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Spatiotemporal visualisation of a deep sea sediment plume dispersion experiment

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Abstract

Deep sea mining for metals as Ni, Cu, and Co as in manganese nodules (Mn-nodules) is currently further developed e.g. with respect to technological and economical feasibility but always poses the threat that these sensitive ecosystems are destroyed for a long time. To evaluate the impact of Mn-nodule mining activities, the JPI Oceans project Mining Impact II, studies the distribution of a sediment plume created by a mining vehicle. It uses in situ observations of a small-scale experiment and related ocean current and sediment settling numerical models. This is done to validate the model itself, to have a prognostic tool to determine at which location what type of sensor is need to capture the plume dispersion in the best possible way, and, finally, to present the results to none-experts. Through the contextualisation of a wide array of sensors and computer model parameters, we created a visualisation of a small-scale deep sea sediment plume dispersion experiment. Our 4D visualisation environment helps explore the dynamics of the sediment transport and deposition across time and space in an interactive and user-explorable way.

1. Introduction

The demand for metals particularly for a green economy is constantly growing and the industry is pushing towards resource exploitation at unconventional places. This is the case for deep-sea mining of manganese nodules, where an enormous source of valuable metals such as cobalt, copper, nickel but also rare earth elements lays on the seafloor in 4 to 5*km* water depth e.g. in the Pacific Ocean [GSA*18]. One of the proposed methods for mining consists in removing the upper 20*cm* of seafloor and separating the valuable nodules from the sediment. The sediment is discharged to a very large extent through an exhaust at the back of the vehicle. This results in a plume of suspended sediments that gets transported by the water currents. The plume precipitation, dependent on particle size and flocculation processes causes more or less rapid deposition of particulate matter [BKP*10]. which beyond a certain concentration and duration can have strong negative effects on individual fauna and the entire ecosystem

In order to asses the environmental impact resulting from such industrial mining activities, the expedition SO268 took place in the frame of the MiningImpact II project in 2019 [LH20]. The expedition developed monitoring concepts for one of the proposed *Mn*-nodule mining zones in the German license area (GLA) at the Clarion Clipperton Zone in the northeast Pacific Ocean. At the same time, an hydrodynamic computational model was developed to quantify the related consequences in a virtual environment. If the model proves accurate, it would represent an invaluable tool to calculate the effects of future mining activities before these take place. Different deep sea marine sensors that use acoustical or optical methods to detect and quantify the amount of suspended particulate matter exist. Similarly, diverse ocean models with plug-in sediment settling and distribution modules have been developed. They are best validated with real world measured data. This spatiotemporal contextualisation of multiple data sources is a difficult cognitive task which can be greatly aided by the use of computer-based methods. Visualisation techniques that accurately capture the essence of what is studied can support the building of world models and lead to acquisition of knowledge [CRA00].

Here we present a virtual visual environment which implements the exploration of multiple heterogenous datasets through time and space. We use the Digital Earth Viewer software [BSG*21] to access and simultaneously display in situ data of deep sea terrain (bathymetry), water velocity, water turbidity, as well as the outputs of sediment transportation and deposition models.

2. Materials and Methods

2.1. SO268 in situ data

In April 2019 the SO268 expedition carried out a dredging experiment in the GLA. An array of measuring devices consisting of several sensor platforms was deployed at a depth of 4180 meters below the sea surface. Seven of these platforms housed an acous-

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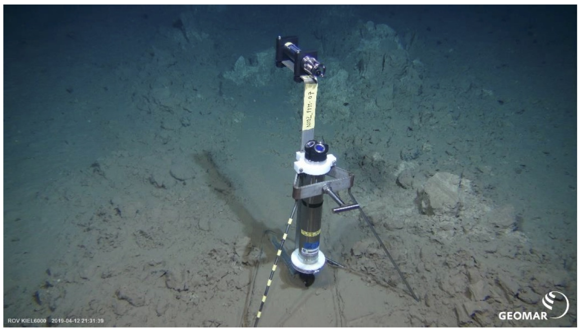

