MIDAS

Managing Impacts of Deep Sea Resource Exploitation

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MIDAS MANAGING IMPACTS OF DEEP SEA RESOURCE EXPLOITATION

Analysis of data requirement for near-field model validation

Deliverable 2.4

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1. Introduction

Awareness of the pristine, background environmental conditions lies at the basis of an effective and sustainable approach to deep-sea mining, as well as of any potentially environmentally harmful human activity. When deep-sea mining is considered, background topographic, hydrographic and hydrodynamic conditions typical of the mining site area represent the primary information needed in order to understand, predict (model) and thus mitigate the response of the site to human intervention. For this reason, we are here interested in compiling some guide lines, to point out which observational parameters should be carefully monitored (before, during, and after mining operations), and at which time and spatial scales, in order to be effectively used as model inputs, as well as to be able to validate and improve model performances themselves.

The environmental conditions determine the biological and ecological networks sustained at and near the site. In this report, we will focus only on the characterisation of a mining site in terms of physical data, leaving the biological and ecological characterisation to the experts.

From a physical oceanographic point of view, the different aspects of a site's characteristics (topography, hydrography and hydrodynamics) are deeply intertwined, and, moreover, are connected to the larger, basin-wide system surrounding the site. For example, the hydrodynamic nature of deep sea sites can widely vary in combination with local, site-specific conditions, such as 1) the geographic latitude; 2) the topography of the area; 3) the local stratification conditions and variability; 4) the prevalent tidal regime and 5) the connections and relations to the correspondent surface current system, as well as 6) to the large scale ocean circulation. These physical aspects combine then in a unique, site-specific manner, and set the environmental background supporting the renowned ecological richness of deep sea sites, whose nature is paramount to respect and preserve.

It is this variety of conditions, the possible combinations of physical characteristics, and the several unknowns related to the mining techniques that will be adopted, that make numerical modelling a powerful and crucial tool in the decision making over a specific site. With models, in fact, few parameters can be changed at a time, and consequences isolated and evaluated for almost every single scenario.

Most importantly, it is likely that the largest impact of deep sea mining activities on deep-sea environments and ecological communities will depend on

- the mining techniques leading to direct sea bed disturbance;
- the techniques adopted for the mine tailing discharge;
- the techniques adopted for the spatial dilution of the produced mining plumes.

As physical oceanographers, we have no control or expertise on the specific techniques mining industries will adopt. However, we can point out that the initial behaviour and dilution of a mining discharge will depend on flows, and density stratification, at scales of hundreds of metres or less, encompassing turbulent processes down to viscous scales (centimetres and below). Obviously, the initial behaviour of a discharge plume will primarily depend on the discharge methodology, but also on the processes involved in equilibrating the plume with ambient water, and the hydrographic and hydrodynamic nature of the site.

As a first step, thus, in this report, we focus on the validation of near-field modelling only, at distances of $\mathcal{O}$ (10) m - $\mathcal{O}$ (10) km from the mining/discharge site, which contrasts to the far field modelling, $\mathcal{O}$ (100) km to basin scale.

Doing so obviously bears some limitations, mainly due to the consequences of remote effects. Flow structures in the ocean, in fact, span a continuum of scales. Clearly, for a high resolution model with open boundaries to the surrounding ocean, there is no way to provide information on the full range of scales at the boundaries, even when the model is nested within a larger-scale model domain. A large part of the small-scale complexity is locally generated and extracts energy from large scale flows and tides interacting with local topographic features. This component is included in a near-field model.

However, there will always be an energy deficit, reflecting incoming, small-scale energy from remote sources that are not represented in the near-field model. Perhaps the most notable omission is the misrepresentation of propagating internal waves that are not bound to a single spatial scale, and thus remain elusive in most of the numerical models. This includes the general oceanic background internal wave field (Garrett and Munk, 1979), as well as the presence of local near-inertial waves and internal tides (site-specific). The influence of strong internal waves on a plume could be, in principle, substantial. They could distort the plume, or lead to enhanced shear and mixing/diffusion at internal wave hot spots near to (reflection locations) and/or far from (internal wave attractors) the local topography (Hazewinkel, 2010 and references therein). However, these limitations of numerical models are known and dealing with them falls far from the scope of this report.

In order to analyse the data requirements for near-field model validation we will proceed as follows. In Section 2 we will point out which are the main small-scales, near-field characteristics and processes that may interact with the discharged plume and influence the impacted area. In Section 3, an overview is given on the near-field models currently used for studying hydrodynamics and plume dynamics in stratified fluids in realistic contexts. Moreover, data requirements for model initialization and testing are also reviewed. Given the processes we want to study, the input needs and the performances of the models available, in Section 4 we will review the instrumentation and monitoring techniques currently used for the acquisition of the required in situ oceanographic data. A list of useful online databases is provided in Section 5. On these websites, data are available for download and might provide a good starting point in assessing an historic background of a site where it has already been the subject of an oceanographic campaign. A summary of the guidelines for data acquisition and analysis for near-field validation is given in Section 6.

