April 2020

Joint Newsletter on Visualisation of Heterogeneous Autonomous Sensor Systems

This newsletter shows results from the close collaboration between the projects *Digital Earth*, *MOSES* and the *DataHub* Initiative and presents examples of recent work and the joint activities and developments ahead. MOSES the ***M**odular **O**bservation **S**olutions for **E**arth **S**ystems* (https://www.ufz.de/moses/) is a Helmholtz financed observing system to investigate "trends and events" in the Earth System. It comprises highly flexible and mobile observation modules, which are designed to investigate the interactions of short-term events and long-term trends across Earth compartments. During its implementation phase from 2017 until 2021, the scientific topics that bring different Helmholtz centres together are organized in what has been named "event chains". One of the four event chains are the "Hydrological Extremes" that look e.g. into high and low flow events in river systems and their estuaries. A second event chain concerns "Ocean Eddies", which transport energy and nutrients efficiently across the oceans and are still an understudied phenomenon because of being not contestant in space and time.

MOSES Campaigns in the German Bight

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Sea-going campaigns pose a particular set of challenges that distinguish them from other field campaigns. Beyond the obvious challenges involved with the organization and handling of research vessels, communication and data exchange during cruises between ships and other platforms in the coastal area as well as comparability of measurements turn out to be more complicated than initially anticipated by involved scientists.
To achieve a holistic understanding of events as part of the MOSES "Hydrological Extremes" event chain, the propagation of anomalies through the different earth systems, from the atmosphere, through the terrestrial and hydrological systems of the catchment area into the river system estuaries is being investigated. This complex system poses a formidable logistical challenge, not just in regard to measurement logistics but also with regard to handling, processing and interpreting of extremely heterogenous data. This is why "flood events" in the Elbe catchment have been chosen as one of the show cases in Digital Earth and as test scenario for data driven science.
In 2019, three campaigns involving two or three research vessels from different research institutes (Fig. 1), were carried out in the German Bight between Cuxhaven, Büsum and Helgoland. The goal of these campaigns was to identify potential problems and complications in coordinating ships and cruise plans while investigating water masses originating from the Elbe river catchment area and their spreading in the German Bight. The collected data were also part of ongoing efforts to determine a "baseline" or "normal" state of the respective estuary system.

Figure 1: Photo of all three ships participating in the experiment in Cuxhaven: "Ludwig Prandtl" (foreground), "Littorina" (left) and "Uthörn" (photo by G. Flöser, HZG).

For cruise planning, as well as for later interpretation of data collected, it is necessary to put point data measured during cruises in a spatial and temporal context. One tool used for this contextualization is the web application *DriftApp* developed at HZG that uses regular data provided by the operational hydrodynamical model of the German Federal Maritime Agency (BSH) allowing to determine back and forward trajectories for water masses in space and time. This tool was especially useful for trying to track the origin of a methane anomaly discovered during one of the cruises (Fig. 2).
One, well known, major challenge was to assure that data measured on different ships are actually comparable. To that end, all ships had times scheduled - usually in the morning of a cruise day - where they stayed in close proximity for approximately thirty minutes to record a set of standard parameters such as temperature, salinity, oxygen, CO_2 and methane concentrations simultaneously, which - in an ideal world - should be nearly identical.