Figure 1: *Sensor platform housing and Aquadopp current profiler and an optical OBS turbidity sensor. The complete sensor array consists of 7 such platforms scattered around the projected dredging track.*

tic Aquadopp current profiler and an optical OBS turbidity sensor (fig. 1). To simulate a sediment plume during a mining activity the seafloor was dredged with a $1m$ wide dredge for about 12 hours resulting in eleven stripes with an average length of $500m$. The turbidity measured by a calibrated OBS sensors served as a proxy for the amount of suspended sediment particles that resulted from the dredging activity [DCS01]. The current velocity data helped to characterise the dynamics of the water at the time of the dredging event. Prior to the dredging experiment, a high resolution bathymetry dataset was acquired using a multi beam echosounder mounted on a deep sea autonomous underwater vehicle.

2.2. Hydrodynamic sediment transport and deposition model

The hydrodynamic model applied in this study is the Massachusetts Institute of Technology general circulation model (MITgcm) coupled to a sediment transport module [MAH*97] [MHP*97]. The model integrates the incompressible Boussinesq equations in a conservative form on a staggered Arakawa C-grid [AL77] using the finite volume method. The sediment transport module's algorithm is described in [GPC*19]. The ocean model with a Cartesian grid has a horizontal resolution of $25mx21m$. The vertical resolution of the model varies from $1m$ in the seafloor vicinity to $100m$ in the mid ocean depth. The ocean model is forced by current speed and direction, temperature, and salinity measured in the vicinity of the dredging tracks. The sediment particle size, settling velocity, and their mass weight distribution are adopted from a previous study ([GPC*19]). A suitable estimation of sediment release rate is accomplished by validating the model results against suspended sediment concentration measured at two observation stations. The results of numerical simulation with highest statistical correlation with the observations was chosen for further analysis.

2.3. Digital Earth Viewer

The Digital Earth Viewer is a 4D visualisation platform for environmental data. Built as a server-client-application with a server consisting of a set of source plugins and data transmission infrastructure and a thin web-based client. As its name indicates, it was developed in the context of the Helmholtz Association's Digital Earth project. This tool is capable of ingesting multiple data types upon which it performs a 4-dimensional spatiotemporal contextualisation (fig.2). It also allows to quickly navigate a virtual planetary environment and to perform visual inspections of heterogeneous data sources. It is also a suitable tool for presenting scientific findings to a wider audience.

3. Results

The sensor array data including current velocity and turbidity measurements, the bathymetric map of the region, as well as the sediment transport and deposition model results were imported into the Digital Earth Viewer. The software automatically assigns the data values to objects in a virtual 3D environment and filters time dependent values with the use of a designated UI element. Further UI controls implement customisations of data layers such as assignment of colormaps to value scales, toggling of visibility properties, and spatial displacements. Two dimensional graph overlays provide quick access to the data measured by individual sensors. As a result of this, the entire sensor array is correctly placed on top of the bathymetric terrain, resulting in a visual confirmation of the array's geometry. The output of the deposition model is projected onto the seafloor in the same way. In situ measurements of current velocities and water turbidity share the 3D space in the water column with the outputs of the sediment transport model (fig.3).
Exploring this virtual environment along the temporal axis reveals the development of the data sources over time: before the begin of the dredging experiment, current trajectories change with the tides but turbidity sensors, modelled suspended particles, and modelled sediment deposition all show values minimal values. Once the experiment starts, an increased activity of the sediment plume is observed downstream of the dredging track, and the values measured by the turbidity sensors begin to spike as they are reached by the sediment cloud. Shortly after, the cumulative values of the sediment deposition model projected into the sea bottom begin being noticeable and keep on increasing long after the actual dredging has concluded.

4. Conclusions

Using the Digital Earth Viewer to create a virtual environment of the deep sea resulted in a visual exploration platform for a small scale dredging experiment. In this way the software provided a quick visual corroboration of the correct operation of the sensors deployed as well as of the accuracy of the hydrological models. Moreover, it enabled the user to distill information of the physical mechanisms that take place during the experiment, which in turn will lead to a better assessment of the impact future mining activities can have in fragile deep sea ecosystems.