2. Relevant physical characteristics and processes in the near-field

Deep-sea mining is supposed to take place, as the word says, in the deep sea. This is commonly defined as the water column and seabed below 200 meters in depth. At these depths, the ocean is considered a low-energy system, because of the distance from the main energy input in terms of light and winds: the surface. This aspect of deep sea is at the base of the predicted slow recovery of its ecological communities after human intervention. However, although the deep ocean might be considered a low-energy system when compared to shallow, coastal seas, it still remains an interesting place dynamically. In fact, the deep sea might present weak stratification, weak tides and weak background flows, however, at the same time, it might be highly turbulent, highly three-dimensional, complex and non-linear. Moreover, its properties can vary on relatively small spatial scales, especially because of the prominent role played by the local bottom topography. All these factors render the deep sea a challenging and interesting environment both from the observational and from the modelling point of view. In this section, we will isolate the relevant physical characteristics and processes that usually describe a deep-sea environment in the near field of a site of interest. Obviously, each item on this list might be more or less relevant for a particular site. By using in situ observations, one should be able to assess the relative importance of one particular characteristic or process for the site of interest, and the value of having it represented (or not) in a numerical model.

2.1 Direct observations: hydrography, hydrodynamics and topography

A complete physical description of the near-field area around a deep-sea site of interest ($\mathcal{O}$ (10) m to $\mathcal{O}$ (10) km from the site) should include:

- **Topography:** Topography is obviously a key element defining a deep-sea site. It might play a major role in converting barotropic to baroclinic motion, generating internal waves, enhancing currents or turbulent diapycnal mixing patches. Moreover, it also plays a role in the definition of prevalent currents, i.e. in the presence of submarine canyons or seamounts. Following Dale and Inall (2015), we can distinguish two main types of deep sea environments that are of potential mining interest:
    - Mid-ocean ridge environments: characterised by complex and rough topography, often including an axial canyon at their spreading centre and transverse canyons at the flanks. An example of this is the Mid-Atlantic Ridge, and its series of hydrothermal vents.
    - Abyssal plain environments: relatively flat areas with isolated and abrupt topographic features. An example is the Clarion-Clipperton Zone (CCZ) in the Pacific Ocean.

Complementary seabed geological data are also used in case of particle tracking modelling.

- **Hydrography:** the deep sea is a stratified environment. Although stratification might be weaker than the one encountered in the first hundreds of meters, it is still present, and, in principle, inhibits vertical displacement (of water and of particles). Moreover, stratification and water mass composition present time variability at different timescales, going from the local buoyancy frequency to annual or even longer scales. Time scales up to seasonal might be of most interest in near-field modelling.

- **Hydrodynamic**: the deep sea is an active environment. Although currents might be weaker than in the surface layers, these are still shaping the dynamics of a site. Moreover, currents can be steady or oscillatory, and in this second case they present a time variability that spans different timescales, going from inertial (that might be faster or slower than tidal, according to the latitude of the site), to tidal to annual, seasonal, etc. Inertial, tidal and seasonal variability might be of most interest in near-field modelling.

These three elements directly correspond to the quantities a typical oceanographic campaign can measure (temperature, conductivity, depth, current speed). We will review the instrumentation and the data analysis typically used for this purpose in Section 4.

2.2 Processes in the deep sea

In this section, we will briefly review all (observable) processes in the deep sea that might act in the near field of a mining (or discharging) site, and may interact with the size and shape of the impacted area. Attention is thus focused on the area within tens to hundreds of metres of the possible source and especially on the lower part of the water column, since the near-bottom environment is of particular interest in this context. Site-specific processes and characteristics of relevance will be:

- Local turbulence and mixing patches;
- Potentially highly non-linear enhancement of vertical transport. This might be connected to:
    - topography
    - stratification
    - barotropic to baroclinic tide conversion

  - internal waves (tidally induced or inertial)
  - current speed.

- Processes leading to flow separation from the benthic boundary layer as a possible route for suspended material to enter the adjoining stratified water column, meaning (see Dale and Inall (2015) for details on each of these processes):
  - synoptic variability
  - benthic storms
  - benthic mixed boundary layer
  - interactions between steady flow and isolated topographic features
  - internal bores
  - conversion of barotropic tide into baroclinic tide via interaction between tides and isolated topographic features.
- Presence of eddies and deep penetration of eddies (see Inall et al., 2015), connections between deep and surface dynamics;
- Bottom intensification of currents. Mainly due to topography and stratification;
- Bottom intensification of waves. Mainly due to topography and stratification;
- Local internal wave field;
- Wave focusing, not necessarily near the bottom. Mainly due to topography and stratification, may induce hot spots for wave energy, mixing and vertical or oblique transport;
- Tidal rectification (mean transport due to correlation of wave and sediment concentration);
- Non-hydrostatic dynamics, due to the weak stratification (small Rossby radius);
- Hydraulics and lee waves;
- Rapidly-evolving and difficult-to-categorise dynamics at the sub-mesoscale (kilometres);
- Gravity currents;
- Particle-laden gravity currents in the vicinity of natural or artificial plumes.

It is clear that we listed here processes involving a wide range of different temporal and spatial scales, from minutes to seasons, from centimetres to kilometres. In particular, non-hydrostatic dynamics and turbulent, three-dimensional, potentially highly non-linear behaviour require that modelling for the near field must be done at very high resolution (100 m resolution or less) and locally. This might result in very costly numerical simulations, and might require even more costly sea-going oceanographic campaigns in order to provide an adequate observational knowledge of the site. Basic physical measurements that are usually performed at sea (temperature, conductivity, depth, current speed), the identification of the above-mentioned processes, and the evaluation of their relative importance for a specific site, require some further analysis. We will review the main techniques in Section 4.

