Forecasting, Environment Agency.
3. The licence for the bespoke version of our POLTIPS software was renewed in November 2012 for the transport of Airbus wings on the River Dee; Andy Jones, Holyhead Towing Company. see: http://www.holyheadtowing.co.uk/vessels/afon-dyfrdwy/
4. NOC provides tidal data to many UK ports and harbours including the major operators Medway Ports (Sheerness and Chatham) – Phil Woodgate (philwoodgate@medwayports.com) and Port of Liverpool – Russell Bird (russell.bird@peelports.co.uk).
5. Meteogroup purchase data for 140 ports around whole of UK and Ireland for distribution to newspapers and the media. Contact: Rob Hutchinson (Robert.hutchinson@meteogroup.com).
6. Sellafield Nuclear Power Station – Janice. ridley@sellafielddssites.com; Hinkley Point Power Station – richard.a.harris@magnox.co.uk; Connah’s Quay Power Station (steve.houghton@eon-uk.com)
9. Offshore ship operations and planning. Examples: Shell Oil – Anne Ellis (ellis@logica.com); Subsea7 – David Yule (david.yule@subsea7.com).
10. Met Office Marine Business Unit: Karen Barfoot (Karen.barfoot@meto.gov.uk).
12. Biodiversity monitoring: Matthew Wit – University of Exeter (m.j.witt@ex.ac.uk)

5. Contacts for further information

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NOC14: Ocean business exhibitions supporting UK marine scientific industries

1. Summary of the impact (maximum 100 words)

Working with a start-up company Intelligent Exhibitions, Ocean Business was established in 2007 to meet industry demand for a new event involving hands-on trials of instruments and training sessions. Following the first event (146 exhibitors and 1534 visitors from 48 countries) Ocean Business has successively grown in exhibitor and visitor numbers, with the 2013 event sold out to >300 exhibitors and 4000+ visitors anticipated. Following their successful start-up, Intelligent Exhibitions has gone on to diversify into additional markets, including the LiDAR Mapping Forum, Marine Electromagnetics Conference Marelec and the weekly Oceanbuzz publication, an ocean technology newsletter with over 13,000 subscribers.

2. Nature of the impact

The UK marine science and technology sector in 2012 had estimated turnover of £1.35 billion (double the 2010 figure) with exports of £500 million. Since 2008 the sector has been growing year on year. Though the UK is a dominant innovator and manufacturer in this global market, the industry is dominated by SME’s (85%) with turnover of less than £50 million, hence the industry relies on close collaboration with research innovators. The drivers of this growth have been the progression of oil exploration into deeper water, expansion of offshore wind and marine renewable energy, continued advances in maritime defence, and expansion of environmental monitoring as increased shelf/coastal development occurs (e.g., aquaculture, aggregate extraction, shipping). NOC is a world leader in developing new technologies for marine science, that are translated into new products for UK companies (see NOC12), and these are contributing to the growth of the sector.

In addition to technology development, NOC has facilitated collaboration and exchange within this emerging industry by hosting the bi-annual Ocean Business company exhibition and trade vendor forum at its Southampton campus. This initiative commenced in 2006 when Intelligent Exhibitions (starting as a one-person events company) and NOC jointly identified an opportunity and initiated the 2007 Ocean Business exhibition with 146 exhibitors and 1534 visitors from 48 countries. Successive exhibitions in 2009 and 2011 have expanded, and the 2013 event is already sold out of exhibition space with over 300 exhibitors and over 4000 visitors anticipated. Intelligent Exhibitions Ltd has expanded to 11 permanent staff, now organises four different industry events (including Ocean Business), and publishes a weekly industry sector e-newsletter (OceanBuzz) with over 13,000 subscribers. The success of this start up demonstrates how the combination of private entrepreneurship with the international brand and facilities of a national research institution has convened and met the needs of a major industry sector.

The international marine science industry now views Ocean Business as the key event in their marketing/sales strategies. The three-day exhibition has seen a number of satellite events emerging within NOC and City of Southampton itself, with The Society of Maritime Industries, The Canadian High Commission, The Sensors Industry Group and IMAREST all running events alongside the show to ensure a maximum amount of attendees at their events. Southampton city benefits from hosting ~4000 visitors and the various satellite events during the week, with estimated income to the cities hotels, restaurants and bars at around £1 million.

The beneficiaries of NOC hosting Ocean Business are profound and diverse, allowing this industry sector to meet, conduct business, run workshops and demonstrate equipment utilising unique NOC facilities including vessels, dockside, test tank, and conferencing facilities. NOC and Intelligent Exhibitions recognised that Ocean Business would be a significant opportunity for student career development and in 2009 launched the Ocean Careers event. Ocean Careers runs alongside Ocean Business for the three days of the show and gives students from across the UK the opportunity to listen to presentations from early career industry personnel, and also hold one-to-one meetings with these presenters to find out more about the industry, and how best to prepare themselves for a career in marine science and technology. Whilst at the Ocean Careers event students have the opportunity to visit Ocean Business exhibitions and demonstrations...
and many use this opportunity to successfully seek employment.