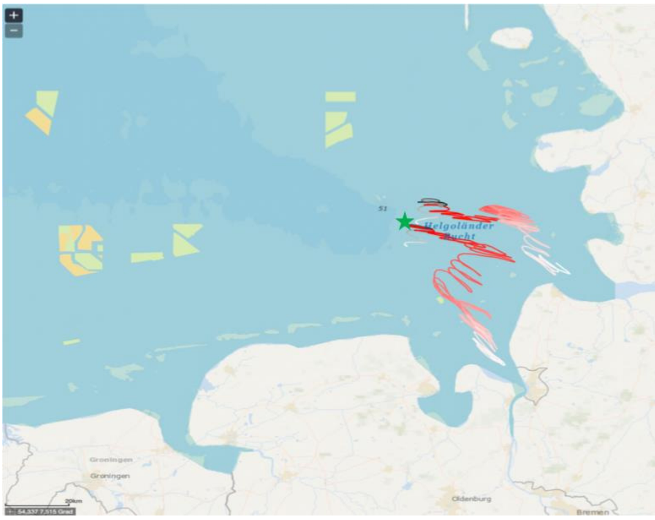

Figure 2: Backward trajectory covering two weeks (lighter colors depict earlier positions) for a water mass with the highest methane concentrations measured during the cruise originating at the location marked with the green star. As comparison a trajectory originating approx. 6 km to the North. While the trajectory for the methane plume maximum originated two weeks before in the Weser, the northerly water mass originated in the Elbe.
Calculations performed using the HZG drift tool (https://coastmap.hzg.de/coastmap/modeldata/DriftApp/).

As already suspected from laboratory intercomparison experiments, this was not the case. It was quite sobering to see how even temperature, a seemingly simple parameter, can differ when measured using different systems on the same ship, for example, with an *in-situ* CTD and a FerryBox (Fig. 3) resulting in systematic or random errors to such an extent that made corrections necessary to use the data at all. These experiences in data handling, ship to ship communication and intercalibration will be published in Reports on *Polar and Marine Research* (*https://doi.org/10.2312/BzPM_0741_2020*).

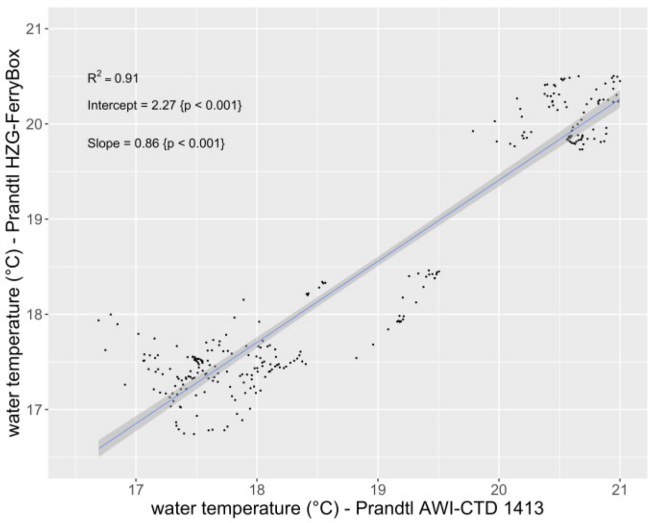

Figure 3: Water temperature measured by two sensors on board RV Ludwig Prandtl during cruise "Stern 2". Shown are the data from a calibrated AWI CTD and a calibrated FerryBox. Both, the intercept and the slope are significantly different so that correction algorithms have to be applied prior to data use.

While ocean-going research vessels tend to be equipped with satellite communication systems, coastal vessels often still rely on radio communication (or simply use mobile phone connections, where available) to communicate ship-to-ship. While this is sufficient for nautical issues it is blatantly insufficient if scientific problems require the exchange of data between ships in order to make decisions on cruise planning on-the-fly, or even, as envisioned for future MOSES campaigns, between ships and air-borne measurement platforms (sail gliders, zeppelins or others). It is crucial for campaigns in an actual event case (here a flood event) to be able to compare measurements taken during cruises on different platforms to coordinate and inform future measurement strategies (for the next hours). As much as advance planning and numerical modeling are helpful in preparing such campaigns, it is essential to have all necessary information for decision making ready at hand while out in the field. This includes combining information from model results (e.g. from the drift tool mentioned before) with remote sensing data (satellite, radar and air-borne) and imagery, as well as data collected *in-situ* on ships and stationary platforms.

The challenge here is the processing and displaying of diverse and heterogenous information in tools that provide easy access to the information content in the field (one aspect of the event explorer being developed as part of Digital Earth), as well as the ability to transfer this data and information to the colleagues in the field. While this is challenging at times for land-based campaigns due to e.g. limited mobile phone coverage, it is greatly exacerbated as soon as ships leave the proximity to land. Special communication and antennae systems have been developed for ship-to-ship and ship-to-aircraft communication. One remaining challenge is to condensate useful and needed information from available data such as remote sensing and modeling data sets, as these tend to be large and contain excess information that is not needed for decision making in the field.