References

[AL77] Arakawa, A. and Lamb, V. R. (1977) "Computational design of the basic dynamical processes of the UCLA general circulation model." *Methods in Computational Physics* 17, 173–263. 2

[BKP*10] Bridges, T.S., et al. (2010) "Dredging Processes and Remedy Effectiveness: Relationship to the 4 Rs of Environmental Dredging." *Integrated Environmental Assessment and Management* Volume 6, Number 4—pp. 619–630. 1

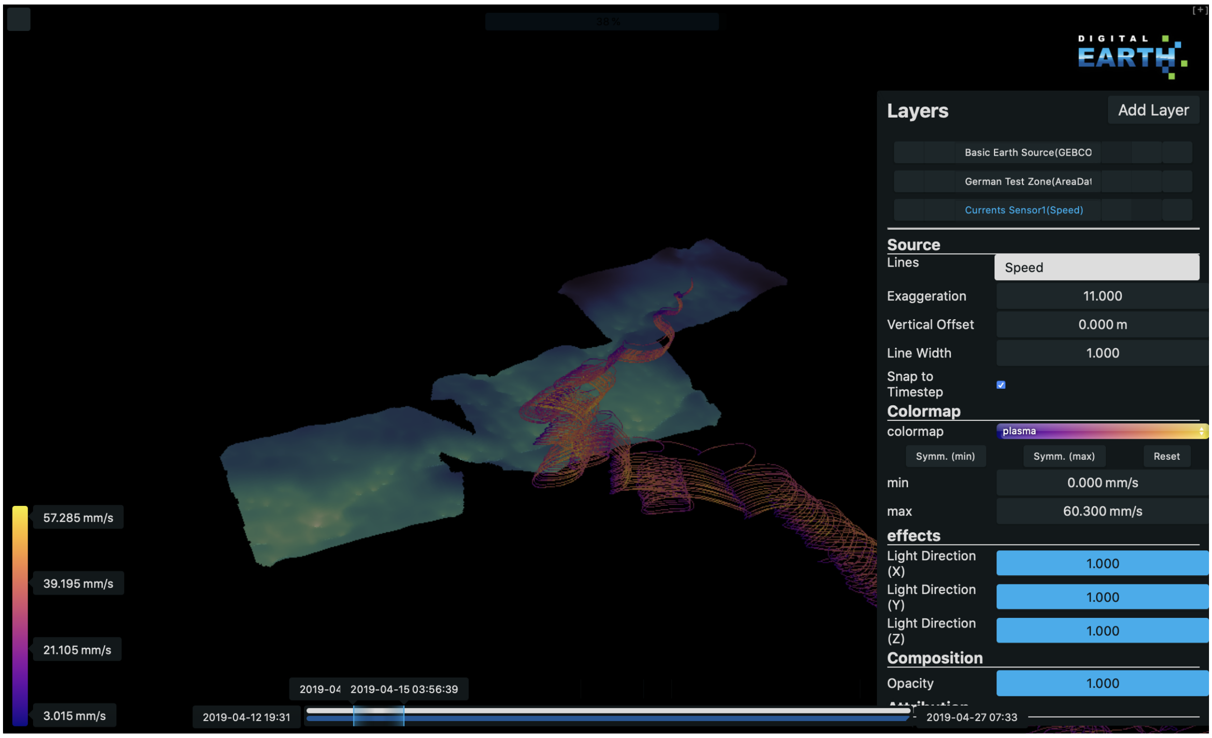

Figure 2: *The user interface of the Digital Earth Viewer displaying the GLA bathymerty and the trajectories of an Aquadopp current sensor.*

[BSG*21] Buck, V., Stäbler, F., González, E., and Greinert, J. (2021). "Digital Earth Viewer: a 4D visualisation platform for geoscience datasets." *Workshop on Visualisation in Environmental Sciences (EnvirVis) (2021)* 1

[CRA00] Crapo, A. W., et al. (2000). "Visualization and the process of modeling: a cognitive-theoretic view." *Proceedings of the sixth ACM SIGKDD international conference on Knowledge discovery and data mining.* 1