In addition, to Ocean Business, NOC has hosted a variety of other specialised vendor/technology exhibitions and industry workshops. The Autonomous Underwater Vehicle 2012 (AUV2012)\(^4\) in association with the Ocean Engineering Society (IEEE-OES)\(^5\) was a three-day specialised conference where all the major AUV innovators and manufacturers from industry, military, and research community met, and was the first time the IEEE-OES AUV conference had been hosted in the UK, providing a unique opportunity for UK companies. Previous IEEE-OES AUV conferences attracted around 80 attendees, while the NOC-hosted event was sold-out to 130 attendees with a waiting list of further potential attendees. A sponsors-only exhibition held alongside the event sold out within the first month of advertising and new opportunities had to be developed to cope with additional demand to be associated with the event.

The Unmanned Underwater Vehicle Showcase (UUVS) was hosted annually at NOC Southampton\(^6\) from 1998 to 2010. This was a two-day conference and exhibition organised in collaboration with the Society of Underwater Technology\(^7\), attracting 40 exhibitor companies and around 300 visitors each year.

On a six monthly basis, NOC runs the “Manufacturers Breakfast Club” which was initially a forum to provide UK industry a forward look at NOC science interest and direction. This event has evolved and now includes topics that are of interest to NOC and the UK Marine Science industry (e.g., Law of the Sea). The meeting typically has attendance of 20-50 industry participants depending on the discussion topic.

In April 2012 NOC hosted the Sensors Water Industry Group (SWIG)\(^8\) meeting on Bathing Waters. Seventy delegates attended to listen to presentations from NOC, Environment Agency, NERC, and water industry representatives industry.

### 3. How the Centre contributed to the impact

NOC’s contribution to these industry fora is significant, and is firstly a function of NOC’s excellent credibility as a research leader and technology innovator, and secondly a function of a research campus providing access to and operation of demonstration vessels, dockside, test tank, high-spec analytical laboratories, micro-fabrication technology workshops, and conferencing facilities. NOC’s proven and long-standing record of marine science technology development and deployment is a major marketing tool for these events (particularly Ocean Business), and industry exhibitors and visitors greatly appreciate the opportunity to visit NOC and engage with scientists and technologists at the leading edge of ocean science.

In starting Ocean Careers in parallel with Ocean Business the impact of the event has been broadened to ensure that the event helps provide advice and support to students considering a career in the industry. NOC provides significant input to this part of the event through providing the coordination of speakers from across industry and the NOC itself.

Additionally NOC plays an integral part in Ocean Business by:

- Providing technical advice to Intelligent Exhibition on the planning of the Training and Demonstration programme for the event. NOC staff sit on the Ocean Business Technical Committee advising on potential clashes of competing products and mobilisation requirements for the equipment attached to the 9 inshore survey/charter vessels operating parallel trials over the three day period.
- Providing industry knowledge to Intelligent Exhibitions to raise awareness of company products, ensuring that visitors are directed toward appropriate vendors and their products
- Advising on the design of the dockside, and test tank demonstration program, ensuring that all these activities are undertaken with maximum opportunities for visitors to see the equipment in operation.
- NOC is a member of the steering committee for Ocean Careers working with IMARestT, SUT and industry representatives, to select motivational speakers to encourage students from across the UK to join the industry, by providing advice on what the industry requires in terms of qualifications and giving real examples of working in the industry.
4. Evidence and sources to corroborate the impact

The strength of feeling for the show is demonstrated by testimonials from leading ocean technology companies and bodies (a full list of testimonials can be found on the Ocean Business website9):

“Ocean Business is now a recognised core show that has aided in the growth of our company” Callum Magee, Business Development Manager, AC-CESS Co UK Ltd, UK.

“Ocean Business has undoubtedly been our most successful show ever! The marine science and business community is stronger following all your efforts! We WILL see you all in 2013” David Hitchcock, Managing Director, Coastline Surveys Ltd, UK.

“Ocean Business gets better every time. The IMarEST are proud to continue the support of this show and having its name associated with this event!” Samantha Dawkins, Manager, IMarEST, UK.

“Ocean Business has quite rightly established itself as a "must do" event for the marine survey industry...perhaps you should rename it Great Ocean Business...” Andy Smith, Director, Hemisphere GPS European Office, Saderet Ltd, UK.

As well as these testimonials, Ocean Business has twice been recognised by the UK Association of Marine Scientific Industries who have awarded those involved with the AMSI Business Person of the Year Award. In 2008 Versha Carter (Director, Intelligent Exhibitions) was the first recipient of the award in recognition of the success of the first show in 2007 and during the 2013 Ocean Business event Keith Birch (NOC) will be the first person from a public sector organisation to ever receive the award in recognition of his contribution to Ocean Business over its four shows to date.

2 http://www.intelligentexhibitions.com/
3 http://www.imarest.org/
4 http://www.auv2012.org/
5 http://www.oceanengineering.org/
6 http://www.hydro-international.com/issues/articles/id1232-Unmanned_Underwater_Vehicle_Showcase_UUVS.html
7 http://www.sut.org.uk/

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