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The Science Of Deepwater Oil Spills – Results From The 2013 Marine Scotland Science Modelling Workshop

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This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science.

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The Science of Deepwater Oil Spills

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Workshop Recommendations

The workshop on "The Science Of Deepwater Oil Spills – Modelling" held in Aberdeen in September 2013 included more than 50 experts drawn from academia, government, consultants and industry to discuss aspects of the science needed to respond in an effective way to a deepwater oil spill west of Shetland. Experts in oceanography, circulation modelling, oil dispersion modelling, oil spill response and deepwater ecology were present.

Throughout the four sessions of the workshop, certain themes and ideas were repeated by the participants. These have led to the following principal recommendations:

Baselines

There is a need to develop physical, chemical and biological baselines in the deep waters west of Shetland so that we have data to compare change against in the event of a spill and the response to a spill. Without these we will never be able to identify or quantify effect.

Benchmark Dataset

A "Benchmark Dataset" should be assembled for the area West of Shetland, open to all users. The benchmark dataset should include aspects such as circulation model forcing fields (e.g. meteorological, tidal, density), boundary conditions, observational validation data (e.g. vertical current profiles, drifters), and bathymetry. Such a benchmark dataset would then allow all models of the area to be run with common features in order to aid inter-model comparisons. Such a dataset would be tested by users, and users would be familiar with the data, its access and use. Hence, in the event of an incident, the benchmark dataset would be a principal tool to initiate oil spill models to be used operationally, in the absence of more suitable data.

Model Challenge

A model challenge for circulation and oil spill models should be promoted where models are challenged to simulate a set of specified scenarios west of Shetland. Model outputs should be provided in a specified format again to allow inter-model comparisons, or post-processing scripts for formatting model output should be shared. Such a challenge will have multiple benefits. It will bring together user and modelling communities. It will promote communication and networking prior to an event happening. A model challenge event could be used to address questions such as data assimilation, how to explain and interpret models, model ensembles, model validation, model process scales, etc. It would develop a more standard model output so that models could be more easily compared. It would prepare us to work together in the event of a spill west of Shetland. A model challenge would also enhance linkages between users and modellers in the area west of Shetland.

Tracer Experiment

We should consider a joint industry/science experiment west of Shetland where a tracer is purposefully released sub-surface under conditions that we may experience during a real oil spill event. Observing the dispersion of such a tracer will develop our capacity and practical ability to survey released oil in the event of a real sub-surface oil spill. It can be used in real time as a modelling exercise to test our operational response strategies. It will provide observational data on dispersion processes in the Faroe Shetland Channel, and will provide a benchmark dataset for future modelling work. It will bring together science, industry and regulator in a common exercise. It would test the whole system, and show us how models are embedded in the response system. It would help us develop methods to communicate model predictions to responders.

Community Connections

We should consider how to improve connections and communication between the different sectors which need to work together in order to improve our ability to respond to an oil spill west of Shetland. The sectors include: university based and government agency based oceanographers, chemists, ecologists; university, government and private sector modellers; environmental consultancies; environmental professionals in the oil and gas sector; government and industry responders; oil and gas operators; and government regulators. As spilled oil west of Shetland will rapidly cross national boundaries, these communities should be also include neighbouring countries: Norway, Faroe and Iceland. These communities need to understand each other's needs, and establish personal links before an event occurs, not during one.

The Science of Deepwater Oil Spills

Workshop 1 – Modelling

Workshop Report

Introduction

A workshop on “The Science Of Deepwater Oil Spills – Modelling” was convened by Marine Scotland Science, Marine Laboratory Aberdeen, Scotland, 18-19 September 2013. The aim was to investigate the science needed to model a deep water accidental oil release in the region of the Scottish shelf break/Faroe Shetland Channel (here forth referred to collectively as FSC, unless specifically stated otherwise). This first workshop focused on the science needed to improve the modelling of a spill. Further workshops will focus on other aspects, including monitoring spills.

Oil exploration in UK waters is taking place at increasing depths, in areas of complex oceanographic and extreme environmental conditions such as the FSC. In the case of an environmental incident, numerical models are potentially critical tools to guide the monitoring and response effort. However, modelling the behaviour of oil spills at depth is still under development and current hydrodynamic models of these waters are not yet able to fully describe the complex oceanographic patterns observed.

The workshop was used to investigate the modelling capacity to respond to a deep water oil spill in the FSC.

The three specific workshop objectives were:

- To review the current state of the art modelling capacity, applicable to the FSC area.
- To identify knowledge gaps.
- To recommend future improvements and propose specific research topics.