The cooperation and interaction between Digital Earth and MOSES is a prime example for exchanges between natural and data scientists that yield mutual benefits. In the future this interaction will be intensified with the goal to create an end-to-end involvement and integration of all participating disciplines.

Near-real-time mission monitoring during MOSES Eddy Study II (RV Meteor Cruise M160)

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The rapid development of autonomous vehicles and platforms for ocean observations enables marine scientists to investigate ocean phenomena with an unprecedented spatio-temporal resolution. The integration of these platforms into classical ship-based oceanographic process studies allow (i) to gain valuable station time of research vessels and (ii) to obtain a more synoptic view of the process of interest. However, this combination also introduces new challenges such as an increased effort in concerting multiple platform deployments with ship-based operations as well as securing near-real-time data streams for adaptive survey schemes.

During a recent MOSES field campaign in November/ December 2019 off West Africa (MOSES *Eddy Study II*) several MOSES modules of the Helmholtz Centre for Coastal Research Geesthacht (HZG) and GEOMAR were employed in conjunction with a dedicated research vessel campaign of RV Meteor (M160).
The main goal of M160, the second in a row of three expeditions, was to carry out both detailed mesoscale and sub-mesoscale studies of two individual mesoscale eddies selected through an early detection, tracking and verification scheme based on remote sensing and *in-situ* information from autonomous MOSES platforms collected prior to the cruise.
Using refined automated detection methods employing remote sensing products (sea level anomaly, sea surface temperature, ocean color) early detection of eddies was possible during the months preceding the cruise. For ground truthing of potential candidate eddies, two ocean gliders and one wave glider were deployed from the 'Ocean Science

Centre Mindelo' (https://www.oscm.cv/) prior to the cruise. Further, two Saildrones also joined the pre- as well as the actual M160 survey (https://www.saildrone.com/). During M160, up to 12 ocean gliders, two Wave Gliders, several Argo floats and drifters as well a research gliderplane were utilized. All these platforms were used to (i) provide guidance and evidences for the decision-making processes with regard to ship-based survey planning and to (ii) conduct high-resolution (sub)mesoscale surveys in individual eddy candidates. This set-up called for a concerted approach to handle and also visualize near-real-time data streams.

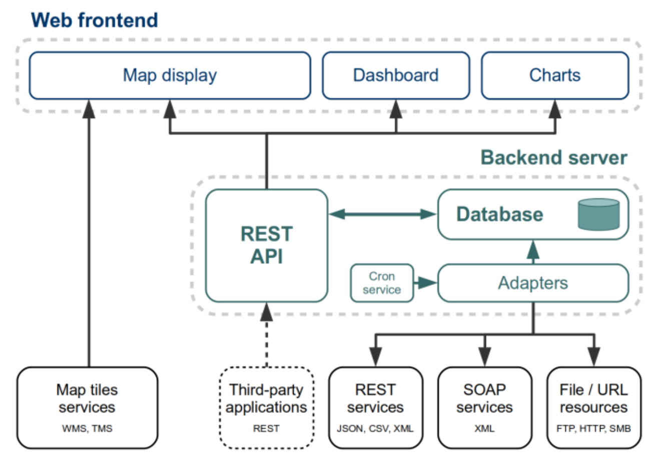

Figure 4: System architecture of the GEOMAR Navigator

For the MOSES *Eddy Study II,* we used the web-based application Navigator (navigator.geomar.de) that was developed at GEOMAR *(Leibold & Al Abri, 2019)*. The application was designed to provide a comprehensive overview of multi-platform surveys through an easy to understand situational awareness dashboard. Data of all kinds of autonomous platforms are visualized by a web-based interface together with remote sensing products, such as weather- and oceanographic data overlays.