3. Near-field numerical modelling

In Table 1 an overview is given on the existing numerical models currently available and used for near-field studies of hydrodynamics and plume dynamics in realistic contexts. The list is by no means exhaustive, however, it collects models that have been used or are currently used for feasibility studies in potential deep-sea mining sites. References are given in the table. It is important to note that because of the difficulties in communication between the academic and the industry communities, the majority of the listed models are mainly used in the academic context and are free. However, ROMS, Delft3D, CHEMMAP and CORMIX certainly have a larger user base across most areas of engineering and science, from both commercial and academic organisations.

3.1 Data requirements for model initialisation and testing

Despite the variety of existing numerical models, data required for model initialisation and/or testing in case studies do not vary much. As we have previously seen, the necessary types of data are bathymetric data, seabed data, hydrographic data and hydrodynamic data.

In fact, it is important to notice that near-field models are possibly used in combination with particle tracking models. According to the performance of each model, they are able to capture processes like coagulation, floculation, settling and buoyancy of particles entrained in the plume, both of natural sources as well as the ones produced by the seafloor disturbances due to mining. Particle tracking models can also usually account for different sedimentation rates (that can affect for example the local coral and mussel communities) and for different grain sizes of the particle, settling at multiple space and time scales. If the coupling of hydrodynamics and particle dynamics is studied, it is clear that geological and seabed data from in situ campaigns and from laboratory studies are also needed to constrain the models.

Moreover, modelling of local, near-field dispersion and dynamics acting on and in combination with a natural or artificial plume often constitutes only the first step of a feasibility study. In fact, near-field, small-scale models are usually nested within large-scale models, and results from the first can serve as a starting point for feeding models of basin-scale transport and dispersion. Large-scale models are usually initialised by basin climatologies, available for most of the world's oceans in open databases or upon request. A list of these databases is given in Section 5.

The sample time and spatial resolution needed for feeding each model has obviously to meet the standards set by the model time and spatial resolution itself. For near-field modelling, this might require spatial scales in the range of $\mathcal{O}(1)$ m - $\mathcal{O}$ (10) km in the horizontal, and of $\mathcal{O}$ (1) m in the vertical. Time scales for near-field modelling can vary in the range of $\mathcal{O}$ (1) minute to seasonal. However, this is extremely site-specific: in general, 1 year of observations would be enough for a mid-latitude site, but certainly more than 1 year is needed at lower latitudes to be able to capture low-frequency phenomena and trends such as ENSO (the El Nino-Southern Oscillation phenomenon; see for example Dijkstra and Burgers, 2002 and references therein), that might largely influence basin as well as local hydrography and hydrodynamics.

Collected in situ data must then be gridded according to the model needs. For this, horizontal maps could be produced, for example to see the boundary of a natural occurring plume and/or density anomaly spreading horizontally. Mapping could be a challenging task, especially when the number of data points is low. Various methods of optimal interpolation could help, as for example the DIVA software (Data-Interpolating Variational Analysis[1]).

[1] http://modb.oce.ulg.ac.be/mediawiki/index.php/DIVA

Table 1: Examples of numerical models currently available and used for near-field studies of hydrodynamics and plume dynamics in realistic contexts.

Model	**Users**	**References**	**Examples of relevant applications**
Delft3D	Academic & commercial	http://oss.deltares.nl/web/delft3d	central Chatham Rise area (Lecinski et al., 2014)
ROMS	Academic & commercial	https://www.myroms.org/ Haidvogel et al. (2008)	central Chatham Rise area (Had_eld, 2013)
CHEMMAP	Commercial	http://www.asascience.com/software/chemmap/	Solwara 1 (Co_ey Natural System, 2008)
MITgcm	Academic	http://mitgcm.org/	MAR and CCZ (Aleynik et al., 2015)
FVCOM	Academic	http://fvcom.smast.umassd.edu/fvcom/ Lai et al. (2010)	
MOHID	Academic	http://www.mohid.com/Hydrodynamics.htm	
OpenFOAM	Academic & commercial	http://www.openfoam.com/	de Wit et al., 2015
CORMIX	Commercial	http://www.cormix.info/	
PLUMES	Commercial	http://www2.epa.gov/exposure-assessment-models/visual-plumes	
VisJet	Academic & commercial	http://www.aoe-water.hku.hk/visjet/visjet.htm	

In order to provide adequate input to near-field models, a typical checklist of in situ measurements is given below. Obviously, in situ measurements are extremely costly and demanding in terms of facilities and sea-going equipment. However, relatively cheap numerical results are worthless if not compared with measured in situ properties of a site.

Given the information needed in order to initialise and test near-field numerical simulations, as from the list in section 2.1, the required in situ data will then be:

Bathymetric data:

- resolution for near-field modelling should be 25 x 25 m or 50 x 50 m (see also databases in Section 5);
- a detailed bathymetry should be used near possible release sites (10 x 10 m to 1 x 1 m);
- collected multibeam data (gridded and smoothed) should be combined with existing datasets.

Seabed data:

- bed concentration in the top seabed layer (~1 m);
- particle size distribution and settling velocity of the top seabed layer (1 m);
- annual sedimentation rate;
- variations of natural/artificial plume discharge rate from the nearby hydrothermal vent(s).