The workshop only considered aspects directly relevant to modelling. It was organised into four themes:

1. Oceanography of the area.
2. Circulation modelling.

3. Dispersion modelling.
4. Processes affecting the behaviour of the oil, e.g. interaction with sediments, natural oil degradation and the science behind chemical dispersants and their effects.

Expressions of interest were invited from experts from relevant academic and research organisations, industry and industry bodies, consultancies and government departments.

Participants were organised into working tables. After each theme's presentations the working tables considered the aspects of "State of the Art", "Knowledge Gaps" and "Future Recommendations". A plenary session then gathered feedback from each table and these were recorded by the convenors. In "State of the Art", participants were asked to emphasize any particular issues shown in the presentations but also to identify areas of present knowledge not included in those, while "Knowledge Gaps" refer to aspects where our present knowledge is inadequate or non-existent. The division between what we know but was not presented at the workshop, what we do not know and what we should know is somewhat artificial and this is reflected in some degree of overlap between these categories in the notes taken of the discussions. In this report, however, we have attempted to re-organise the discussions based on the definition of these three categories, as defined above.

Marine Scotland Science, and the authors of this report, would like to acknowledge the expert contributions from the following participants to the workshop:

Name	Surname	Organization
Dmitry	Aleynik	Scottish Association for Marine Science
Babatunde	Anifowose	Coventry University
CJ	Beegle-Krause	SINTEF Materials and Chemistry
Bee	Berx	Marine Scotland Science
Alison	Brand	BMT Cordah Ltd
Eileen	Bresnan	Marine Scotland Science
Anna	Buckingham	DECC
Craig	Bunyan	Chevron
Ana	Carrasco	Norwegian Meteorological Institute
Neil	Chapman	Maritime and Coastguard Agency
kevin	colcomb	Maritime and Coastguard Agency
Julie	Cook	DECC
Knut Frode	Dagestad	Norwegian Meteorological Institute
Andrew	Dale	Scottish Association for Marine Science
Andrew	Davies	ConocoPhillips
Tim	Endean	RPS Energy
Therese	Follin	DECC
Sine	Gabbott	Maersk Oil UK
Alejandro	Gallego	Marine Scotland Science
Ian	Greenwood	Shell
Tony	Gutierrez	Heriot-Watt University
Liam	Harrington-Missin	Oil Spill Response Ltd.
Peter	Hayes	Marine Scotland Science
Sean	Hayes	Genesis
Lars Robert	Hole	Norwegian Meteorological Institute
Michelle	Horsefield	BP Exploration Operating Company Ltd.
Mark	Inall	Scottish Association for Marine Science
Gillian	Kinsella	Oil & Gas UK
Sebastien	Legrand	RBINS / OD Nature
Lucie	Lépissier	BMT Cordah Ltd
Joanna	Lester	Xodus
Charlie	Main	National Oceanography Centre
Silvia	Maßmann	BSH
Andrew	Matthews	Petrofac

Hannah	Moir	Genesis Oil and Gas
Nicole	Mulanaphy	RPS ASA
Clare	Murray	Chevron
Rory	O'Hara Murray	Marine Scotland Science
Louise	O'Hara Murray	Oil & Gas UK
Bruno	Pereira	Qualitas Remos
Katya	Popova	National Oceanography Centre
Jon	Rees	Cefas
Petter	Rønningen	SITNEF Materials and Chemistry
Toby	Sherwin	SAMS
Lucy	Short	Oil Spill Response Ltd.
John	Siddorn	Met Office
Paul	Stainer	Marine Scotland Science
Nataliya	Stashchuk	The University of Plymouth
Bill	Turrell	Marine Scotland Science
Vasyl	Vlasenko	The University of Plymouth
Sarah	Wakelin	National Oceanography Centre
Ursula	Witte	University of Aberdeen

Theme 1 - Oceanography of the Faroe Shetland Channel and Scottish Shelf Break

State Of The Art

Presentations:

1. Setting the scene (Bill Turrell, MSS).
2. Marine Scotland Science monitoring/research and collaborative projects (Bee Berx, MSS).
3. Internal mixing processes (Mark Inall, SAMS).
4. Eddies (Toby Sherwin, SAMS)

The introductory talks illustrated the complexity of the oceanographic processes in the FSC and off the Scottish shelf break. In addition to a complex residual circulation, with currents at different vertical levels in the water column and across the area transporting water in sometimes opposite directions, there is a strong internal tide, generating intense pulses at points such as the seabed, and localised and intense mixing events e.g. when internal waves break.

