COSYNA

COSYNA

Coastal Observing System
for Northern and Arctic Seas

Helmholtz-Zentrum Geesthacht

Centre for Materials and Coastal Research

COSYNA Mission

It is COSYNA's mission to develop and operate an integrated observing and modelling system suitable for investigating the environmental state and variability of coastal areas, with a focus on the North Sea and Arctic coastal waters.

COSYNA aims to provide data and knowledge tools to help evaluate the role of coastal systems for local and regional scientific questions and to provide authorities, industry, and the public with tools to plan and manage routine tasks, respond to emergency situations and to evaluate trends. COSYNA specifically develops scientific products and instruments, and provides its infrastructure to the scientific community.

COSYNA showroom: presenting and working with real-time observational data and numerical model results.

COSYNA-Partner

COSYNA is financed and coordinated by the Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research GmbH. The scientific work is carried out jointly with the following partners of the Helmholtz association, universities, and monitoring authorities.
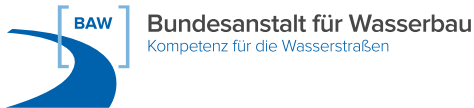
Why COSYNA?

The automated observing and modelling network COSYNA has been established in order to better understand the complex interdisciplinary processes of Northern Seas and the Arctic coast, to assess the impact of anthropogenic changes, and to provide a scientific infrastructure. Data and infrastructure are available to all COSYNA partner institutions. The principal objective of observations and instrument development is to improve our understanding of the interdisciplinary interactions between physics, biogeochemistry and ecology of coastal seas, to investigate how they can be best described at present, and how they will evolve in the future.

The natural processes of the North Sea and other coastal areas are in numerous ways connected to the well-being of human societies. Recurrent issues are safety of transportation (e.g., extreme waves, or hazardous spills), coastal defense against storm surges and a slowly rising sea level, morphology changes due to sediment transport, or the role of coastal areas for global carbon and energy budgets. COSYNA data and model results play a central role for investigating the role of natural variability, extreme events, trends and human influence on coastal systems.

In COSYNA, data and knowledge tools are developed and provided to be of use for multiple interest groups in industry, agencies, politics, environmental protection or the public. These data and products can support national monitoring authorities to comply with the requirements of the European Water Framework Directive and the Marine Strategy Framework Directive. The coastal observatory involves national and international contributions to international programs, such as COASTAL GOOS, GEOSS, GEOHAB and GMES.

The observational data is used for improved model descriptions and hourly updated forecasts of the environmental status of the North Sea. All data are publically available for free in near-real time at www.cosyna.de.

Since COSYNA is one of the densest observing systems located in one of the most heavily used coastal areas in the world, it may serve as a role model for other parts of the "Global Coast". Many global problems such as climate change, sea level rise, or ocean acidification influence in particular the ecosystems and communities along the coasts. The impact of these problems as well as the choice of the tools for their management, however, varies strongly with region.

General Objectives

COSYNA aims to significantly advance the scientific understanding of hydrodynamic and biogeochemical processes, improve operational models, provide products for various interest groups, investigate extreme events and support measurement campaigns and techno-logical development, e.g. for automated, quality controlled routine measurements or for error and data analysis. A major challenge is a system-wide integration to build a coherent platform for sharing or retrieving data, products, and infrastructure.

COSYNA Research Questions

COSYNA provides research infrastructure enabling research on a wide range of temporal and spatial scales, from extreme events to long-term trends, from small scale turbulence to North Sea-wide.

COSYNA addresses the following fundamental research questions of coastal and operational oceanography:

Scientific Questions

- What are the relevant short-term physical processes of the North Sea, the Wadden Sea and adjacent river estuaries and how do they influence biogeochemical and biological dynamics?

- How do those processes influence the carbon budgets in the North Sea, what are the ramifications for regional carbon cycles and how do they interact with the North Atlantic?

- How important are extreme events, such as storms and river floods, for the physical and biogeochemical environment and how do they influence general trends? How stable is the system with regard to extreme events? Do multiple system states exist and if so, where are the tipping points?

- What impact do long-term anthropogenic changes have on natural processes and quantities, such as currents, waves, temperature, salinity, turbidity, ocean acidification, biological productivity or sediment transport?

- How large is the exchange of heat, fresh water, suspended matter, nutrients, and organic matter between the river systems, the Wadden Sea, the North Sea and the Atlantic Ocean?

- What are the driving factors for algal blooms?

- To what extent is regional knowledge applicable to a global context and how can we upscale regional results to be useful in other regions or worldwide?

Questions of Operational Oceanography

- Which key regions have the largest influence on coastal seas and what is the ideal instrumentation and strategy to observe them?

- How can the large range of relevant spatial and temporal scales ranging from minutes to decades and from meters to hundreds of kilometers be captured simultaneously?

- How can an observing system be optimized to provide relevant and high-quality information in a cost-effective way?

- How can an observing system be constructed in a modular way to be used for a variety of processes, scales and scientific questions?

- How can observing systems become "intelligent", i.e. sensors communicate with each other and use this information to create their own measurement strategies?

- How are observational gaps filled and model uncertainties reduced by new methods of merging observational data with dynamic models and statistical methods (data assimilation)?

- How can the data be made publically available in an easily accessible and comprehensive way?


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COSYNA Research and Science

COSYNA is designed to provide the capability to investigate processes as well as long-term trends. Its infrastructure is available to support field campaigns and to deliver necessary background time-series that help evaluate the results from those campaigns.

COSYNA is involved in MOSES (Modular Observation Solutions for Earth Systems), a research initiative of nine Helmholtz Centres from the "Earth and Environment" research field that provide sensor and observing systems which are combined into "modules". MOSES modules measure environmental states and fluxes as well as processes related to energy, water, nutrient and greenhouse gas cycles by utilizing a cross-compartmental approach. The modules are being set up to integrate observations in the atmosphere, at the land surface, in coastal regions, in the ocean and in the cryosphere. COSYNA partakes in the hydrological extremes event chain, while it provides logistic support for the ocean eddies event chain.

The event chain approach for investigating hydrological extremes aims at a better understanding of the interactions between short-term hydrological events causing large-scale floods and their long-term ecosystem effects. In this context, COSYNA provides and expands its observational capabilities for investigating flood events in the Elbe river system. This integrates seamlessly with the pan-European Research Infrastructure DANUBIUS–RI "The International Centre for advanced studies on river-sea systems", a European Strategy Forum on Research Infrastructures (ESFRI) roadmap project supporting interdisciplinary research on river-sea (RS) systems. The "Elbe Estuary Supersite" is part of DANUBIUS-RI and is managed at the Helmholtz-Zentrum Geesthacht.
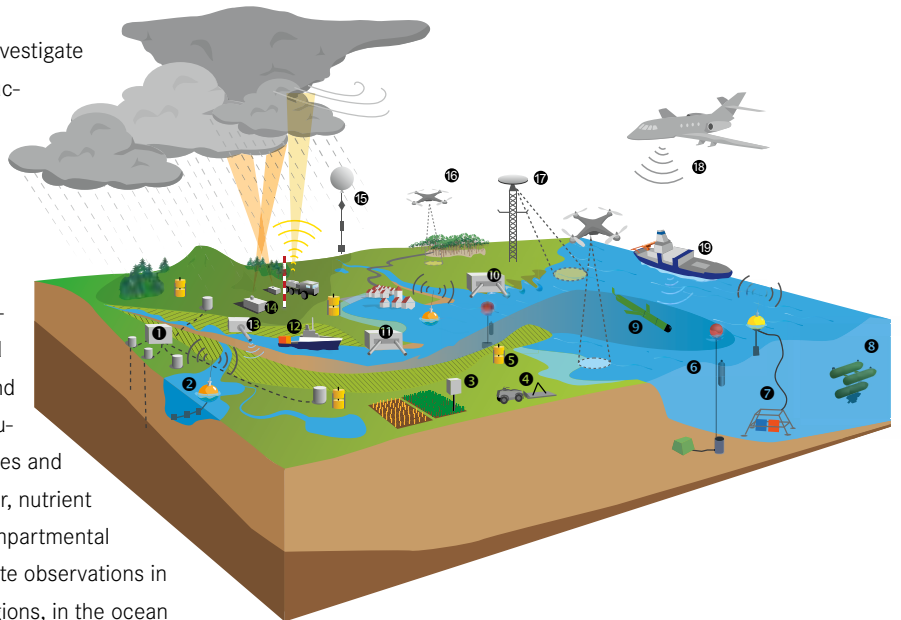
MOSES measurement infrastructure for observing hydrologic extremes using the following modules: module biota with (1) Functional microbiome changes measured by online metagenomics and metabolomics, (11) Mobile mesocosms, (12) Stream research vessel; module flow and sediment dynamics with (2) Buoy with multi-parameter sensors, (6) Vertical profilers for coastal and limnic sensors, (7) Underwater nodes with surface buoys, (13) River flow and sediment monitoring system; module water balance with (3) Soil moisture determination using mobile Cosmic Ray sensors, (4) Mobile hydrogeophysics to determine subsurface soil properties, (5) Gravimeter unit for water storage monitoring; module autonomous vehicles with (8) Swarm of underwater-robots, (9) Ocean gliders; module coastal and marine mobile systems with (10) Container with lab equipment, (18) Airborne IR and hyperspectral cameras, (19) Coastal research vessel; module atmospheric dynamics with (14) Lidar, X-Band-Radar, wind with KITcube, (15) Ballon sondes for water vapour, ice particles and tracer; module soil and water quality with (16) UAV for monitoring water quality and vegetation; module fixed point observatories with (17) HF-Radar system.

Implementation of COSYNA

The Helmholtz-Zentrum Geesthacht received from the German Federal Ministry of Education and Research about 9 M€ of investment capital for construction and development to develop COSYNA. The project has been implemented between 2010 and 2014 and will continue to expand its range of products after the initial phase. COSYNA is developed and operated jointly with 9 partner institutions in order to broaden and support the scientific and operational goals of COSYNA and its partner institutions. Money for personnel, operation and main- tenance is provided entirely by the Helmholtz-Zentrum Geesthacht and its partners.

Integrated Approach – From Data to Information

COSYNA was established with its sights on understanding and describing the environmental state and variability of coastal waters in the North Sea and the Arctic. COSYNA develops marine monitoring systems and methods for the current state of the coastal system and for generating state reconstructions and short-term forecasts. Understanding and describing coastal systems is of a high value, not only from a scientific point of view, but also due to its societal value. One important motivation for COSYNA therefore is the continuous provision of near real-time and post-processed products, bridging the gap between operational oceanography and the various users of forecasts of the coastal waters state.

COSYNA aims to provide data, informational products and knowledge tools to answer scientific questions at various time and length scales and to provide authorities, industry, and the public with tools to plan and manage routine tasks, respond to emergency situations and to evaluate trends.

In order to serve this purpose, one of the distinguishing features of COSYNA is the integrated approach combining observations and numerical modelling.