Hydrographic data:

- temperature, salinity, density, fluorescence, turbidity and transmissivity, most importantly for the lower ~500m of water column, but preferably surface to bottom;
- vertical resolution of 1-2 m;
- hydrographic fields have to be known near possible release sites, but also in the surrounding area, within approximately 20 km;
- hydrographic, background fields should be monitored in the beginning and after the end of all major operations;
- time variability of hydrographic fields at different time scales: from local buoyancy frequency to seasonal, to annual at low-latitudes, especially for the lower ~500 m of water column.

Hydrodynamic data:

- first model runs can be forced with (a) tidal only velocity and (b) tidal + climatological velocity forcing runs (see databases in Section 5);
- more accurate model runs should include local measured background velocity field;
- 3D Velocity profiles of the lower ~500m of water column at possible release sites;
- as for the hydrographic data, observations should be also performed at the boundary of the area of interest to obtain more accurate model forcing, practically to feed the model open boundaries;
- time series of current velocities at different time scales: from local buoyancy frequency to seasonal, to annual at low-latitudes, especially for the lower 500m of water column;
- measured extreme values for velocities are valuable observations;
- satellite observations (altimetry, derived geostrophic currents, etc.), if any link is recognized between deep current dynamics and surface dynamics.

Near-field models are then usually run under different scenarios, to account for different dynamical regimes of a site. This might include spring/neap tidal cycle, different mean flow regimes, topographic steering, transit of eddies. When in situ data are available, it is also good to test any possible anomalous behaviour captured in the time series, or in the measurements in general, such as periods with enhanced near sea-bed velocity, internal wave signatures, energetic hot spots or mixing hot hotspots. These test cases allow for measuring the model performances in \normal" and \anomalous" times and locations, adding value to the numerical predictions.

Besides, when near-field models are run, different mining techniques can be considered as well. Mainly, two different dumping mechanisms are possible: instantaneous and continuous release of sediments. Moreover, different injection depths, and different injection particle sizes and/or temperature are considered. Parameters and descriptions for the possible techniques should be provided by interested companies.

4. Instrumentation, monitoring techniques and data analysis

In this section, we will review the instrumentation and the data analysis techniques that are necessary to provide the modellers with an adequate input for the near-field numerical modelling. For an in depth description of monitoring technologies currently in use in European Research and industry, see the MIDAS report D10.1 (Janssen and Boetius, 2015).

4.1 Bathymetric data

Modelling with an accurate bathymetry is crucial, especially if one is interested in the small-scale, three-dimensional motion characterising the near field in the vicinity of a discharge site, or of the plume injection. Bathymetric maps at spatial resolutions from 100 m down to a few cm can be nowadays produced using for example a multibeam system. This can be shipborne, deep towed, or mounted on ROVs and AUVs. Bathymetric data acquired by multibeam have then to be gridded and smoothed to be used in a numerical model, since raw data often present holes or spikes due to spurious measurements (see Figure 1).

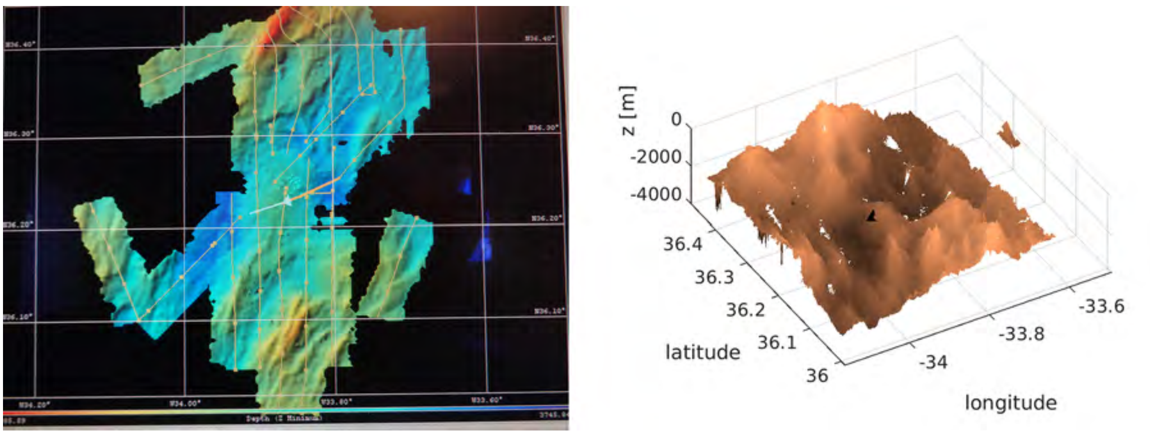

Figure 1: Left - Photo of real time acquisition of multibeam data on board of RV Pelagia, during the 2014 64PE388 MIDAS-TREASURE cruise. The snapshot shows acquired bathymetry in colour, within 33.4º W and 34.2) W, 36ºN and 36.5ºN. Photo by M. Lavaleije. Right - Visualisation of the raw multibeam data acquired during the 2014 64PE388 MIDAS-TREASURE cruise, in the surroundings of the Rainbow hydrothermal vent fields (marked by the black triangle). Data have a resolution of 0:0005 x 0:0005 degree (approximately 50 x 50 m). Holes and spikes are still visible in the dataset.

4.2 Seabed data

The surroundings of the mining site obviously must be subject to geological investigation prior to any human intervention. This is because the geological properties to the area must be known in order to operate safely and efficiently, both from the industry as well as from the environmental point of view. Even in polymetallic nodule fields or in areas of massive sulphide deposits, the deep sea environment can strongly vary in its geological properties, even on small (sub-metre) scales (Janssen and Boetius, 2015).