There is also considerable meso-scale variability in currents, with meanders and eddies, and considerable spatial variability in these phenomena. A long established monitoring effort takes place in the area, in addition to more focused process studies and observations spanning over several decades. However, even though a wide range of methods are being used (ship-based hydrographic observations, moored profiling current meters, satellite altimetry and other remote sensing methods) and new methods are appearing on the horizon (e.g. HF radar, autonomous underwater vehicles), observations remain relatively sparse in the context of the spatial and temporal scales of the processes controlling the oceanographic variability in the area.

Specific items identified by the workshop participants in the discussions to characterise the state of the art were:

- *Wind Field Variability:* We need an adequate description of variability in wind field patterns, something that was not addressed in the review presentations. A related topic refers to characterising the effect of wind rotation (vorticity) on the circulation in the area.

- *Vertical Interactions:* Deep currents, including those generated by phenomena such as internal tides, can interact with surface currents. We need to characterise such interactions – an aspect likely to require additional research.

- *Spatial Resolution:* The degree of spatial variability was identified in some of the review talks. Such variability needs to be taken into account to avoid the dangers of inadequate spatial resolution in models. A key question remains, what is the minimum spatial resolution needed to model the key dispersion processes in the FSC?

- *Remote Sensing:* Sea Surface Temperature (SST) and altimetry are useful remote sensing products but additional remote sensing products should be considered to study the oceanography of the area, e.g. HF Radar. However, surface sensing from satellites or radar is valuable but how well does it represent conditions within the water column?

- *Ocean-shelf Exchange:* Ocean-shelf exchange was not explicitly addressed by the presentations. However, it is the subject of on-going research (e.g. the FASTNEt project http://www.bodc.ac.uk/projects/uk/fastnet/project_overview/) It needs to be considered as most socio-economic impacts of spilled oil will be on the continental shelf.

- *Distant Waters:* The review concentrated on the FSC, which is understandable, but released oil may move quickly into other areas (i.e. the Norwegian Sea and the Iceland Basin); can we be confident that we understand the oceanography (and can model it) in those areas? Is the focus of the current exercise too local and should it be extended to other areas that can be affected, e.g. the Minch, the Fair Isle Gap? Coastal processes were not mentioned, and will become of importance as oil spreads.

- *Additional Data Sources:* There are additional data sources beyond the ones presented, such as the UK Met Office, the offshore oil and gas industry, the MoD, and international datasets. These should be captured in a more comprehensive review.

- *Academic Modellers/End User Disconnect?:* How well can our understanding of the oceanographic complexity reviewed here be used in operational modelling? Is there a disconnect between academia and end users?

- *Internal Processes:* Internal mixing is very important, as are vertical velocities. We also need to study the effect of overflows over ridges due to internal tides.

- *Holistic Approach:* In addition to individual processes, we also need to study and understand the interactions between these processes, i.e. take a more holistic approach.

- *Data Assimilation:* We need to discuss the options for real time monitoring and assimilating these data into models.

Knowledge Gaps

- *Winter data/seasonality:* There is a need for continuous winter data from throughout the water column (e.g. from gliders and other autonomous vehicles), as most of the data gathered is outside the winter period, for understandable reasons and with some brave exceptions.

- *Horizontal Dispersion:* We need a better quantification of horizontal dispersion.

- *Intermittent Turbulence:* Intermittent turbulence needs to be better understood and how this may affect an oil release close to its source.

- *Shelf-Ocean Exchange:* Observational evidence describing shelf-ocean exchange is still required to improve the models.

- *Predictability:* The degree of predictability of the processes under consideration needs to be quantified better to be able to incorporate them into models. Our understanding of the chaotic nature of the system is still relatively basic.

- *Forecasting vs. Statistical Approach:* A considerable body of observational evidence may be required for forecasting operationally, while a statistical modelling approach (identifying trends and patterns of variability at various temporal and spatial scales based on past observations) may help and be useful to planning operations.

- *Real Time Observations:* Present observations are far from real time at the moment, and this is needed if they are to be assimilated into models. It might be possible to use other locations for monitoring instruments such as offshore platforms.

- *Interaction with Bathymetry:* Bathymetric controlled processes and interactions with the sea bed are still not well understood.

- *Process Spatial Scales:* Specifically, the scale of the key processes under consideration at exploration areas needs to be described adequately.

Future Directions

- *The Top Five Processes:* Coming up with top five processes resulting in the dispersion of released oil may help focus minds and generate projects and attract funding.