The observations comprise a variety of in situ techniques as well as remote sensing from shore by radar and from space by satellite. At the core of the COSYNA observations is a standard package of sensors mounted on stationary and mobile platforms. Key physical, sedimentary, geochemical and biological parameters are observed at high temporal resolution in the water column and the upper and lower boundary layers. COSYNA's modelling part consists of structured and unstructured nested models with different grid sizes for hydrography (salinity, waves, currents), for suspended matter and for biogeochemical and ecosystem processes. By using sophisticated data assimilation procedures, observational data are integrated into models in order to close the spatial and temporal observational gaps and to improve the reliability of now-casts and short-term forecasts.

With its integrated approach, the COSYNA automated observing and modelling system is geared towards high flexibility and can be used on a variety of scales and problems that are of scientific or societal interest. The COSYNA data products are provided on a pre-operational basis, i.e., they are not experimental but developed towards a later operational use.

COSYNA's integrated approach combining observations, modelling, data management, stakeholder interaction and outreach activities.
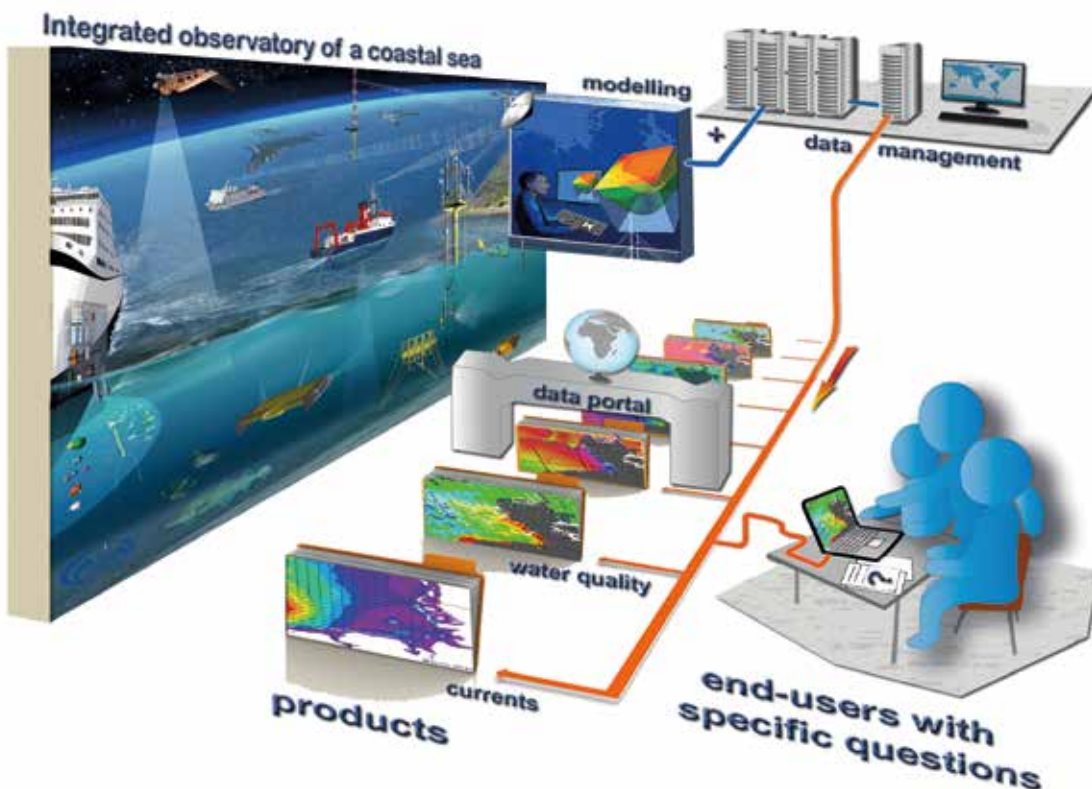
Integrated Approach – Stakeholder Interaction

COSYNA's objective is to make scientific data, results, and data products available to a broad audience by reaching out to different target groups and users, such as the scientific community, potential users in business enterprises and authorities, as well as the general public. The data and plots are publicly available in near-real time through a data portal (codm.hzg.de/codm) that provides free access to data download and visualization.

As for the dissemination of information, data, and products, besides traditional ways like print products and a website in German and English, COSYNA has developed an interactive app for Android- and iOS-based tablets (available in the stores). The app provides explanatory texts and pictures describing the observing systems, instruments, models, and products, as well as the COSYNA partners. Near-real-time data and short-term forecasts for several platforms and parameters are available.

In order to ensure that products are useful and applicable, COSYNA has developed and pursued a broad range of activities for knowledge transfer and stakeholder interaction. Potential user groups of data and data products include, but are not limited to science, administration, business enterprises (e.g. renewable energy sector), engineering, tourism, nature conservation, and the general public.

A dialogue with stakeholders, allowing for direct feedback and input to COSYNA, is integrated into a COSYNA product life cycle. It is exemplified for the product "Surface Current Fields in the German Bight" in the figure below: A complete set of stakeholder interactions was applied, ranging from initial situational analysis through external evaluation, interviews and workshops with potential users, to meetings focused on data exchange and joint measurements. Through the various interactions with different stakeholders the COSYNA products could be improved substantially. In addition, especially the interaction with the key stakeholders from the offshore energy sector led to essential insights into the demands and constraints concerning the use and usability of COSYNA products, and identified new research questions.
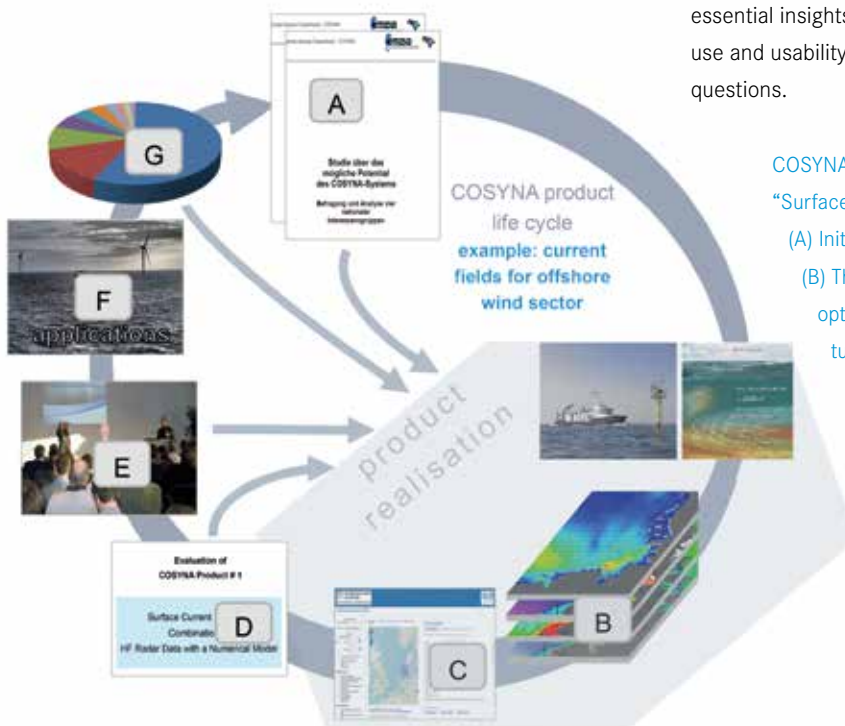
COSYNA product life cycle depicted for the COSYNA product "Surface Current Fields in the German Bight" as an example: (A) Initial surveys reveal COSYNA's potential relevance. (B) The mathematical–technological realisation provides optimised parameter fields for currents, waves, temperature, etc. (C) The data are freely accessible via the COSYNA data portal. (D) External evaluation of COSYNA products. (E) Interviews and workshops with stakeholders from the offshore wind sector. (F) Improved COSYNA products are available to users. (G) Evaluation of impact.

COSYNA Focus Regions – German Bight

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North Sea

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The North Sea is a shallow shelf sea in Northern Europe characterized by complex interdisciplinary processes governing a large range of interconnected length and time scales. The North Sea is one of the best investigated shelf sea areas, but we are only slowly beginning to understand the interconnected forces that govern energy budgets, material fluxes, and the factors directly controlling ecosystem dynamics. Tidal exchange flows with the extensive intertidal mudflats of the unique World Heritage Site Wadden Sea dominate circulation, turbidity, and productivity of large areas of the German Bight, while contributing to global carbon and nitrogen cycles. At the same time, long-term changes of temperature and ocean acidification due to global change become more and more evident. Since the North Sea is surrounded by densely populated, highly-industrialized countries, it is influenced by multiple, often conflicting uses, such as fisheries, waste disposal, oil drilling, transportation, coastal defense or recreation.

Arctic Coast

In the Arctic, the influence of a changing climate is already visible: the sea ice cover, for instance, has been shrinking during the last decades. Major anticipated consequences include: a largely ice-free Arctic Ocean in the summer or higher erosion of permafrost cliffs due to increased wave activity. Higher concentrations of nutrients as well as dissolved and particulate matter will change the productivity of phytoplankton in coastal waters. In addition, emissions of the greenhouse gas methane from the thawing permafrost could influence the global climate.

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Global Coast

The "global coast"—the importance of the coastal oceans for large-scale processes—will become a focus of COSYNA. Among the topics of interest are the carbon exchange between the coastal seas and the open ocean as part of the global carbon cycle and the ocean's energy budget as one of the important influences on worldwide climate.

For investigating these questions and similar issues, COSYNA develops and builds mobile measurement stations, which can be utilised in research projects all over the world. The data obtained is analysed and fed into computer models. This serves not only to examine and improve the models, but the data can also be used to describe and understand central processes and mechanisms in the coastal seas.

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COSYNA Products

Quality-controlled, science-based, near real-time environmental information derived from observations and model results can assist governmental and local authorities as well as other stakeholders to manage routine tasks, emergency situations and evaluate trends. An operational system in the heavily used North Sea may serve as a role model for many coastal areas worldwide.

Thus, one of the main characteristics of COSYNA is the development of pre-operational (i.e., routine provision of) 'products' that improve present routinely applied observational and modelling techniques.

These products comprise hourly updated maps, model results, and 6 hour-forecasts of ocean currents, salinity, temperature, and waves, as well as monthly-mean chlorophyll maps, and ship detection maps.

Future products will include wind fields, and biogeochemical parameters. A COSYNA focus is on information derived from an optimized synthesis of observations and model data (see COSYNA product "current").