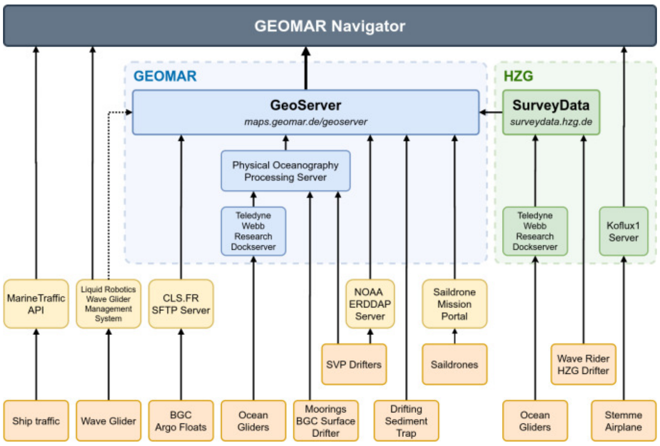

Figure 5: Configuration of data flows to the Navigator during M160

The information is aggregated by adapters, transforming the data of various third-party systems to a common structure stored in the database of the backend server (Fig. 4).
In the context of M160, the GEOMAR *GeoServer* was used as the primary data source to merge meta-information of a large number of different autonomous systems (Fig. 5). Data from platforms operated by HZG was collected by the HZG *SurveyData* server and then forwarded to GEOMARs *GeoServer*.
Data from the *GeoServer* are redistributed to (i) the Navigator application for further processing and visualization and (ii) a virtual AIS system that was temporarily installed on the research vessel. The web front-end of the Navigator was primarily used by the scientific parties on board (Fig. 6) and at shore, whereas the virtual AIS system broadcasted locations of all platforms as virtual AIS targets for the nautical crew of RV Meteor and the surrounding ship traffic. This concerted approach allowed a safe co-existence of ship-based and autonomous surveys in a well-constrained study area.

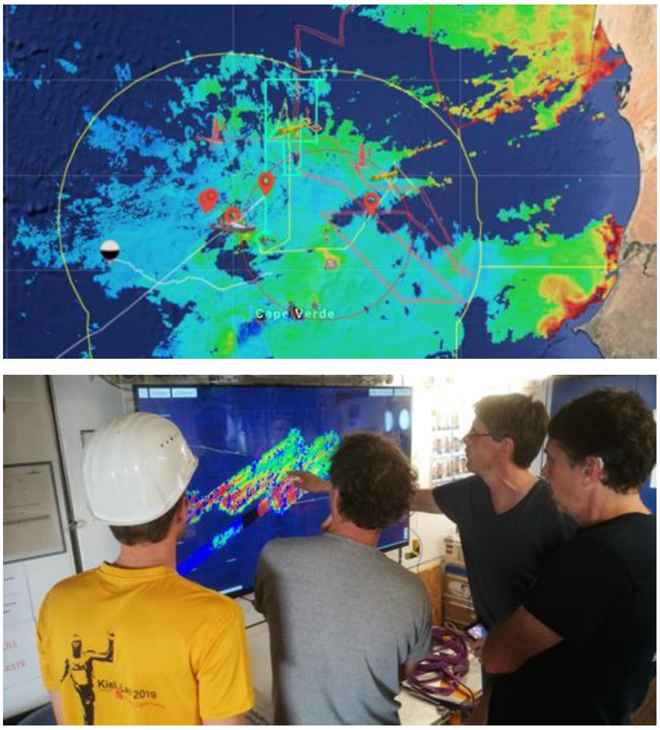
Figure 6 Upper: Screenshot taken from navigator.geomar.de during the MOSES Eddy Study II. Near-real-time positions of several autonomous and mobile platforms such as Wave Gliders, Saildrones, and drifters are depicted in an interactive map tool. A satellite fluorescence data image from the previous day is shown as a background layer. Lower: Instantaneous interpretation of data coming in from the research gliderplane and other platforms in the vicinity of RV Meteor for further decision-making (source GEOMAR).