- *Spatial Integration:* We need to examine our present knowledge in a way that integrates across spatial scales and oceanographic regimes.

- *Shelf-ocean Exchanges:* Shelf-ocean exchanges are important and need to be better studied.

- *Fill the Winter Data Gap:* It is important to address knowledge gaps with long duration observations, including in winter.

- *A Tracer Experiment?:* It would be useful to carry out an "artificial oil spill" (tracer?) to track and predict, to challenge the existing models and to lead to improvements. Such an experiment would also further develop our ability to monitor spilled deepwater oil in a real situation.

- *Predictability:* Understanding predictability of processes better would be useful. Is the system truly chaotic? At what space/time scales is the system predictable?

- *Use of Ships of Opportunity:* Ferryboxes are likely to provide useful datasets and should be explored further. In this context we should note the SERPENT project (http://www.serpentproject.com/default.php). Can we take advantage of observation opportunities in collaboration with the offshore oil and gas industry?

- *An Instrument Pool:* It was suggested that there should be an EU (or UK) collection, or register, of scientific equipment which could be used in emergency response (e.g. drifters, gliders, ROVs, ADCPs).

- *Possible Funding Sources:* There is a large range of potential funders of research in this area, e.g. NERC, EU, MoD, DECC, SG. We should consider ways of harnessing all of these, and bringing in other interests into the picture, including industry.

Theme 2 – Circulation modelling

State Of The Art

Presentations:

1. Operational modelling (John Siddorn, UK Met Office).
2. Model development (Sarah Wakelin, NOC-L).
3. Small scale processes (Vasyl Vlasenko, Plymouth University).
4. International perspective (Lars R. Hole, Met No)

Presentations were made by representatives from the UK Met Office, the UK National Oceanographic Centre - Liverpool, Plymouth University and the Norwegian Meteorological Institute. A brief review of the state-of-the-art of hydrodynamic regional models for the UK continental shelf was presented. A validation of the FOAM AMM7 modelled currents in the FSC was presented. Validation of other regional scale models were also presented, including currents, CTD, tracer tracks, drifters, and sub-surface fluxes. A comparison with a real oil spill was also shown. Some attention was also paid to small scale processes that require high resolution modelling, such as internal waves and some wind driven currents.

Specific items identified by the workshop participants in the discussions to characterise the state of the art were:

- *Oceanographic Fronts:* Oceanographic fronts are often areas of enhanced convergence and vertical velocities (sinking). Such fronts are known to exist in the FSC, and require consideration. Are such features captured by the current models?

- *Data Assimilation:* This was again identified as a priority to enhance present modelling in the FSC.

- *Temperature/Salinity Structure:* The vertical distribution of temperate and salinity in the FSC is well described by the repeat monitoring that is undertaken there. Temperature/salinity profiles should be used more to test the skill of circulation models. The vertical density structure is a key factor when considering the initial dynamics of a released oil plume.

- *Model Validation:* In the presentations of models of the FSC, few talks mentioned model validation using observations. More information on model validation, especially sub-surface currents and processes is needed.

- *Explaining the Models:* If models are to become the basis of most of the dispersion planning and prediction in the FSC, then we need better simple descriptions of ocean models in order to explain what is being done.

- *Expert Interpretations:* Expert interpretation is needed to aid end-users' understanding and use of circulation models and their outputs.

- *Stokes Drift:* It was questioned to what extent this dispersion process (resulting from the interaction of waves and currents) is incorporated into current dispersion models in the FSC, and if observations were available to show the magnitude of this dispersion mechanism under the extreme conditions found in the FSC?

- *Waves in UK Models:* The workshop questioned to what extent surface waves and their interactions were incorporated in the current generation of circulation models, particularly those used by UK institutes.

- *Regional Model Suitability:* It was suggested that different models may work best in different regions (e.g. the FSC, the Norwegian Sea, the Iceland Basin, the UK Continental shelf). The question was put, which models work best in which region?

- *Model Applications:* It was felt that there had been a focus on the operational use of models in the FSC, and less on the use of models to hind cast events or as planning tools. These different uses support spill response vs environmental assessment.

- *Bathymetry:* It was noted that there are many bathymetric effects on circulation and mixing in the FSC. It was questioned how well bathymetric effects are included in the current generation of models, and if accurate bathymetries are available for the region.

- *Meteorological Models:* It was recognised that most meteorological forcing data fields come from models, and hence a review is needed of the available meteorological forcing models, their strengths and their weaknesses.