Investigation is made by visual inspection, thanks to cameras mounted on ROVs or AUVs, and from the analysis of georeferenced samples collected at the seafloor. Coring of the seafloor is usually also accompanied by real-time video information, and is performed using pistons, multi- and box-corers (see Figure 2), TVgrabs or the modular, thruster-manoeuvred HyBIS (Janssen and Boetius, 2015). These operations are essential for assessing the geological properties of the site for near-field model initialisation and validation when the particle tracking module is included in the numerical model. Time series for particle settling velocity of the top seabed layer and annual sedimentation rate are also needed for validation of the particle tracking modelling. These measurements are usually achieved using one-year (or longer) deployment of a lander equipped with sediment traps. Regarding the geological context needed for modelling purposes, one of the major unknowns is certainly the possible variation of natural plume discharge rate from the nearby hydrothermal vent(s). This can also be monitored using video-survey or long-term moored instrumentation in the vicinity of the source.

Figure 2: Left - Box-core on deck of RV Pelagia during the 2014 64PE388 MIDAS-TREASURE cruise in the Rainbow hydrothermal vent field area. Right - Retrieval of a box-core in the same cruise. A section of the first 1 m of the seabed is visible. Photos by A. Rabitti.

4.3 Hydrographic data

Two types of hydrographic data are used as near-field model initialisation and validation: data from a ship-based CTD (conductivity-temperature-depth) profiler, or data from moored instrumentation.

The CTD rosette can be lowered from the ship to the seafloor (usually about 5 m above bottom), sampling the whole water column, or just a part of it (lower 500 m). Besides measurements of conductivity (and thus salinity), temperature and depth, the frame is usually equipped with extra sensors (for example, fluorescence, turbidity and transmissivity sensors). Vertical resolution is 1 m, time resolution of the sampling is usually 1 second. Together with CTD measurements, water samples are often collected using the Niskin bottles mounted on the frame, used mainly for calibration of turbidity measurements. The spatial distribution of the sampling stations can be decided according to the model needs, and according to the model spatial scales. However, surface to bottom, far away (~20 km) stations are always required to feed the model open boundaries. To asses tidal variability of the hydrography of a site, it is common to perform 13-hours of continuous CTD measurements at the same location (if the semidiurnal tidal component is the dominant one). This type of measurement provides a first idea of the daily changes in stratification for the area of interest. However, longer time series of hydrographic data from moored instrumentation are also needed for near-field model validation, especially to resolve the seasonal and the annual cycle. Measurements of physical parameters can be performed at fixed positions along a moored line using simple thermistors (measuring temperature only) or using combined sensors for temperature, conductivity and all other parameters of interest (see for example Seabird microCAT sensors[2]). Otherwise, measurements can be performed along a portion of the water column, thanks to autonomous profilers such as the McLane moored profiler[3]. On the profiler, different sensors can be mounted, according to the user's needs. Obviously, due to battery limitations, increased sampling resolution of the moored instruments comes at the expense of the time series length. Typical time resolution for thermistors or microCATs goes from 1 second to 15 minutes. Time resolution for profiling instruments goes from "as fast as possible", and thus depends on the depth span of the profile, to once per day or once per several days, according to the user's needs. Spectral analysis of the measurements then gives information on the dominant frequencies for the variability of hydrographic properties.

In near-field modelling, diffusivity/viscosity parametrisations (vertical and horizontal) are one of the major unknowns, and a crucial element for obtaining realistic results. Fine-structure measurements (microstructure profiling or similar, see for example Waterhouse et al. (2014) and Salehipour & Peltier (2015) and references therein) provide direct estimates of these parameters. Otherwise, from classical CTD or LADCP (Lowered Acoustic Doppler Current Profiler) measurements, an indirect estimates of these quantities is also possible (see for example Thorpe (1977) for Thorpe scale analysis, and Kunze et al. (2006); Polzin and Firing (1997), for LADCP shear and CTD strain analysis), although with less vertical resolution. See Figure 3 for an example of vertical diffusivity estimate from a recent MIDAS cruise.

[2] http://www.seabird.com/sbe37sm-microcat-ctd
[3] http://www.mclanelabs.com/master_page/product-type/profilers/mclane-moored-profiler