The COSYNA products, data and metadata, are disseminated over the internet for further use by different end-users. COSYNA coopera-tes with government agencies, which, at some stage of the product development, could convert the pre-operational to operational products – a process that has been pioneered for the pre-operational analysis system for current fields in the German Bight based on real-time HF radar data.
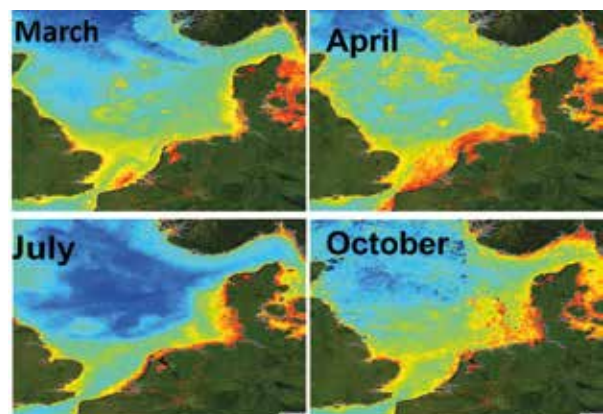

Overview of COSYNA products and their current status. Green points depict products in (pre-) operational state, orange products that are foreseen to be available, yellow products that are envisioned for the long run.
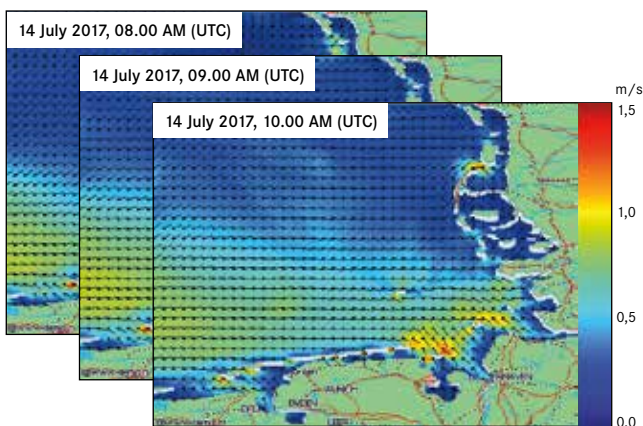
COSYNA Product: Currents in the German Bight, snapshots from 14 July 2017.

COSYNA product Monthly mean chlorophyll concentrations (for 2017). After the first algal bloom in April chlorophyll concen-trations decrease in July due to lack of nutrients. In October the concentrations increase again (fall bloom).

Product Surface Current Fields

Surface current data from three high-frequency (HF) radar stations at Wangerooge, Büsum, and Sylt is continuously measured and transmitted in "real time" to the Helmholtz-Zentrum Geesthacht. After automated quality control, current vectors are calculated. Every hour, these data are linked to and assimilated into a 3D hydrodynamic model (General Estuarine Transport Model, GETM). Due to this data assimilation, the model results are closer to reality thus reducing forecast errors. In particular, the dominant (M2-) tidal signal is well represented.

The deviation from the measured HF radar current data is typically about 0.1 m/s, with large spatial variations. Time series of current maps are publicly available for download from the COSYNA data portal and available in the COSYNA app. They can be utilized, for instance, for ship traffic safety, for the spreading of pollutants, or for rescue operations.

Product Temperature

Sea surface temperatures (SST) from satellites (Operational Sea Surface Temperature and Sea Ice Analysis – OSTIA) and FerryBoxes are assimilated into a North and Baltic Sea version of the three-dimensional circulation model GETM (General Estuarine Transport Model). The output is validated against independent data sets (for instance, the MARNET Deutsche Bucht station).

Product Chlorophyll

Satellite data from ESA that have been processed using an algorithm developed by HZG for coastal regions are downloaded daily. From these data a COSYNA product is generated that masks cloud coverage and averages the chlorophyll value over one month.

Product Waves

The pre-operational COSYNA wave forecast model system runs twice a day at 0 and 12 UTC and provides a 72 hour forecast horizon on the regional scale for the North Sea and on the local scale for the German Bight (resolution: 1 km). With boundary information from the regional wave model EWAM (DWD) various wave parameters such as significant wave height, period, and total wave direction are calculated. Wave rider buoys serve for validation of the model output.

Product Ship Detection

In cooperation with the CMRE a processing chain for ship detection, tracking and fusion has been developed. The ship detection is performed on site at each HF-radar station every 33 seconds, while the tracking and fusion is performed in a postprocessing step at HZG. In the future the system will be incorporated into the COSYNA network to demonstrate the near real time capabilities.

COSYNA product: Modelled temperature results, after assimilating remote sensing data (OSTIA data set) for July 2018.

Example of resulting ship tracks after tracking and fusion of 30 minutes of HF-radar data collected on 1. August 2013. The data provided through this source complements official sources based on AIS reports.

COSYNA PRODUCTS

COSYNA Underwater Node System

Within COSYNA, a stable underwater node technology has been developed for shallow-water (< 300 m) applications. Underwater nodes provide the necessary infrastructure, i.e., power and data communication, to continuously operate even complex and power consuming sea bottom based sensor systems. The cable connected system can be deployed for a maximum distance up to 30 km from shore for year-round operations, especially in shelf sea systems with harsh environmental conditions.

The system is specifically designed to host a broad variety of near-bottom measurement systems providing flexible power supply and data communication. The COSYNA Underwater-Node System is designed for water depths between 10 m (in high-energy environments like the North Sea) to a maximum of 300 m. It comprises a land-based power unit and server providing 800 or 1000 VDC, a GBit network connection, and virtual computer technology for up to 20 different users. This land-based control system is connected to the underwater node unit via a fibre-optic and power hybrid cable that can be up to 30 km long (see figure).

The COSYNA Underwater Node System is comprised of up to 10 docking stations for independent sensor units as well as a land based server system providing remotely accessible virtual user desktops for the scientists.

Permanent research stations equipped with state-of-the-art sensor technology are highly valuable to provide consistent time-series of hydrographic and biological parameters. Remotely accessible stations operated independently of ship cruises are most important especially in COSYNA's target areas North Sea and Arctic Ocean where access for maintenance or repair work is significantly limited by weather.

In 2017, three COSYNA Underwater Node Systems are in operation, one in the Southern North Sea off Helgoland, one in the Eckernförde Bight in the Baltic Sea and one in the Arctic Ocean at 79°N off Spitsbergen (see figure).


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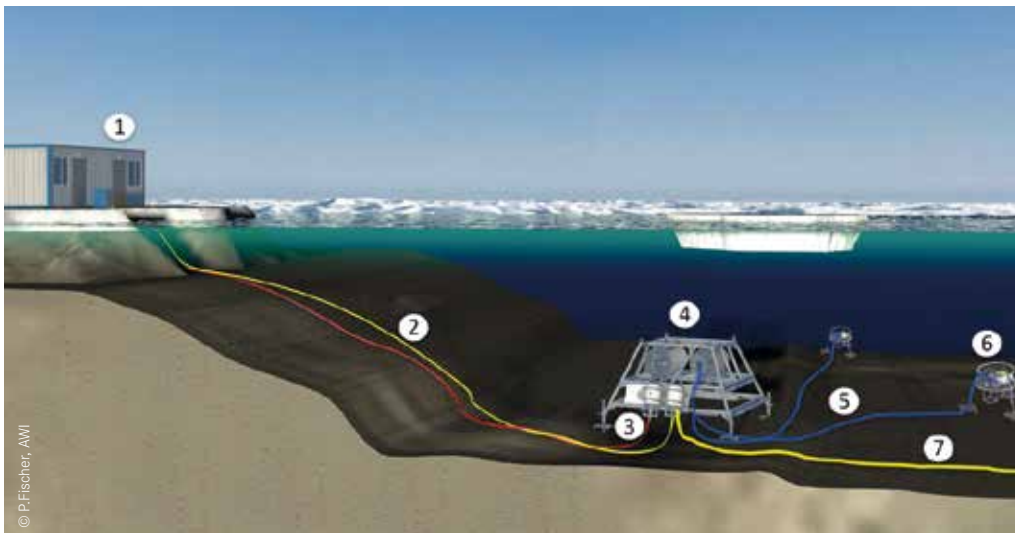
Set-up of the COSYNA Underwater-Node System with (1) land-based server and power supply, (2) cable connection (max. 10 km) to the first primary underwater node, (3) breakout box to connect the primary node to the underwater cable, (4) primary node system, (5, 6) cable connection (max. 70 m) to sensor units, and (7) cable connection to a second node. A third node can be connected to the second node.

Data are transferred to the users at 100 MBit/s (max. 1 GBit/s) for land stations with internet access, otherwise at speeds determined by wireless connections. The COSYNA underwater node technology has been developed and operated jointly by Helmholtz-Zentrum Geesthacht and the Alfred Wegener Institute Helmholtz-Center for Polar- and Marine Research in close co-operation with the two companies 4H-Jena (Jena, Germany) and loth-informatik (Wiesbaden, Germany). The Boknis Eck site in the Baltic Sea is operated jointly by HZG and the GEOMAR – Helmholtz Centre for Ocean Research Kiel.

Future research efforts aim at making the underwater node concept usable for short-term deployments as part of a modular observation system. To this end developments are under way to change the power and data link to buoys powered by photovoltaic, wind energy and fuel cell systems. Further technological advances include research into anti-fouling technologies and the use of underwater nodes as docking station for autonomous underwater vehic.

COSYNA underwater node system off Helgoland-North Sea
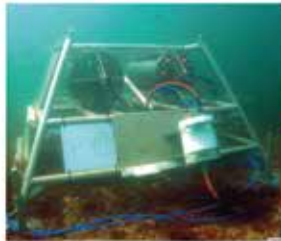
COSYNA underwater node system Eckernförde Bight Baltic Sea

AWIPEV-COSYNA underwater observatory at 79°N (Svalbard)
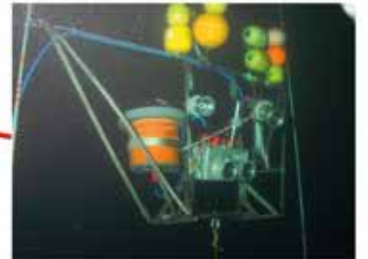
The COSYNA underwater node system at Helgoland and Eckenförde Bight (left) and in the Arctic Ocean at Spitsbergen (right). (Fotos: HZG, AWI)
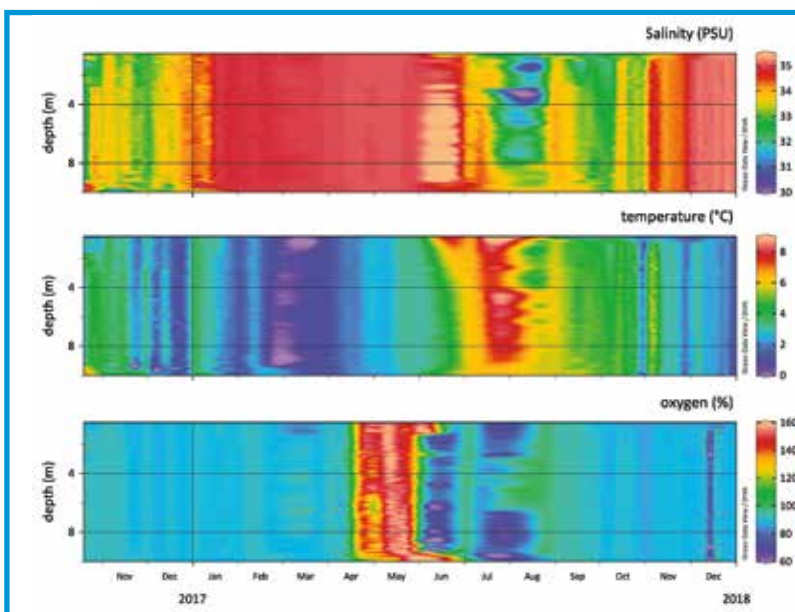
Salinity, temperature and oxygen from daily vertical CTD profiles at the AWIPEV-COSYNA Underwater Node at Spitsbergen. Data were measured within a depth range of 10-0 m between November, 2016, and December 2017. It is conspicuous that the salinity that was very high between January and May decreases with the onset of melting icebergs. However, some plankton bloom (oxygen over-saturation) already occurred in April after the ice cover was diminishing.