- *Circulation Models:* Similarly a review of all available ocean circulation models could be useful in order to identify input for spill models.

- *Model Skill:* One validation method might be to test model skills in terms of predicted trajectories, including above deep water, the shelf edge and in coastal waters. Here drifters would provide useful *in situ* validation data.

- *Parameterised Processes:* Most models parameterise sub-grid scale processes and do this in differing ways. A discussion is needed of the sub-scale physics included in each model.

- *Probabilistic Ensemble vs Deterministic:* There is a distinction between probabilistic ensemble vs deterministic model runs. However, the workshop asked what is more valuable for the end-user?

- *Driving Factors Behind Model Choice?:* What is the driving factor behind the choice an offshore operator/regulator/monitoring agency/environmental consultancy makes as to which model to purchase and use? In reality it was thought that it may be the cost and availability of a model rather than its applicability or accuracy. Additionally, circulation models may be being selected simply as they meet the input requirements of spill models (e.g. format/scale) rather than being the most skilful models.

- *IT Considerations:* There are also issues concerning the hardware (e.g. data storage, processing power, etc.) that may influence model selection, mode resolution and model use.

- *Understanding by the Regulator:* The workshop discussed if there was a lack of critical understanding by the regulator of the complexity of the field of hydrodynamic modelling and oil spill modelling. This might be a barrier to the correct selection and application of models in the FSC.

Knowledge Gaps

- *A Holistic Modelling System:* Currently there are many models that include the FSC region, each including different processes and at different geographical scales. There should be an effort to bring these different models together in order to create an holistic modelling system of the region. No single circulation model seems to be able to capture all relevant processes at the moment.

- *Lack of Measurements:* There is still a need to provide *in situ* measurements in order to support high resolution modelling. Modelling and observation must be performed at similar time and space scales.

- *Lack of Validation:* There are still very few comparisons between measurements and models in the FSC.

- *Minimum Standards:* We need a definition of what is the minimum requirement for an underlying hydrodynamic model used to support oil spill prediction in the FSC.

- *Comparison Exercise:* We need a systematic comparison exercise between models, and between models and observations in the FSC area.

- *Model Ensembles:* The use of model ensembles (different models using the same parameters and forcing datasets) and ensemble runs (individual models run with parameter perturbations and/or different forcing datasets to account for uncertainties in those) should be explored and compared to single model runs in order to include and quantify potential variability.

- *Standard Outputs:* We need standard (in terms of temporal and spatial resolution, region and format) FSC model outputs so that users could run their own comparisons between models and their various outputs. If this is unrealistic, an open library of post-processing scripts for model output re-formatting into common standards could achieve the same objective.

- *Research Dissemination:* There exists an end-user knowledge gap concerning what is available from the academic research community. More focus is needed on user-friendly dissemination to the end user, not just peer reviewed publications.

- *Different Model Uses:* We must acknowledge the different needs of planning scenarios vs emergency response, and create a system to support these different needs.

Future Directions

- *Benchmark Datasets:* It was suggested that “benchmark” datasets of driving forces should be established (e.g. wind fields/boundary conditions) in order to facilitate inter-model comparisons.

- *Flexible Data Assimilation:* Models with flexible data assimilation schemes should be developed. These could target where an incident occurs and improve models locally where needed.

- *Remote Sensing:* Remote sensing to provide real-time data for assimilation into models should be considered (e.g. HF Radar for surface currents and waves data).

- *Industry Data:* Industry (e.g. ADCP) data should be used more, and made more available to the research and modelling communities.

- *Community Disconnect?:* Workshop participants thought there was a disconnect between end-users, modellers and experts, and that a mechanism was needed in order to close this gap. This should include regional partners as well as national ones, for example through the EU and including Norway. Likewise, better connection between government, academia and industry is needed, possibly through the industry bodies (e.g. Oil & Gas UK) and regulators (e.g. DECC etc, MS, MMO).

- *Real-time Data:* For operational modelling, and data assimilation into operational models, real-time ocean data needs to be transmitted to modellers. The systems needed to do this (e.g. the Global Telecommunications System, GTS) should be investigated.

- *Funding of Model Development:* Industry should be encouraged to the development of regional circulation models, in collaboration with Government and funding councils.

- *Standard Model Outputs:* Standard model outputs for different regions in standard formats, freely available for easy comparison, including the forcing datasets.

- *Model Challenges:* There should be organised model comparisons, both between different models, and between models and observations in order to test their validity, consistency, strengths and weaknesses.