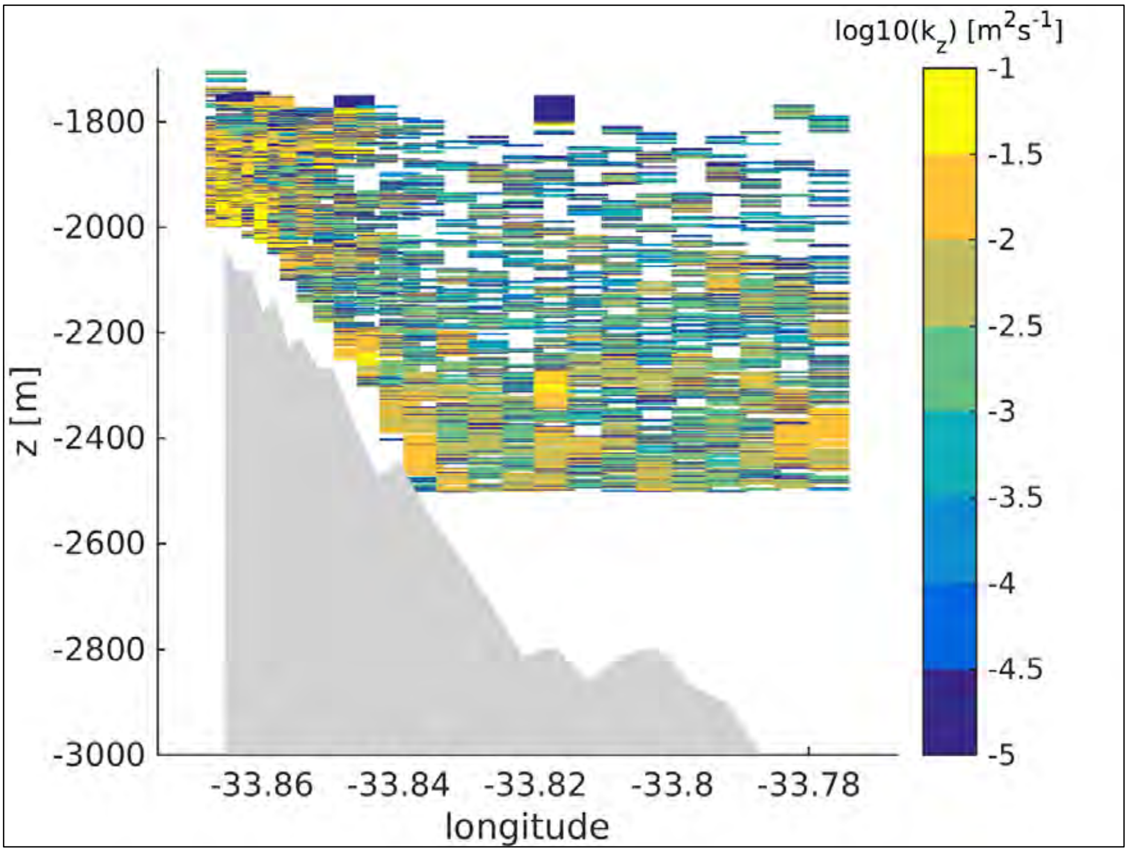

Figure 3: Example of vertical diffusivity, k_z ($m2s^{-1}$), estimation using Thorpe scales (Thorpe, 1977) from CTD data. Data are from a tow-yo transect (towed yo-yo CTD profiling) performed in 2014 during the 64PE388 MIDAS-TREASURE cruise in the Rainbow hydrothermal vent field area. The transect has been sailed in direction South-West to North-East, starting on the eastern flank of the Rainbow hill. Values of k_z are high if compared to average deep sea values, since they are relative to a very rough portion of the ocean floor (MAR). Within the transect, values of k_z are higher near the steep topography than far away, presenting a vertical and horizontal spatial variability on the 50 to 100 m scale.

4.4 Hydrodynamic data

As for the hydrographic data, two types of hydrodynamic data are used as near-field model initialization and validation: data from ship-based LADCP (Lowered Acoustic Doppler Current Profiler) measurements, and data from moored instrumentation.

LADCP data are acquired together with CTD data, thanks to two ADCPs mounted to the CTD frame. One ADCP is upward-looking, and one is downward-looking, in the so-called master-slave configuration. For the acquisition procedure and the processing details we refer to the method developed at Lamont-Doherty Earth Observatory (LDEO) by M. Visbeck and now maintained by A. M. Thurnherr (http://www.ldeo.columbia.edu/~ant/LADCP.html). A typical vertical resolution of LADCP pro_les is about 10 m. As for CTD data, 13-hour of continuous LADCP measurements at the same location resolve the tidal variability of a site (if the semidiurnal tidal component is the dominant one). Tidal ellipses can then be obtained over the whole water column, assessing the relative strength of the barotropic and of the baroclinic tidal motion. To do so, models for barotropic tidal predictions can be of use, such as TPXO/OTIS[4] or fes2012 from AVISO[5].

[4] http://volkov.oce.orst.edu/tides/global.html
[5] http://www.aviso.altimetry.fr/en/data/products/auxiliary-products/global-tide-fes/description-fes2012.html.

Time series for current velocities can be obtained by moored instrumentation at fixed positions along a mooring line. Measurements can be punctual and performed by mechanical or acoustic current meters, or can span a portion of the water column, using moored ADCPs. ADCP measurements are usually made up of 60 bins above or below the instrument itself, and each bin can represent from few centimetres to 10 m of the water column. This means that a long range ADCP anchored at the sea-bottom can adequately monitor the bottom 500 m of a site, with a reasonable time resolution of the measurements of the order of 10 minutes. Spectral analysis of the time series will then provide information on the typical time variability of the local, three-dimensional, current and wave fields (see an example of ADCP measurements and relative spectral analysis in Figure 4). Interestingly, due to the measurement principle employed by the ADCP, together with the current velocities, a time series of the backscatter intensity for the four acoustic beams is also provided by this kind of measurements. This can also contribute to the estimation of turbidity variability and to the plume tracking.

Besides in situ observations, satellite data from the area of interest can also provide useful information on the local hydrodynamics. Geostrophic currents, as well as the transit of eddies, can be evaluated by satellite altimetry. It is known, in fact, that these surface structures might influence the whole water column hydrodynamics. Connections of deep-sea dynamics to surface dynamics have been detected also for deep-sea sites (see for example Inall et al., 2015). Even if this might be more relevant for far-field modelling than for near-field modelling, sometimes surface (satellite) data can help in the interpretation of extreme, local events in the deep-sea. In this case, a time delay has always to be considered between surface and bottom dynamics. Moreover, satellite data can be useful for tracing large internal waves in an area, whose presence and interaction with the topography can be relevant at small scales as well.