OBSERVATIONS: IN SITU

Surface Transects – FerryBox

FerryBoxes are automated measurement systems used to determine physical and biogeochemical parameters in surface waters. They are either mounted on 'ships of opportunity', such as ferries or container ships that serve regular routes, or are operated as fixed installations (for example in Cuxhaven and Spitsbergen).

The unique advantage of FerryBox systems lies in their cost effectiveness as well as their low maintenance needs. During FerryBox operations no ship costs arise, energy supply is virtually, regular maintenance is possible, transects are sampled repeatedly and problems with biofouling of sensors can be controlled relatively straightforwardly.

To operate a FerryBox water is pumped from a subsurface intake into the measuring circuit containing multiple sensors. The system is equipped with an automated self-cleaning and antifouling mechanism, and can be remotely controlled via satellite. The installed systems can integrate water quality data and meteorological sensors with GPS information into a data stream that is automatically transferred from ship to shore via a satellite or cell phone connection. The data is then made publically available free of charge. FerryBoxes thus enable real-time detailed investigations of physical and biogeochemical processes and can be assimilated into models.

FerryBoxes have been developed at the Helmholtz-Zentrum Geesthacht (HZG). They are now used worldwide to monitor environmental conditions not just in coastal waters but also in the open ocean. To make the collected data available a common European FerryBox data base has been established that is hosted by HZG.
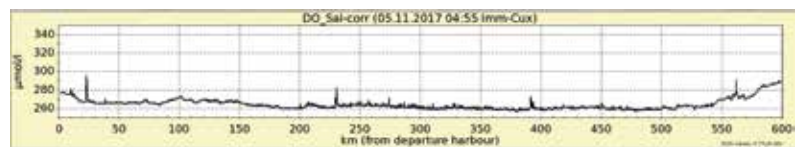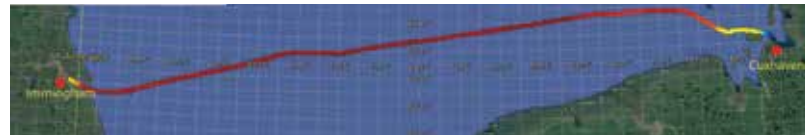
Parameters
Temperature, salinity, turbidity, chlorophyll-a fluorescence, pH, pCO_2, alkalinity, dissolved oxygen, algal groups, nutrients, automatic water samples for further lab analysis

Future
flow-cytometer, gene-probes (bio sensor)

The insight of a FerryBox showing control panels and measurement devices. (Photo: HZG)

Data from a FerryBox cruise between Cuxhaven (Germany) and Immingham (UK) on 5. November 2017 are depicted. The rise of oxygen saturation and pCO_2 that is correlated as well as decreasing salinities towards both ends of the cruise is very distinct (river influence).

The stationary FerryBox located in a container in Cuxhaven, Germany at the mouth oft he River Elbe. (Photos: HZG)
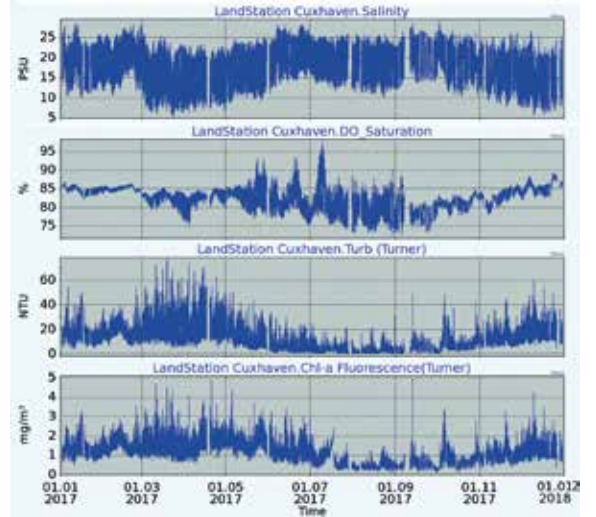
Time series from the FerryBox in Cuxhaven in 2017: Salinity, oxygen, turbidity and chlorophyll-fluorescence. Note the tidal fluctuations and the long-term variations caused by changing river flow and wind conditions. The chlorophyll concentration variations are mainly governed by mixing of marine and river water, less by plankton growth/decay.
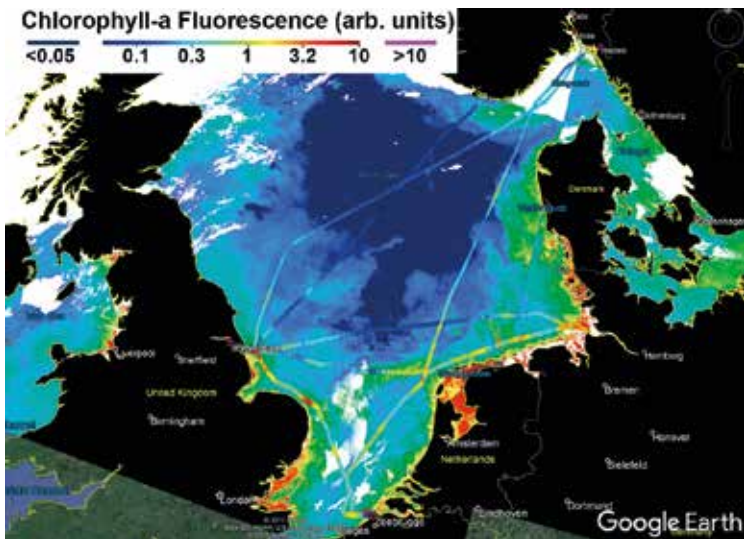

Measurement of chlorophyll-a: Comparison between FerryBox and Sentinel-lll satellite data from June 2017. Differences can be explained by a) the different methods: Sentinel-lll: light absorption; FerryBox: Chlorophyll-a fluorescence and b) by the time difference between overflight and ship cruises.

Map depicting European routes on which FerryBox systems are operated. Red lines depict FerryBoxes operated by HZG.

OBSERVATIONS: IN SITU
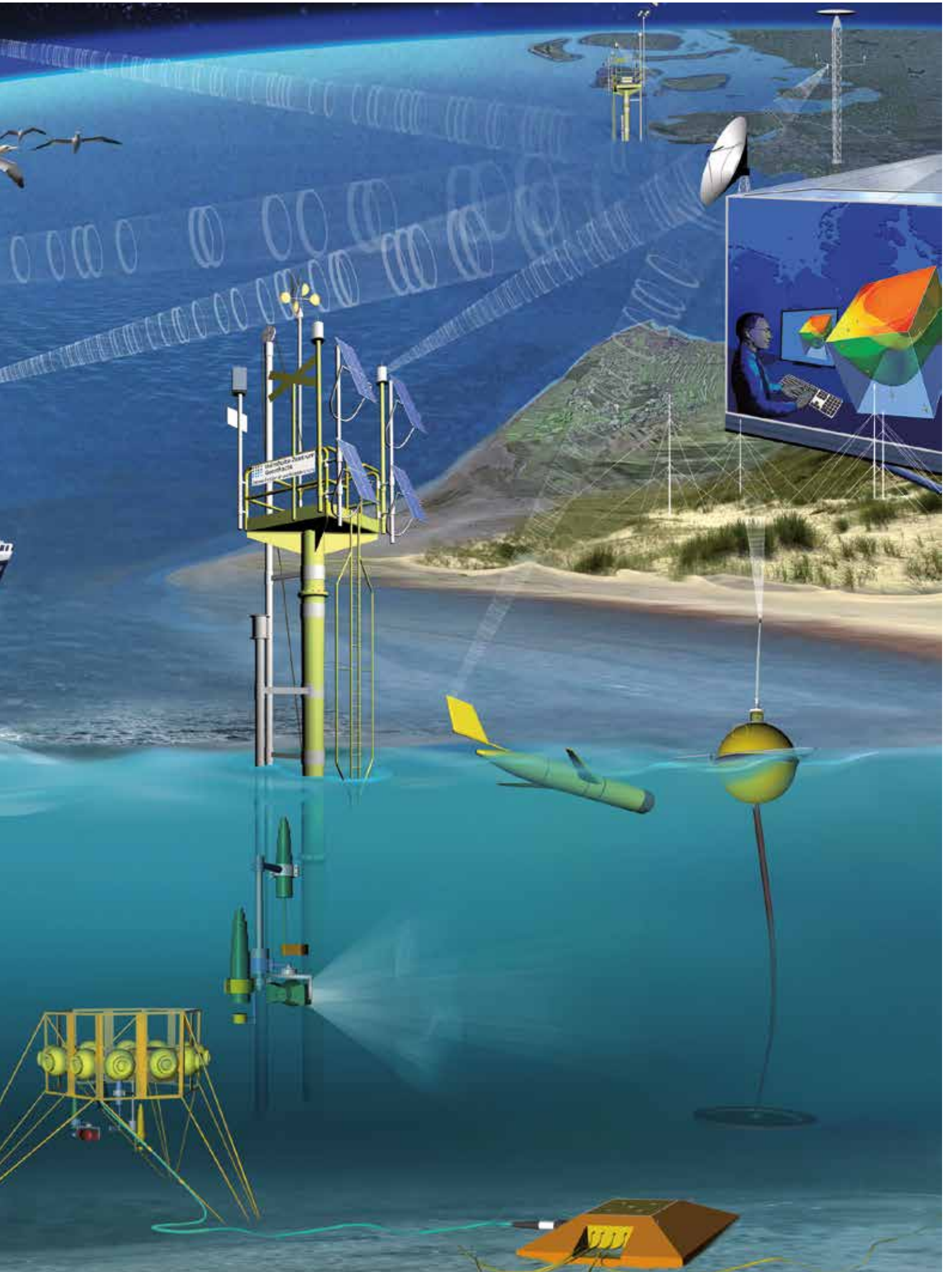
Stationary Platforms

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Stationary platforms in the COSYNA network offer the advantage of producing continuous, high-resolution time series of meteorological, oceanographic, and water quality parameters. They yield insights into the system's variability from seconds to inter-annual variations. In the German Bight, COSYNA has operated various installations such as on the offshore platform FINO3, and smaller, self-contained poles in the Wadden Sea and at the mouth of the Elbe to record data used to study the exchange of energy and matter between the shallow, intertidal near-coastal basins and the German Bight.

Time series of oceanographic, meteorological, and biogeochemical data have been continuously recorded since 2002 at a measuring pole of the Institute for Chemistry and Biology of the Marine Environment in the tidal channel of the Otzumer Balje close to the island of Spiekeroog. This station is part of the COSYNA network since 2012. The acquired data sets are fundamental for the improvement and validation of model results as well as to answer various research questions such as concerning the impact of storm surges, algal blooms on sediment dynamics, and exchange processes. The data sets are also valuable for assessing the long-term variability of oceanographic and biological parameters and determining anthropogenic impacts.