- *Model Resolution Limit:* As we go to higher spatial and temporal resolution, will there be a limit to the cost-benefit?

- *Oil Spill Modelling Priorities:* There should be an exercise to prioritise what is important for oil spill modelling, and then these priorities should be translated back to priority setting for hydrodynamic modelling.

Session 3 – Oil Dispersion Modelling

State Of The Art

Presentations:

1. Setting the scene (Jon Rees, CEFAS).
2. OSIS (Lucy Short, Oil Spill Response Ltd.).
3. Capabilities of OSCAR, an introduction to 3D oil spill and contingency modelling (Petter Rønningen, Sintef).
4. Research into oil dispersion modelling (Charlie Main, NOC-S).

An overview was given detailing the need for oil spill trajectory modelling, both in response to an incident and for contingency planning. The challenges facing modellers were covered, especially in challenging areas such as the FSC. Overviews of some of the most commonly used oil spill trajectory modelling tools were given, with example screen shots and videos demonstrating how the software can be configured. Example outputs were shown including statistical and probabilistic outcomes. An example of a deep sea plume in the FSC was shown with oil released above 600 m depth going NE, and oil release below 600 m going SW. The fact that there are many oil dispersion modelling tools, all somewhat different, was highlighted, as was the need for validation against any cases of opportunity, such as surface drifters, drifting buoys, real oil spills, etc. The benefits of real time operational oceanography, such as the work carried out by various organisations represented in the North West European Shelf Operational Oceanographic System (NOOS), and collaborative research and sharing of data, were highlighted.

Items identified in the discussions (beyond introductory talks) to characterise the state of the art are:

- *Missing Models:* Oilmap (Applied Science Associates) was not covered/reviewed by the talks in sufficient detail in this session (it did have more coverage in theme IV, however). GNOME (NOAA) was also not mentioned, despite being a common model used in the USA (and is part of the in-house oil spill forecasting capability of MSS).

- *Data Assimilation:* There needs to be more focus on how data sources can be used in real-time with oil spill trajectory modelling tools in order to improve the accuracy of their predictions.

- *Model-GIS Integration:* A subject area not covered was how GIS and other map based software/systems can be used in conjunction with oil dispersion modelling tools to disseminate information to users.

- *Ice Modelling:* Ice modelling was not covered. It is important to know how ice moves and how it interacts with oil. However, this is not relevant for the area under consideration by this workshop. With the expansion of the oil industry into the Arctic, this subject will be of increasing importance to UK industry.

- *User Competence:* The competency of model users was mentioned but more emphasis on this is sometimes needed. Who interprets and uses the models is important.

- *Parameter Sensitivity:* The sensitivity of models (such as OSCAR) to different parameters was not covered in the review talks.

- *Appropriate Model Inputs:* The current state of the art oil spill modelling presentations did not consider whether the current set of hydrodynamic model inputs are appropriate for FSC or not. This is a fundamental question in this region that any model user should ask themselves at the beginning.

- *Data Formats and Web-Based Access:* Data formats were not covered. Common data formats would help academics and responders work together more easily, although some standard formats such as netDCF partially fulfil this requirement. Web based access to data would also be useful.

- *Peer-reviewed References:* References for oil spill models and circulation models were not reviewed. These should still form part of the QA of any oil spill model.

- *A Catalogue of Strengths, Weaknesses and Limitations:* Some strengths and weakness of the models were covered, but a comprehensive list of the strengths, weaknesses and limitations of each individual model would be very useful. This would help with making a decision on selecting the most suitable model for a particular event. So there is a need to be honest about the limitations of each oil spill model. For example, one potential limitation of OSCAR identified is that data is hard to input.

- *Communicating to Responders:* How to communicate model output to responders was not covered here. This is an important topic, and needs more focus.

- *Surface Effects:* Wind driven mixing and the 'windage' factor were not really covered by the presentations – the FSC is an extreme environment and these surface processes need to be validated.

- *Link to Oceanography:* Whether the oil spill models can take on the important oceanographic processes identified in Theme I was not covered.

- *Remote Sensing:* Application of satellite tracking (remote sensing) to help with short term prediction was not covered.

- *"Bespoke" Models:* Preparatory in-house models and academic models were not presented. These are very valuable as commercial models can be limited in terms of data inputs.

- *Model Uncertainty:* The presentations did not address model certainty/uncertainty. Bayesian techniques can be used to address this.

Knowledge Gaps

- *Models in the System:* There needs to be some kind of structured and systematic approach to how models can be incorporated into the emergency response and licensing processes.