References:
P. Leibold and O. Al Abri, "An integrated web-based approach for near-real-time mission monitoring," 2019 1st International Conference on Unmanned Vehicle Systems-Oman (UVS), Muscat, Oman, 2019, pp. 1-6.

DataHub Observatory View - Common Data Service for Cross-Center Activities

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The Earth and Environment DataHub integrates data repositories, infrastructures and services in the next joint research programme "Changing Earth – Sustaining our Future" across Helmholtz centres. Three associated compartment-specific Hubs, ATMO, MARE, and TERRA, form the basic structure of the DataHub. The DataHub focus is on the user-specific visualization and exploration of spatially and temporally high-resolution data sets from long-term observatories and campaign-based observations to record a wide variety of parameters and processes in e.g. the areas of ecosystem studies, biodiversity, biogeochemistry or geophysics. In this respect the DataHub will support cross-centre data exchange and user support which is a fundamental pre-requisite for Data Driven Science in *Digital Earth*.

Figure 7: Demonstrator of the Observatory View with data from the MOSES Müglitztal Campaign 2019. Gravimetric data for near-surface water balancing (GFZ), in-situ mobile wireless sensor network (UFZ) and mobile Cosmic Ray Neutron Sensing (CNRS, UFZ) data for determination of the soil moisture are shown.

As an example, for the Hub TERRA, a holistic approach to cross-domain research and exploration of data streams was developed using standardized interface and an exemplary demonstrator was provided using data from MOSES activities from 2019 (Fig. 7).

This demonstrator and the proposed visualisations are a good example how data acquired in MOSES can also serve as cross-centre test scenario for tools developed through the DataHub as the long-term implementation initiative for Data Management in the Helmholtz research fields *Earth and Environment*. The focus of this application is the user-specific visualization and exploration of spatially and temporally high-resolution data sets with a particular emphasis on terrestrial data. This approach enables the development of fast, customizable aggregation and visualization methods for data at different levels of complexity. In addition, it can be used to control model-driven monitoring activities and design feedback methods for collecting data. Through this it is supporting the strategy of SMART Monitoring in *Digital Earth*. The data is collected and stored by individual scientific groups from different research institutions.

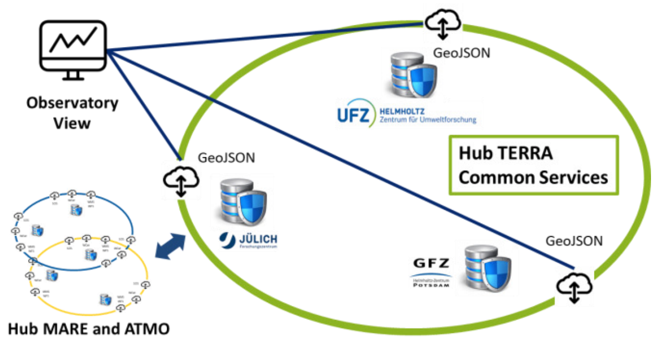

Figure 8: Concept of the common data service layer for the Observatory View in the Hub TERRA and analogous to the other two Hubs MARE and ATMO for the collaborative use of the data using standardized interfaces.

The introduction of a service layer with standardized interfaces agreed upon by the various facilities for enabling data exchange and data formats allows access to the respective data. Currently the data is exchanged in JSON format. The support of OGC Sensor Observation Service (SOS) as the main type of API is under development in order to ensure the sustainability of the approach (Fig. 8).
Future challenges in the current development are the use of fast quality assurance procedures prior to the use and visualization of the data (which links to the related and ongoing activities in the Data Exploration Framework of *Digital Earth*) as well as ambitions for up-scaling to very large amounts of data. For this purpose, data pipeline methods are currently developed at UFZ as part of the Hub TERRA activities. This includes checks of the data quality of incoming data streams from observatories or field measurement campaigns including the data processing in near-real-time using standardized methods. Such methods are continuously further developed within the Hub TERRA and are made available to the scientific community. Respective methods should become a permanent feature of the common data services within the research field Earth and Environment to provide the best possible data sets for Data Driven Science as promoted through the *Digital Earth* project.