The Spiekeroog time-series station consists of a 35.5 meter long pile with a diameter of 1.6 meters that is driven 10 meters into the sediment. The temperature, conductivity, and pressure sensors are deployed within five horizontal tubes (1.5, 3.5, 5.5, 7.5, and 9 meters above the seafloor) that are aligned in the main current direction. A platform is mounted on top of the pile, about 7 meters above sea level. It consists of two laboratory containers hosting a second platform at 12 meters above sea level that is equipped with solar panels, a wind turbine, and meteorological sensor

systems. Oceanographic sensors are installed in special tubes within the pole that are oriented in the main direction of the tidal flow. An acoustic Doppler current profiler is mounted 1 meter above the seafloor on a horizontal arm of 12 meters length. The Spiekeroog time-series station is capable of withstanding storm events and ice conditions.


ICBM pile at Spiekeroog (Photo: ICBM)

Parameters

Meteorology: Wind, air temperature, pressure, precipitation, irradiance, humidity
Oceanography: Current velocity, wave height, temperature, salinity, suspended matter, chlorophyll, pH, oxygen saturation

The figure depicts a typical high-resolution 10 min time series, measured at the pile Spiekeroog. From 4th to 10th December 2017 a strong northerly wind pushed the water masses from the German Bight into the region behind the Frisian Islands where the pile is situated. This lead to an increase of water levels at low water combined with higher salinities during low water. For a more detailed analysis an existing hydrodynamic model has to be applied.
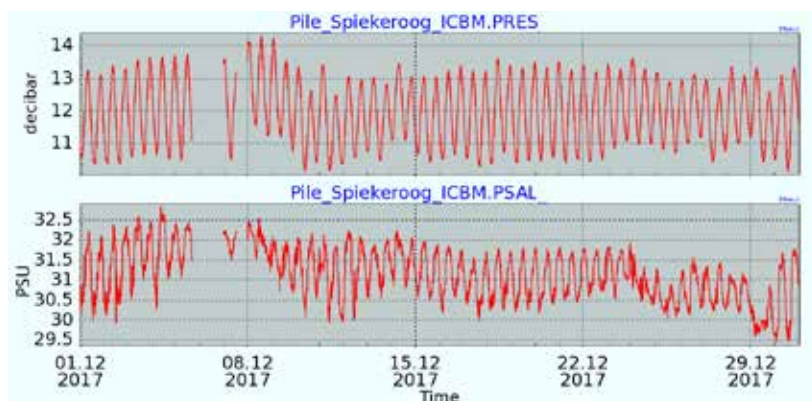
Seafloor Instrument Frame – Lander

Autonomous seafloor observatories (landers) bridge the observational gap between long-term monitoring stations, remote sensing applications, and ship-based field campaigns. The landers are designed for measuring various processes close to the seafloor or in the sediment. The systems consist of a node rack ("lander") with a suite of hydro-acoustic, laser-optical and other sensors, benthic chambers, data storage and power supply. Landers are positioned on the sea floor following hydro-acoustic and photographic pre-site surveys. They are operated autonomously for days or weeks at a time, or may be connected to the COSYNA Underwater-Node System that provides power and data connection. The landers developed and used as part of COSYNA are:

The SedOBS (Sediment Dynamics Observatory) lander measures seafloor dynamics. Observations with SedOBS focus on the interaction of microbathymetry (dynamics of sediments, bedforms, fauna on the seafloor), flow structures (like currents, turbulent patterns), sediment transport on the bed and in the lower water column, and biogeochemical parameters such as oxygen, pH, salinity, fluorescence. SedOBS is operated by the Center of Marine Environmental Sciences MARUM in co-operation with the Helmholtz-Zentrum Geesthacht.

The benthic lander system NuSOBS (Nutrient and Suspension Observatory) is designed to study biological, sedimentological and geochemical exchange processes between the sediment and the water column. NusOBS

Parameters & Instruments for SedOBS
High-resolution current profile (ADCP), turbulence, CTD, eddy correlation, particle size (LISST), floc-cam, high-resolution sonar, noise-recording

**Parameters & Instruments for NusOBS**
Particle sampler, benthic flow-chamber, current CTD, in situ water sampler, in situ porewater sampler, oxygen, pH, nutrients

is operated by the Alfred Wegener Institute. The lander is equipped with two benthic chambers for in situ incubations and with several sensors and sampling devices for biogeochemical parameters such as nutrients, oxygen and pH.

The chamber lander FLUXSO (Fluxes on Sand Observatory) was developed for studying in situ solute nutrients fluxes, dissolved inorganic carbon (DIC), and oxygen in permeable, sandy sediments. The purpose of the lander is to study advection-related processes in permeable shelf sediments, benthic-pelagic coupling, and the importance of the seafloor in shelf seas for organic carbon turnover and as sink or source of nutrients and oxygen. The FLUXSO was developed in collaboration with MPI Bremen, AWI and a German company (K.U.M. GmbH).

Photo of the FLUXSO lander during deployment
(Photo: J. Friedrich, HZG)
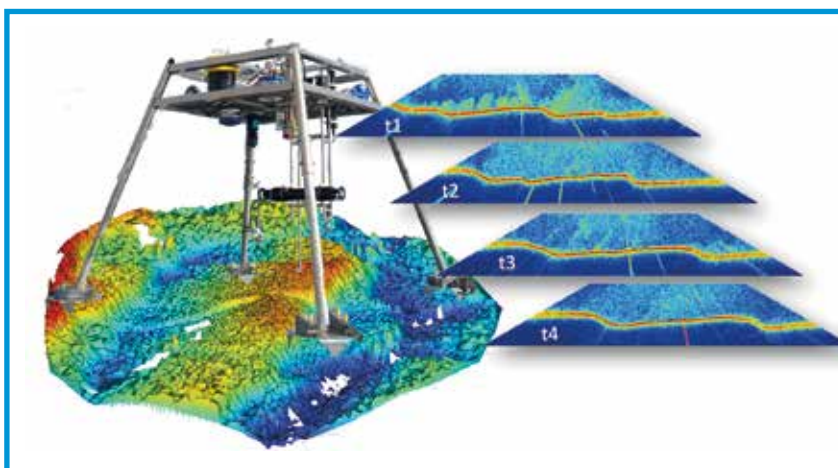
The complex 3-dimensional topography of the sea-floor, the interaction of hydrodynamics and small scale bedforms, seen in the local suspension of sediments on the backs of the bedforms (t1) and the rapid adaptation of the bedform geometry to the tidal currents (t2–t4).
(graph: MARUM, using data from SedOBS)

OBSERVATIONS: IN SITU

Surveys with Research Vessels

Research cruises across the German Bight complement the regular in situ stationary and ship of opportunity observations. They provide a quasi-synoptic overview of the German Bight. The regularly repeated ship-tracks crisscross the North Sea passing by the stationary COSYNA and federal monitoring stations BSH-MARNET thus also covering the East-West and South-North cross-shore gradients in the German Bight. This pattern is complemented by short distance transects. The research vessels RV Heincke and RV Prandtl are each equipped with a FerryBox, profiling water samplers, a newly developed towed instrument chain and an undulating towed instrument carrier ('Scanfish'™, see sketch).

These surveys serve several purposes simultaneously:

- Spatially interpolate observed variables between the locations of the fixed stations
- Add depth information to the surface data from FerryBoxes and remote sensing data
- Calibrate instruments with quality-controlled in situ water samples
- Test new sensor packages for later incorporation into the pre-operational observational sensor arrays
- Study the natural dynamics of the North Sea.

Parameters
Temperature, salinity, suspended matter, chlorophyll, oxygen, local water depth

Scanning the water column

Scanfish™ is a towed undulating vehicle system. Flaps control the up and down movement of the 'fish'. Scanfishs™ are designed to carry several oceanographic sensors. While cruising the German Bight, the steady up and down movement generates a curtain-like data stream of millions of data points along the ship track that allows a detailed and quasi-synoptic view of the ocean (see figures below).

A Towed Instrument Chain was designed as an array of ten to twenty CTDs placed at different locations on a string. The instrument allows rapid repeat sampling with high horizontal and vertical resolution. The Towed Instrument Chain was developed in order to better observe and under-stand dynamically important small-scale processes.
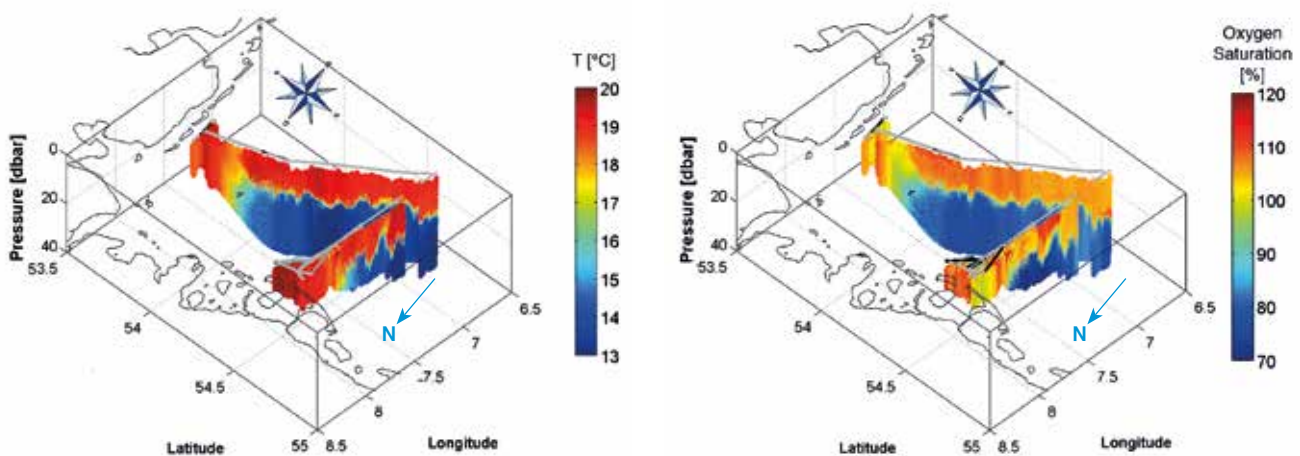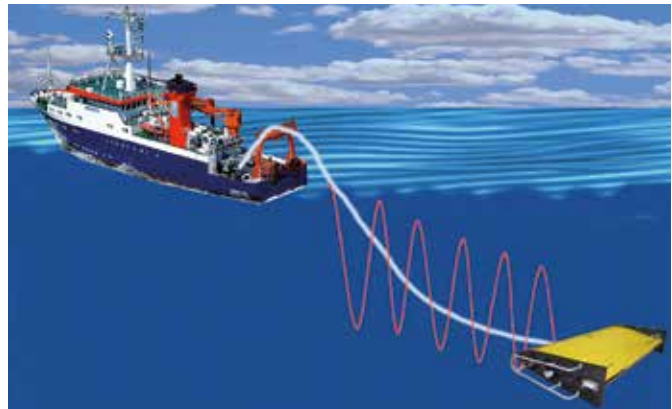
Quasi-synoptic view of water temperatures (left) and oxygen saturation (right) from Scanfish™ data during a cruise in the German Bight, 28 July to 5 August 2013. Note the stratification with higher temperatures and larger oxygen values near the surface.
(Note: Map not adjusted to north.)