- *Communications:* Better communication between the model providers and researchers would be very beneficial. A science-response community interface would also be useful in an emergency. Currently this does not exist, and response exercises are very limited and insular in the communities they involve. For example, are there web based dissemination interfaces, or could they be developed?

- *Access to Data:* There is often a scarcity of data sources and access to data can be problematic. Can data be released from industry during a response, but also beforehand for constructing models before and incident occurs?

- *Wave Data:* Wave data and parameterisations within models. This is important as swell affects the breakdown of oil droplets, for example. Not enough research has gone into waves and the effect of waves in this region.

- *Pelagic Impacts:* What are the impacts of dispersed oil subsurface on the pelagic ecosystem?

- *Model Resolution:* Current hydrodynamic models have too coarse spatial resolution – higher resolution is needed for some oil spill models.

- *Coastal Effects:* How can freshwater runoff be incorporated into oil dispersion models, and is this important near coasts?

- *Oil Physical Properties:* How do the physical and chemical properties of oil change under different environmental conditions, and how can this be incorporated into models? For example, oil may behave quite differently 'on the day' than in the laboratory. This is especially true for the FSC region where environmental conditions can be extreme.

- *Fate and Effects of Dispersants:* Guidance on the (ultimate) fate and effect of dispersants are needed. These should be based on enhanced knowledge and research as current understanding is limited.

- *Scenario Planning:* Scenario planning should be extended in the FSC region, including, for example, experimenting with different well depths/pressures etc., to find out what the existing tools can tell us about a possible event west of Shetland ?

- *Communication*: Better guidance is still required in order to include a much wider involvement and input into the response to an incident. Currently communication lines are too restricted.

- *Datasets:* Compilation of data is needed in order to facilitate rapid access in the times of need

- *Resource Sensitivity:* More information on the sensitivity of resources is needed.

- *Model Validation:* More oil spill model calibration/validation is needed. In order to achieve this more data is required, including current profiles etc., but also data from real events or tracer experiments. Comparisons with reality and real oil releases needs to be done and methods to do this need to be developed. Hind cast or re-analysis runs of real (past) events would be very useful.

- *Model Internals:* Which models are acceptable and provide the best tool for the job? Often commercial models are treated as a black box. We need to know more about the processes each model tries to include, and how they are parameterised.

- *Industry Standard:* A “model industry standard” is needed, which describes the minimum standard of a model for particular situation (3D (deep) for example). This could help identify which tools should be used by consultants?

- *Access to Models:* How can industry get access to the most up to date models, especially from academia and government research? This includes both oil trajectory models, but also the hydrodynamic flow fields.

- *Knowledge Sharing:* Sharing knowledge between consultancies would be very valuable. For example sharing past event runs would be useful to get more confidence in results.

- *Standard Model Inputs:* Is there a need for a standard input to models to be defined by the regulator (e.g. for scenario testing and planning purposes)? Is there a requirement for a minimum of model output and interpretation? This is in order to aid model comparison and validation.

Future Directions

- *Ensemble Modelling:* A possibly better way to employ models, either using a single model run multiple times, or many different models. Ensembles provide a method of quantifying potential variability and uncertainty.

- *Focus on West of Shetland:* Current exploration areas west of Shetland are very complex. There need to be a focus on models of these areas. There is a need for more FSC research and dispersion model development for FSC. The complexity of this region is not currently captured by models.

- *Subsurface Dispersants:* We need to know more about the benefits/drawbacks of subsurface dispersants, for example Rosebank oil properties can change over time, especially when subsurface. We need this in order to be able to include their effect in dispersion models.

- *Bespoke Models:* The oil dispersion models are generic models at the moment. Do we need models specific to a particular location?

- *Basic Physics:* We need to understand more about the basic physics of environmentally important areas.

- *A Range of Models:* A wider range of models are needed to be made available – this might stimulate more model development. Currently the choice of models is too limited. Can the academic community be involved here?

- *Secondary Tools:* More development of trajectory analysis tools and secondary/post processing tools is needed.

- *Cross-discipline Communication:* Cross disciplinary discussion needs to be promoted, to help decisions during a response.

- *Model Comparison Exercise:* A inter-model comparison exercise is needed in the FSC in order to assess the performance of different models and model combinations. Note that NOOS do inter-model comparisons – both drifts (i.e. trajectory modelling) and comparison of hydrodynamics.

- *Drifter Comparison Contest:* Perhaps there should be a contest in order to find out which models can best reproduce real time drifter tracks (a prize could be offered!).