[DCS01] Davies-Colley, R. J., and Smith, D. G. (2001) "Turbidity suspeni) ed sediment, and water clarity: a review 1." *American Water Resources Association* 37.5

[GSA*18] Gazis, I. Z., Schoening, T., Alevizos, E., and Greinert, J. (2018) "Quantitative mapping and predictive modeling of Mn nodules' distribution from hydroacoustic and optical AUV data linked by random forests machine learning." *Biogeosciences* 15(23), 7347-7377. 1

[GPC*19] Gillard, B., Purkiani, K., Chatzievangelou, D., Vink, A., Iversen, M. H., and Thomsen, L. (2019) " Physical and hydrodynamic properties of deep sea mining-generated, abyssal sediment plumes in the Clarion Clipperton Fracture Zone (eastern-central Pacific)." *Elem. Sci. Anthr.* 7:5. doi: 10.1525/elementa.343 2

[LH20] Gillard, B., Purkiani, K., ChatzievangLinke, P. and Haeckel, M. (2020) " Short Cruise Report RV SONNE SO268/1+2" 1

[MAH*97] Marshall, J., Adcroft, A., Hill, C., Perelman, L., and Heisey, C. (1997a). "A finite-volume, incompressible Navier Stokes model for studies of the ocean on parallel computers." *Journal of Geophysical Research* 102(C3), 5753–5766. 2

[MHP*97] Marshall, J., Hill, C., Perelman, L., and Adcroft, A. (1997b). "Hydrostatic, quasihydrostatic, and nonhydrostatic ocean modeling." *Journal of Geophysical Research* 102(C3), 5733–5752. 2

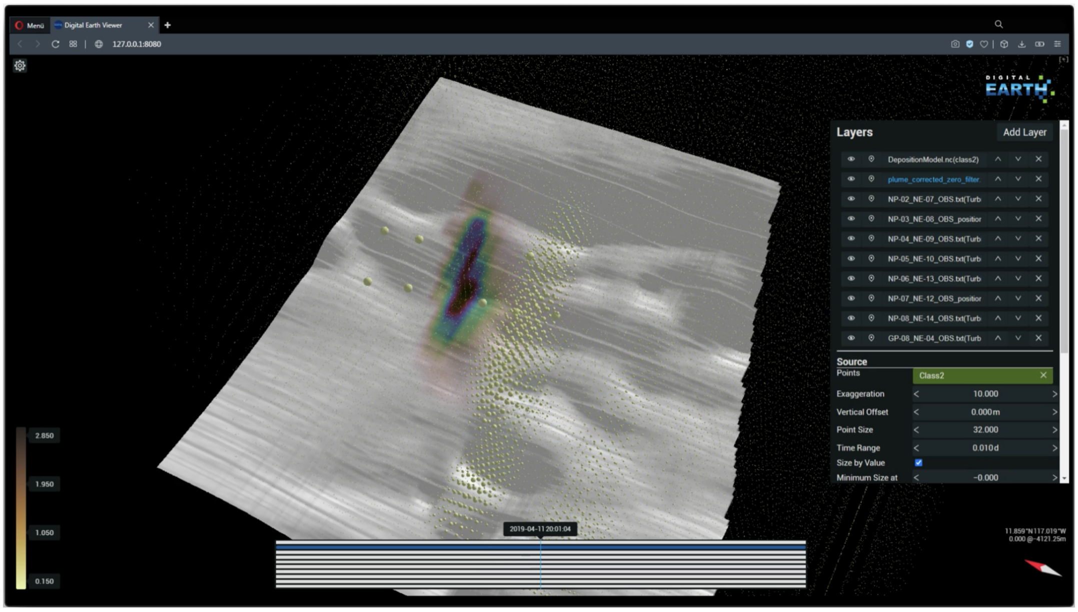

Figure 3: *The plume model rendered along with the OBS sensors in the Digital Earth Viewer. A point cloud represents the suspended sediment particles and the deposition values are projected onto the bathymetric map.*