Three Dimensional Transects – Gliders

Underwater gliders are autonomous underwater vehicles designed for long-term (weeks to months) survey missions. By actively changing their buoyancy the gliders dive and climb using very little energy. Wings convert part of the vertical motion into forward motion, creating a saw-tooth shaped path. Typically, a glider performs 30 to 40 dive/climb cycles before returning to the sea surface after approximately four hours where it communicates with the scientists via satellite. This schedule allows for measurements of high temporal resolution and for near real time retrieval of a subset of the collected data.

Gliders are a cost-effective platform that is unaffected by adverse weather conditions. They are mostly used for measurements along transects, but can also be used virtually stationary. While gliders can be equipped with sensors for a variety of quantities they are particularly useful for the observation of suspended sediment dynamics in the water column using optical backscatter sensors as a proxy for sediment concentration.

The gliders can also be equipped with turbulence microstructure sensors aiming at providing new insights in the mixing of temperature, salinity and suspended sediment. These highly sensitive sensors need a virtually vibration-free platform to operate from, a requirement the gliders match almost perfectly.

Parameters
Temperature, salinity, suspended matter (optical backscatter), chlorophyll a (fluorescence), optically coloured dissolved organic matter (CDOM, aka "gelbstoff"), currents (depth-averaged and from ADCP profiles), microstructure (optionally)
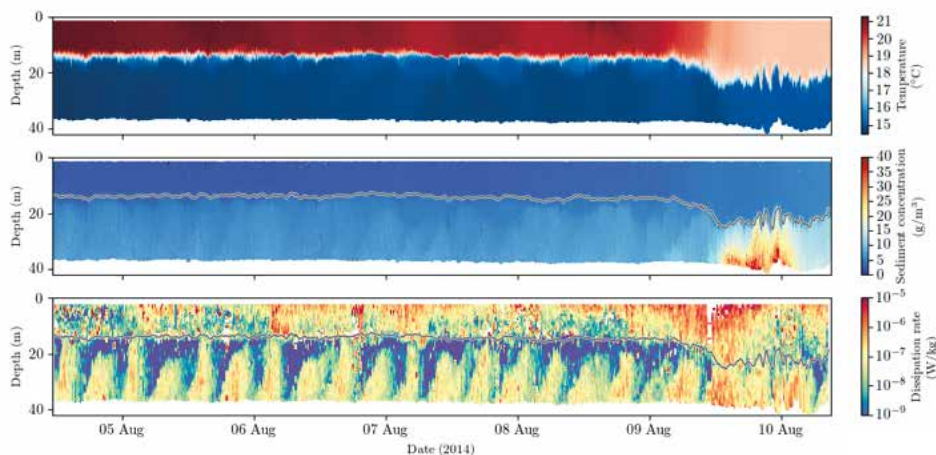
Data from glider "Sebastian", recorded in the German Bight, starting a few days before the passage of storm Bertha (9–11 August 2014).
The top panel (temperature) shows an initially strongly stratified water column, that becomes well mixed during the storm. Before the storm, the sediment concentration (middle panel) shows weak variability with a tidal signature; during the passage of the storm the concentration increases.
The bottom panel shows the turbulent dissipation rate (a measure for the turbulence intensity). In the bottom layer, turbulence is generated by shear in the tidal boundary layer; in the top layer, it is related to wind shear.

OBSERVATIONS: IN SITU

Remote Sensing – Radar

Radar remote sensing is an ideal instrument for monitoring the ocean continuously as it is independent from daylight and weather. Several different types of radar systems are in use at the Helmholtz-Zentrum Geesthacht, Institute of Coastal Research. They are operated from a variety of platforms: Space-borne, coastal, vessel-mounted, as well as offshore. These systems allow us to monitor ocean surface winds, waves and ocean current patterns at spatial scales ranging from meters to hundreds of kilometers. Radar measurements utilize the backscatter from the ocean surface due to its roughness at scales of electromagnetic wave lengths used by the radar. As surface roughness is strongly related to surface winds, waves and currents, these parameters can be retrieved from the radar measurements.

Ground based microwave radars (X-band, 9.4 GHz) are used to observe the ocean surface at short distances (< 2 km) at high spatial and temporal resolution. These systems measure the surface roughness, which can be used to retrieve surface winds, waves, and current information as well as bathymetry in shallow water areas.

In contrast to the X-band, waves in the high frequency (HF) band (3-30 MHz) propagate along the air-sea interface. This allows the signal to sense the ocean behind the horizon enabling coverage of more than 150 km with a coarse spatial resolution. As part of COSYNA, three HF-radar stations along the German North Sea coast are operated acquiring data on a pre-operational basis. Every 20 minutes the radar data are converted in near real time to wave and current fields at a spatial resolution of 2 km.

For larger scale observations, HZG has developed algorithms to retrieve high-resolution surface winds from satellite-borne synthetic aperture radar. The resulting wind maps give an instantaneous view of an up to 500 km wide swath along the orbit of the satellite with a resolution as fine as 100 meters.

Parameters
Wind speed & direction, wave height & period, current speed & direction, bathymetry
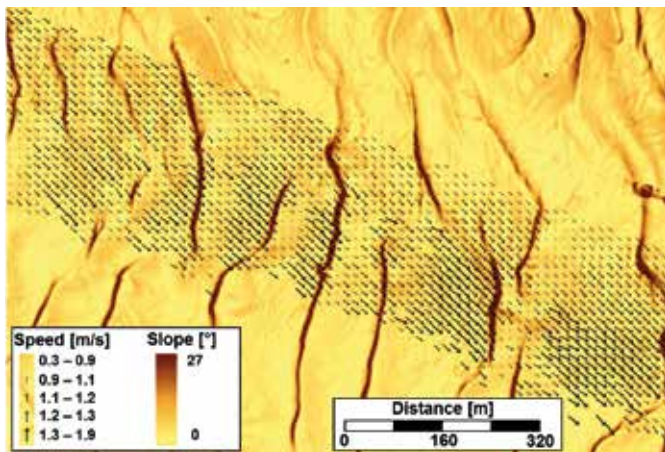
A high-resolution current field measured by the Radar Doppler Current Profiler off the isle of Sylt. The underlying bathymetry map was produced using data from a multi beam echosounder
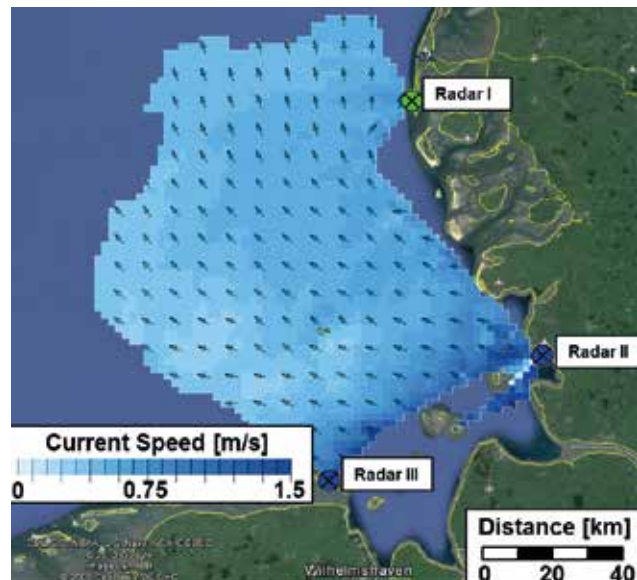
Current field retrieved from HF-radar for 5 January 2014 at 4:19 UTC in the German Bight.

OBSERVATIONS: RADAR

Remote Sensing – Ocean Colour from Satellites

Satellite remote sensing is a unique technique used to observe large areas of ocean and land surfaces simultaneously. The colour of the ocean in the visible light spectrum can be measured and used to determine the concentrations of chlorophyll, suspended matter, and yellow substance (also known as CDOM). The algorithms for the open, blue ocean are well established, whereas they are still subject of intense research for coastal regions with their highly variable water properties. The European Space Agency (ESA) is using an algorithm specific for coastal waters developed at the Helmholtz-Zentrum Geesthacht to process all data from their earlier MERIS and current OLCI spectrometer. This algorithm is improved in regular intervals. It is also used in COSYNA for daily processing, as demonstrated for a snapshot of chlorophyll concentrations in the North Sea on 27 May 2017 (figure below on the right).

This algorithm is now used for OLCI as part of the Sentinel-3 mission with the first satellite launched in 2016 and the next planned for 2018. Monthly means and maxima are derived from the daily fields to obtain an improved understanding of chlorophyll dynamics and to reduce the effect of cloud coverage on data. Optical remote sensing is ideal for obtaining spatial information over large areas for almost every day. The lack of information in deeper water levels and under clouds requires additional information from in situ measurements in combination with numerical models to interpolate missing data. Additional in situ data from measurement campaigns and stationary observing systems are taken to validate and improve satellite-derived data.

Parameters

Concentrations of suspended matter, chlorophyll and CDOM, future products: POC and DOC.

Sentinel-3 satellite (Photo: ESA)
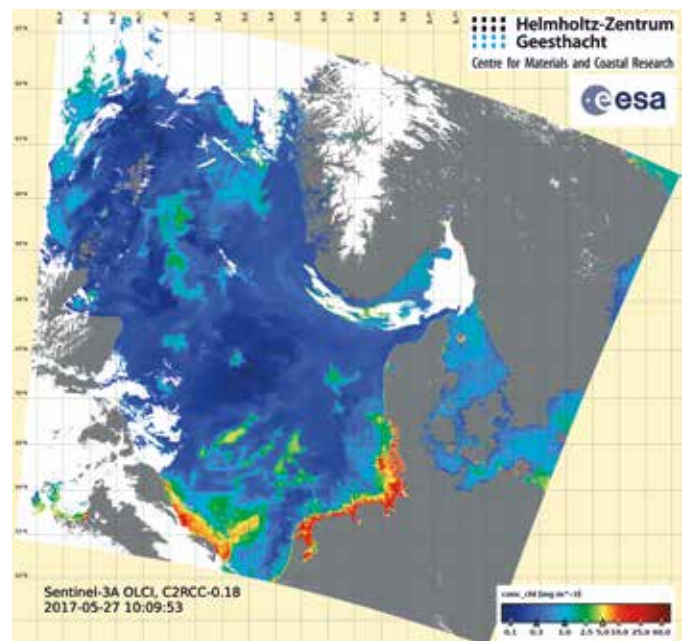
Chlorophyllconcentration of the North Sea, 27 May 2017 at 10.09UTC derived from OLCI with the 'Case-2-Regional' Processor. Note that only natural clouds (no contrails) are visible due to airspace closure over Europe.