Session 4 – Oil Behaviour (Weathering, Sedimentation, Chemical Dispersion)

State Of The Art

Presentations

1. Importance of microbial systems to the fate of oil in the marine environment: the case at Deepwater Horizon (Tony Gutierrez, Heriot Watt University).
2. Oil in sediments (Ursula Witte, University of Aberdeen).
3. Modelling deepwater blowouts with subsurface dispersant applications (Nicole Mulanaphy, RPS ASA).

The three talks in this themed session covered how oil can be incorporated into sediments, the microbial breakdown of oil, and the application of subsurface dispersants. The Deep Water Horizon incident was referenced a number of times, with examples of the microbial breakdown of the oil and the area of seabed affected given. The capabilities of the RPS ASA OilMap software suite were presented by examining model output where dispersants were applied in different ways and quantities. An analysis of the sensitivity of OilMap to different current and wind forcing was also shown.

Items identified in the discussions (beyond introductory talks) to characterise the state of the art are:

- *Sediment/Water Interface:* This interface, and the interaction between dissolved components in the water and the sediment, has been neglected in observational studies, and is absent from much of the modelling. When it is included in models there is little validation of these processes.

- *Sediment Component:* We are currently unsure about the scale of how much of a release enters the sediment (cf. other oils sources e.g. drill cuttings etc.)

- *Oil Identification Methods:* We need more work on oil identification methods, such as biomarkers to identify specific oil .

- *Weathering:* No information was presented on the effect of weathering of released oil. We need more information on these processes in order to include them in models correctly, particularly under the environmental conditions that may be relevant to the FSC.

Knowledge Gaps

- *Degradation Timescales:* We need to know more about the time for degradation to occur under a variety of environmental conditions relevant to the FSC.

- *Toxicological Effects:* Similarly we need to know a great deal more about the toxicological effects of oil and dispersants on fauna typical of the FSC.

- *Relevant Species:* There are currently no studies on deep water sedimentary species. This is partly due to pressure issues.

- *Bacterial Blooms:* We know very little about the implications of bacterial blooms – e.g. on filter feeders, and how these might be imp acted by released oil and/or dispersants.

- *Sediment Biodiversity:* We need to know more about the resident faunal populations in the sediment and the potential changes that might result from introduced oil.

- *AUVs:* Is it possible to develop and use bacterial sensors for AUVs, such as gliders and drifters?

- *Communication:* How does research get into operational response?

- *Definition of Degradation?:* The workshop participants questioned whether there was sufficiently good definitions of the degree of degradation of oil. This is needed when assessing spill impact especially using models.

- *Baselines*: A spill will have an impact on the bacterial biodiversity in the FSC. But what is the baseline population structure to compare change against? What is the impact of climate change on bacterial population baselines?

- *Microbes/Marine Snow/Sediments:* There is little research on microbes/marine snow/sediments in the FSC – e.g. there are few, if any, estimates of fluxes.

Future Directions

- *Laboratory Experiments:* Laboratory experiments can still tell us a great deal about the behaviour of oil at the extreme temperatures and pressures found in the FSC. aboratory experiments could also look at the effect of intermittent mixing on oil.

- *Multiple Dispersants:* If sub-surface multiple dispersants are to be considered, we need to investigate the possible interactions between them, and between dispersants and oil.

- *Release Rates of Sub-surface Dispersant:* If sub-surface dispersants are to be considered, more research is needed into what release rates should be used – i.e. efficiency vs environmental protection.

- *Baselines:* More research is needed on biological and chemical baselines in the FSC prior to a spill occurring.

- *An Effect Proxy:* Can we use within-sediment oxygen profiles as proxy for biological effect?

- *GM Bacteria:* There is a need for research into whether genetically modified bacteria could be used to consume oil.

- *National Significant Spill:* A spill in the FSC is likely to be a National significant spill. However, the same kind of NSS has never been seen twice, i.e. each one is different and we need to be prepared to be flexible and adaptive in our approach.

- *Response Strategy?:* Do we really have yet a viable response strategy for the FSC?

- *A New Super Model?* Is there a need for industry/science/government to pool resources and develop a much more advanced model of the FSC region?

- *User Needs:* We need to put more effort into understanding user needs as well as developing “model interpreters” in order to communicate model results to users.

- *Dispersants – use them or not?:* We need to gain a joint understanding of dispersant use, and an agreed strategy. For example, following a deepwater spill in the FSC, should we rely on natural degradation? We could be using models now to help with this decision.

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