5. Available databases

A list of online resources for bathymetric data, model outputs and in situ observations is given in Table 2. The list is by no means complete, however it can give a first overview on which kind of information is available for a specific area.

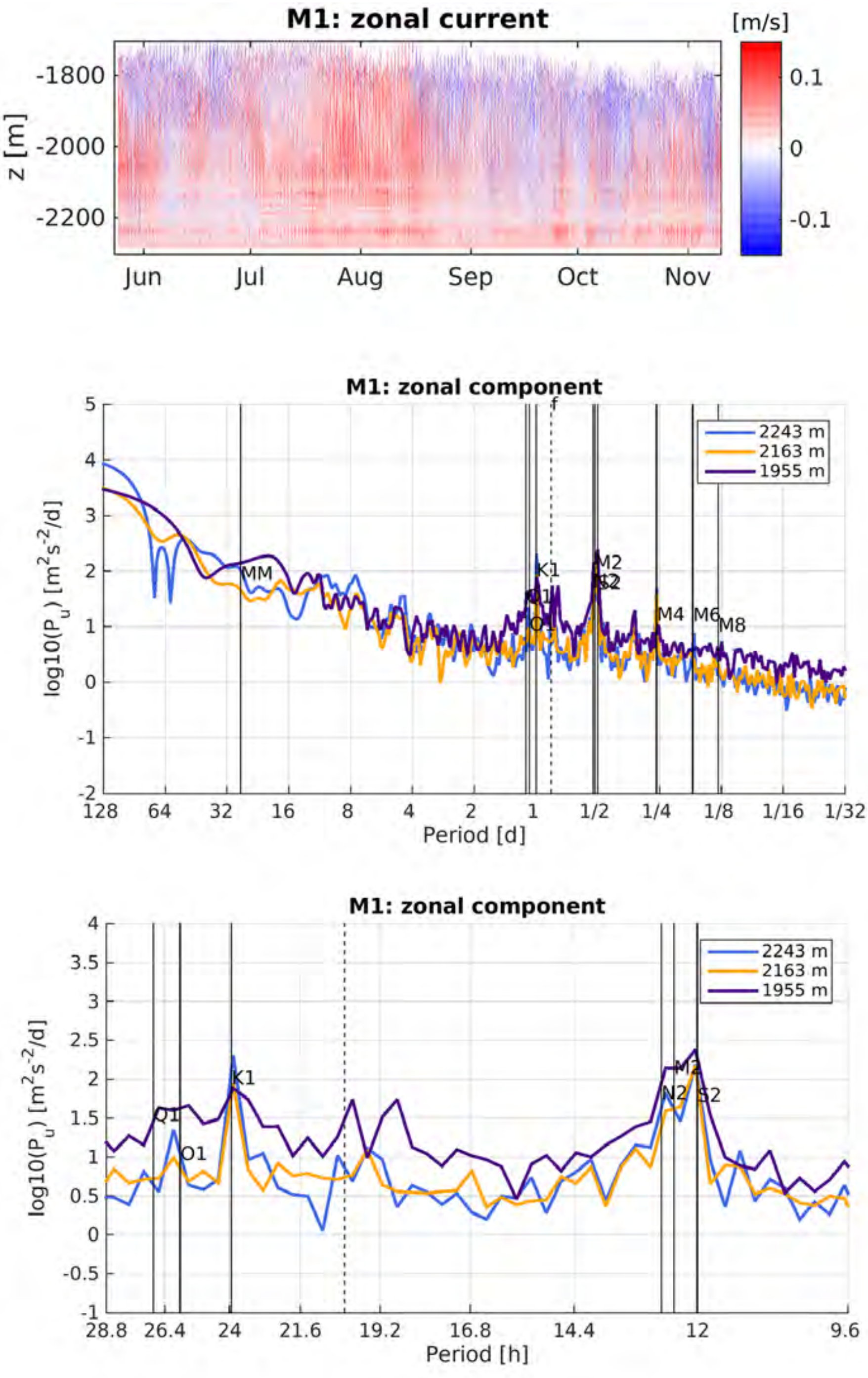

*Figure 4 a) Raw zonal currents measured by a near-bottom ADCP moored in the vicinity of the Rainbow hydrothermal vent field area (site M1). Time goes from May 2014 to December 2014. Each bin is 8 m, and the number of bins reduces in time as the battery power drains. b) Spectral analysis of the ADCP measurements for three bins, at 2243 m (blue line), at 2163 m (yellow line) and 1955 m (indigo line). Main tidal components and inertial period (**f**) are marked with black vertical lines. c) Zoom of b) between 9.6 h and 28.8 h. Note that this is a particularly interesting case, where a near-bottom K1 enhancement is observed, probably due to a local topographic effect. Location of mooring M1 is in fact on the northern tip of the Rainbow hill.*

Table 2: Examples of readily available global datasets of potential use for characterisation of deep ocean sites. These listings are illustrative and are not intended to be comprehensive. Compiled using also information from Table 2 in Dale and Inall (2015).