OBSERVATIONS: REMOTE SENSING

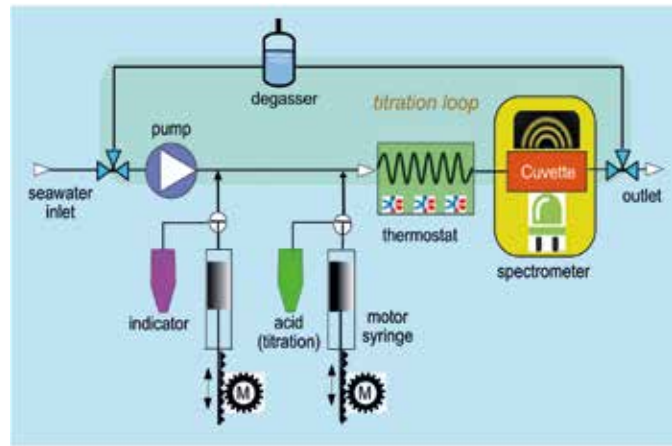# Instrument Development – Sensors for pH and Alkalinity

Shelf seas are a critical interface between the land and the open ocean. Consequently, processes in shelf seas play a crucial role in global biogeochemical and carbon cycles and have a significant influence on ocean CO_2 storage. Continuous monitoring of the carbon cycle in the ocean is highly relevant to understanding climate change and ocean acidification. To fully quantify the complete carbon system in seawater it is necessary to determine at least two variables of the carbon system in seawater. The Helmholtz-Zentrum Geesthacht has therefore developed autonomous underway systems with a high temporal resolution (1/min) for alkalinity and pH value.

The pH analysis system adds an acid-base indicator dye to a seawater sample. The indicator dye's extinction coefficients change with the acidity of the water sample. This principle can be used for high precision spectrophotometric determination of the pH value. One big advantage of this method is that no calibration of the indicator is needed in the field as no drift occurs. Only temperature and salinity have to be known accurately.

Parameters

Precision pH value, total alkalinity

To determine total alkalinity, a tracer-monitored titration with a strong acid is performed. The tracer (bromocresol green) allows to optically measure the concentration of the indicator and, hence, the concentration of the acid. From this the alkalinity can be calculated. In addition, the pH value can be calculated during the titration procedure, which is needed to determine the alkalinity.

Schematic overview of the measurement principle for alkalinity.

Instrument Development – Nucleic Acid Biosensor

The surveillance of marine phytoplankton is greatly facilitated by nucleic acid biosensors. At the core of this biosensor is a multiprobe chip that can be used for the simultaneous detection of a variety of algae. The detection principle has already been verified. The main challenge for COSYNA was to construct an automated device that (1) reliably filters sea water automatically, even with varying amounts and composition of the suspended matter, in order to concentrate algae cells, (2) 'cracks' the cells (lysis) and (3) transports the resulting fluid to the detector.

Such an instrument has been constructed by the Helmholtz-Zentrum Geesthacht, the Alfred Wegener Institute and the company ISITEC. It was tested during different cruises of RS Polarstern and will be applied routinely in the North Sea.


Automated filtration unit for processing filtered algae prior to detection by the biosensor (Photo: ISITEC)

Instrument Development – Hyperspectral Absorption Sensor

Conventional chlorophyll-a estimation by fluorometry is prone to errors associated with phytoplankton composition, physiological status and short-term light acclimatization. In contrast, phytoplankton absorption properties are less influenced by these factors, thus estimation of chl-a from absorption is more reliable. In addition, information about algal groups derived from absorption spectra would be helpful for the assessment of phytoplankton dynamics in terms of changing taxonomic composition.

The HyAbS is an instrument for continuous, flow-through, automated absorption measurement based on the use of an integrating cavity. This cavity overcomes two common problems associated with conventional spectrophotometry in seawater: Measurement biases caused by light scattering on particles and low signal/noise ratios because of low amounts of absorbing material. The HyAbS aims to combine the high quality of the measurements resulting from these advantages with the high resolution and convenience of continuous flow-through measurements. From the obtained absorption coefficient spectra, quantitative and taxonomical information about phytoplankton can be derived.

Minimal human intervention is necessary, because all measurement procedures including the calibration of the instrument are completely automated.
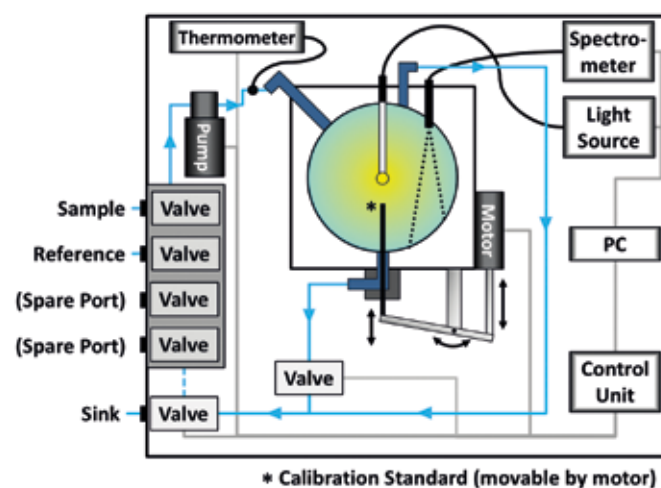

Process scheme of the continuously operating absorption sensor (integrating cavity principle)

Nutrient Analyser

Automated nutrient measurements are important for the assessment of the eutrophication status of coastal waters. Current nutrient measurement require wet chemical analysis with an analysis time of 20 to 30 minutes. An automated and fast analyser was therefore developed that is suitable for the use on FerryBoxes and the detection of small-scale processes, such as algal distributions of blooms associated with fronts.

A new analytical system was developed that applies the method of sequential injection analysis (SIA) for a relatively fast and reliable determination of nitrate, ammonia, and o-phosphate. Special reagents are used that react with nitrate, o-phosphate and ammonia resulting in a color change that is detected with a spectrometer. Analysis times of 6 samples/hour for nitrate, 10 samples/minutes for ammonia and 50 samples/minutes for phosphate are achieved.
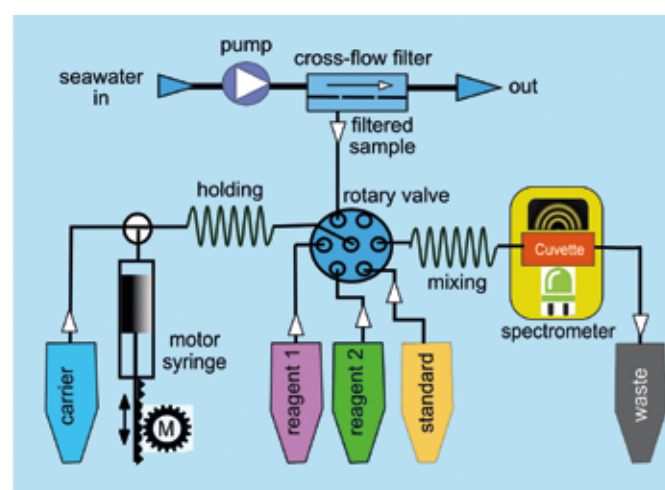
Process scheme of the nutrient analyser

OBSERVATIONS: IN SITU

Hydrodynamic Modelling and Data Assimilation

Numerical models are required to estimate ocean state variables at times and locations for which observations are not available. Of particular importance for the COSYNA project is the ability to provide forecasts of different parameters concerning ocean waves, circulation, and suspended matter. The combination of models covering different processes and spatial scales provides a comprehensive picture of the physical ocean state of the German Bight.

Circulation and Wave Models

COSYNA runs a nested-grid modelling system in pre-operational mode for both ocean waves (WAM model) and ocean circulation (GETM model): The model grid resolution is 1 km for the German Bight and about 5,5 km (3 nautical miles) for the North Sea. With this setup it is possible to compute three-dimensional current, temperature and salinity fields, as well as two-dimensional water elevation and wave parameter fields such as wave heights and mean periods. Model runs are calculated with a forecast horizon of 72 hours and made available in hourly time steps.

Data Assimilation

Ocean state estimates provided by numerical models contain errors that increase with prediction time. Errors are due to imperfect model dynamics as well as to uncertainties in the initial state and the forcing fields. Data assimilation is a technique to reduce estimation errors by dynamically consistent combination of numerical models and observations. In coastal areas data assimilation requires dedicated techniques to deal with the frequently short memory of the system.

COSYNA applies different statistical and variational assimilation techniques to correct the model now- and forecasts. For assimilating HF-radar surface current measurements a spatio-temporal optimal interpolation (STOI) method was developed which allows for provision of short term surface current forecasts with hourly updates.
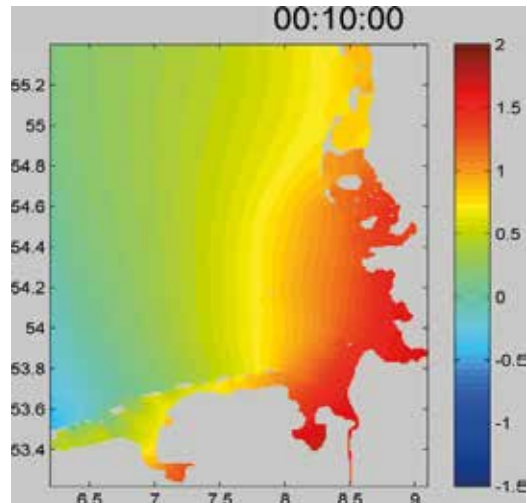
Water elevation [m] computed with the GETM model
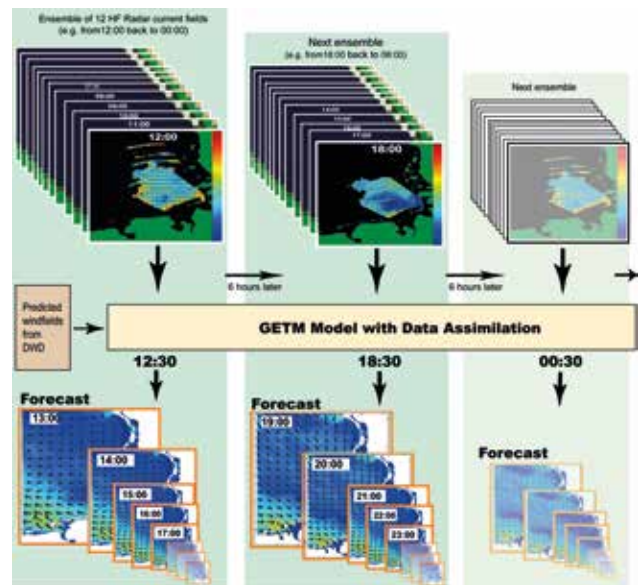
The graph depicts the scheme for improvement of HF measurements by data assimilation with a model: The currents are measured once an hour and fed into a continuous running GETM model. The (corrected) model produces homogeneous data over the whole German Bight together with a 12-hour forecast.
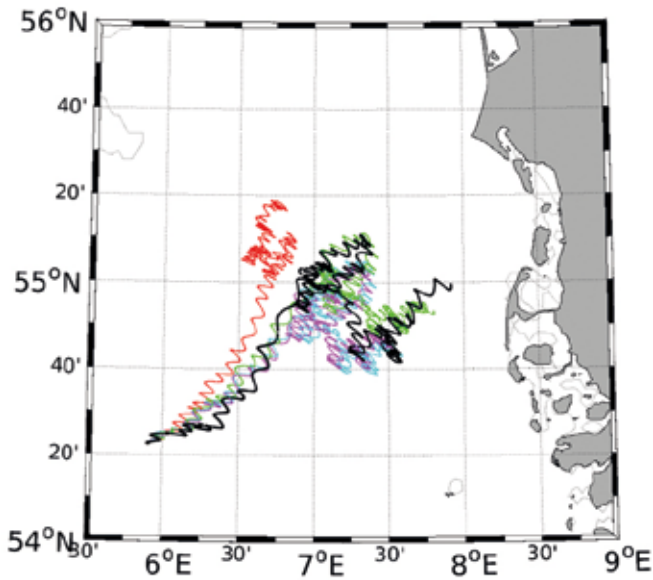
Drifter trajectories (26 May to 30 June 2016) in the German Bight: observed (black line) and modelled (red-line – circulation model only, other colours – coupled wave–circulation model experiments, Staneva et al., 2017, 2018)