Type	**Source**	**Description**
General circulation	HYCOM http://hycom.org	1/12º global data assimilative runs available in hindcast mode
Barotropic tidal model	TPXO global tidal solutions http://volkov.oce.orst.edu/tides/	1/4º global model of the barotropic tide
Altimetry	AVISO http://www.aviso.altimetry.fr/	Surface currents and eddy kinetic energy from satellite
Bathymetry	Smith and Sandwell Global Topography http://topex.ucsd.edu/marine_topo/	1-minute global bathymetry from satellite and ship-based data (resolves scales >25 km)
Bathymetry	http://www.marine-geo.org/tools/	Resolution up to 25 m
Bathymetry	GEBCO http://www.gebco.net/	GEBCO gridded bathymetric data sets, GEBCO Digital Atlas, GEBCO world map and GEBCO Gazetteer of Undersea Feature Names
Climatology of density structure	NOAA World Ocean Atlas https://www.nodc.noaa.gov/OC5/woa13/	1/4ºglobal climatology of temperature, salinity etc. at standard depths.
Hydrographic data	CCHDO http://cchdo.ucsd.edu/	highest possible quality global CTD, funded by NSF and NOAA
Satellite data	EOLi https://earth.esa.int/web/guest/eoli	EOLi (Earth Observation Link) is the European Space Agency's client for Earth Observation Catalogue and Ordering Services
Hydrodynamic data	ARGO http://www.coriolis.eu.org/Observing-the-Ocean/ARGO or https://www.nodc.noaa.gov/argo/	Argo float data portals
Hydrodynamic data	ANDRO http://www.euro-argo.eu/Main-Achievements/Science/Global-Scales/ANDRO	An Argo-based deep displacement atlas
Oceanographic data	Ifremer http://en.data.ifremer.fr/	Ifremer data portal
Oceanographic data	PANGAEA http://www.pangaea.de/	Data publisher for Earth and Environmental Science
Oceanographic data	SEADATANET http://www.seadatanet.org/	Pan-European network providing data deriving from in situ and remote observation of the seas and oceans
Oceanographic data	OceanSITES http://oceansites.jcommops.org/	Worldwide system of long-term, deep water reference stations measuring dozens of variables and monitoring the full depth of the ocean

6. Guidelines

In the following, a few operational guidelines will be listed. These constitute a summary of what we have learned from studying near-field model requirements, but also from direct experience of collaboration during the MIDAS project.

- Observational data are needed in order to initialise and validate near-field as well as far-field numerical models. The types of data are: bathymetric data, seabed data, hydrographic data and hydrodynamic data.
- Online resources (such as those listed in Table 2) can provide information on what is currently available for the area of interest. However, spatial and time resolution of climatologies, or, in general, of global atlases, rarely meets the requirements for near-field modelling. Online resources can be of use mainly for bathymetric maps, for local barotropic tidal models, and for climatologies to apply to the open boundaries of the near-field domain.
- Whenever near-field modelling is planned for a specific site, at least two oceanographic campaigns have to be planned in the area (one for deployment and one for recovery of the moored instrumentation).
- The cruise plan of an in situ oceanographic campaign should be compiled by the sea-going oceanographers and by the modellers in strict collaboration, in order to meet the requirements of both approaches.
- It is best to decide at the beginning whether a far-field, large-scale study will be also performed, since this might have consequences on the design of both the near-field numerical simulations as well as for the required in situ data.
- Oceanographic campaigns need to involve a multidisciplinary team, since geological and physical data acquisition is needed.
- To identify relevant time and spatial scales to be modelled, not only in situ, environmental data have to be acquired. Information from industry is crucial on relevant time and spatial scales involved in typical mining activities, and on mining techniques, that can influence the design of the model runs and of the in situ data acquisition.
- The current analysis for data requirement for near-field model validation is meant to be useful for feasibility studies, prior to any human intervention. However, near-field modelling and observational surveys during and after operations should also be taken into account. During operations, it would be interesting to measure the sedimentation rate near the tailing's release and turbidity within a 500 m radius, perhaps using video survey on AUVs, or sediment traps. After the mining operations, it would be interesting to measure the new bathymetry, bed concentration, bed particle size distribution and ambient turbidity.

7. Conclusions

In recent years, numerical data of temporal and spatial scale of choice are easily produced. However, their value and validity is not easily assessed. Since results from near-field and far-field numerical models will most likely enter in the decision tree, and in the regulations, of future deep-sea operations, it is crucial both for industry as well as for society to rely on robust numerical output. To do so, expensive and time-consuming in situ data are needed.

In this analysis, we limit ourselves to the monitoring of physical processes that may be encountered at a specific site, and in particular, of those that will lead to increased turbulence or current speeds, with consequent enhanced horizontal and/or vertical spreading of the mine tailing material or injections of material into the upper parts of the water column. However, the understanding and, possibly, the prediction, of the final spatial distribution of the mining plume will be crucial in order to foresee and mitigate the physical, but also the biological and ecological consequences of deep sea operations. Coupling of hydrodynamic numerical models with biological and ecological numerical models has not been taken into consideration in the current report, but it would certainly need the implementation of biological and ecological data in the corresponding model modules.

Only a multidisciplinary effort, both observational as well as numerical, in trying to understand the deep sea environment will help mining industries and authorities in developing a set of regulations to permit initial exploration, and ultimately commercial exploitation, of seabed minerals while sustaining the fragile ecosystems that surround them.

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