Drifter trajectories

A real surface drifter trajectory (black line) obtained during a measurement campaignin May/June 2015 was compared to simulations using numerical models of different complexity. It was shown that simulations taking into account different coupling mechanisms between ocean currents and ocean waves lead to significantly better results than the uncoupled model run (red line)

Unstructured Grid Modelling

Global ocean circulation models do not properly resolve shelf seas dynamics due to limitations in grid resolution and physical parameterizations. Similar to global models, regional models often poorly resolve estuarine dynamics and are rather controlled by open boundary conditions. Nested systems are not able to address the question of tracer transport from the river mouth to the open ocean or are hampered by numerical limitations. To investigate ecosystem processes in estuaries at the required high spatial resolution while avoiding the problems associated with nesting solutions COSYNA started using unstructured-mesh physical ocean models (FESOM coastal version and SCHISM). coupled to biogeochemical models.
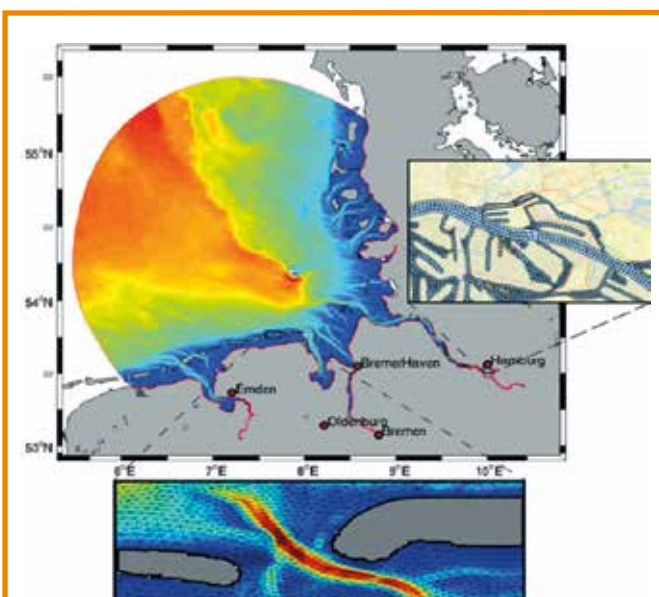
Sample salinity distribution and mesh resolution in SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model)

MODELLING

Data Management

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COSYNA data management is the link between observations, model results, data retrieval and usage. It organizes the data streams between observational and storage systems at the Helmholtz-Zentrum Geesthacht and partner sites, the data documentation and the user interfaces for data retrieval and presentation. Monitoring the actual status of the systems and subsequent pre-operational state reconstructions and forecasts requires fast transmission, automatic quality checks and data assimilation.

The integration of diverse data sources in terms of parameters, dimensionality and observation methods to gain a comprehensive view of the observations is achieved by describing the data in a generic way using metadata and by making all data available for different analyses and visualizations, interrelated and independent of data dimensionality.

The compliance with national and international standards or guidelines for data management and quality assurance ensures interoperability with other marine/coastal data centers regarding information sources, exchange of data and metadata including data quality. This way, COSYNA is prepared to contribute to an European-wide network of coastal observatories. Together, meta, observational and model data will grow into a long-term searchable archive that can be used to detect patterns in the North Sea systems' development over a broad range of temporal and spatial scales.

COSYNA follows an open data policy for users from the scientific community, coastal managers or interested lay persons. The COSYNA data portal presents all COSYNA data and metadata in a comprehensive way. The user can select parameter, data sources, time range and presentation type (overlay raster map or time series diagram) and choose to either display or download the selected data. The actual data retrieval is controlled exclusively by the metadata.

COSYNA data portal: codm.hzg.de/codm
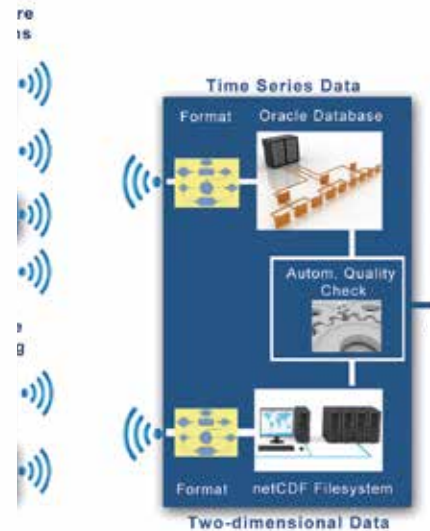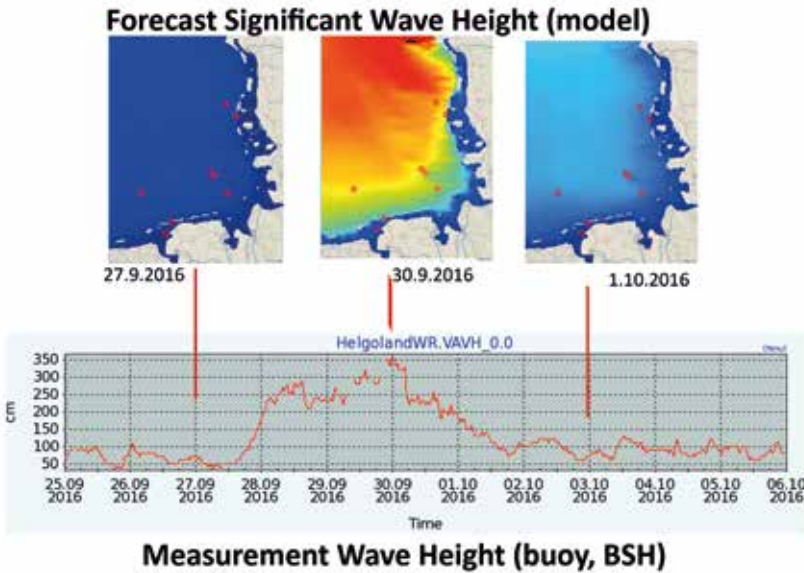
In the COSYNA data portal all routine data that are measured in COSYNA can be selected and displayed in combination with remote sensing and radar data. The example above depicts three forecast scenarios of significant wave height for 29 to 30 September 2016 and 1 October 2016. As can be seen a storm occurs at the 30 September, generating large wave height up to 5 meters in the northern German Bight. The continuous measurements at Helgoland, depicted below are in good arccordance with the forecasts.

Data Usage

COSYNA routinely analyzes user data based on voluntary data pro-
vided by users when accessing the COSYNA data portal to improve
COSYNA's products and services, as well as to justify its efforts to
funding bodies. After a simple user registration procedure for the
COSYNA data portal information is collected on provenance and
user category as well as on purpose of visit. The users' information
is safeguarded by adhering to strict privacy rules and a strictly
statistical analysis of data. Data access and usage is free of charge.
The use of data is governed by adhering to scientific best-practice
standards with regard to citation and co-authorships.

COSYNA data portal users come from all over the world (51 countries
as of 2017, compare figure) and from a variety of user groups. While
science users dominate, interest from public administration, industry
and other stakeholder groups is present and growing. Data usage
has been growing constantly since the data portal went online.
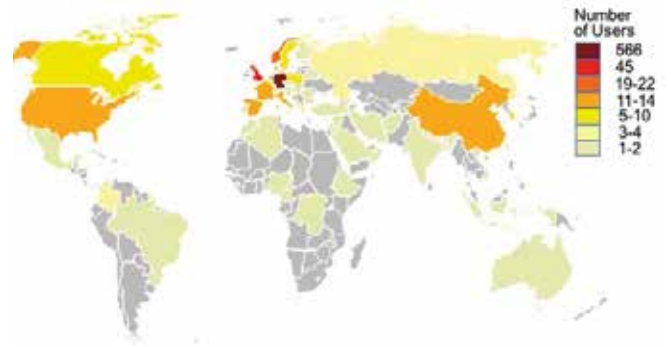
Users of the COSYNA data portal from 2015 through 2017 –
geographical distribution
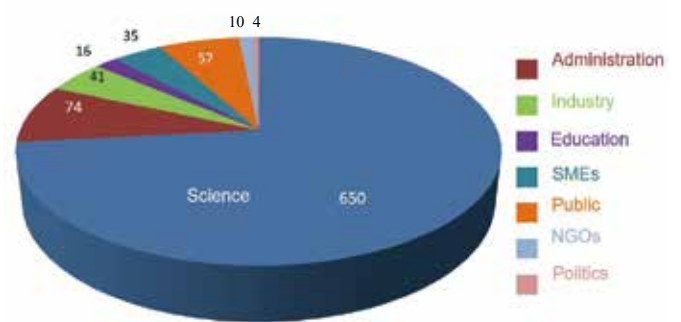
Users of the COSYNA data portal from 2015 through 2017 according
to user category

The graph shows the flow scheme of data from the observation
stations through quality assurance procedures to the presentation in
the data portal.

DATA MANAGEMENT

Using COSYNA Data: Example Elbe River Flood 2013

Within the context of the predicted and observed increase in droughts and floods with climate change, large summer floods are likely to become more frequent. These extreme events can alter typical biogeochemical patterns in coastal systems. The extreme Elbe River flood in June 2013 not only caused major damages in several European countries but also generated large-scale biogeochemical changes in the Elbe estuary and the adjacent German Bight.

Data from COSYNA and other sources captured the flood influence on the German Bight. The investigation by Voynova et al. (2017) is a prime example for the usefulness of COSYNA data. It made use of data collected at the stationary Cuxhaven FerryBox in the Elbe estuary, from a FerryBox aboard the M/V Funny Girl (traveling between Büsum and Helgoland) and combined them with a variety of data from other research institutions and federal agencies (see figure).

Some results:

This flood event serves as an example of how extreme discharges can alter the biogeochemistry of estuarine and coastal regions. Salinity changes in the German Bight persisted for about two months after the peak discharge. The Elbe flood delivered large loads of organic carbon and nutrients. The increased loading of labile organic carbon led to a doubling of CDOM and an initial decrease in dissolved oxygen and pH shortly after the flood event, suggesting increased respiration. Up to two months after the flood, water column stratification and enhanced primary production (evidenced by high pH and prolonged oxygen super-saturation in surface waters) caused a more long-term and widespread effect. The prolonged stratification also led to widespread bottom water oxygen depletion, unusual for this area in summer. This depletion could be another potentially detrimental effect on coastal ecosystems, particularly in summer, when temperature is high and reaction rates are fast. Finally, it is possible that a more prolonged influence on the coastal ecosystem could result from recycling of the increased loads of organic carbon and nutrients.
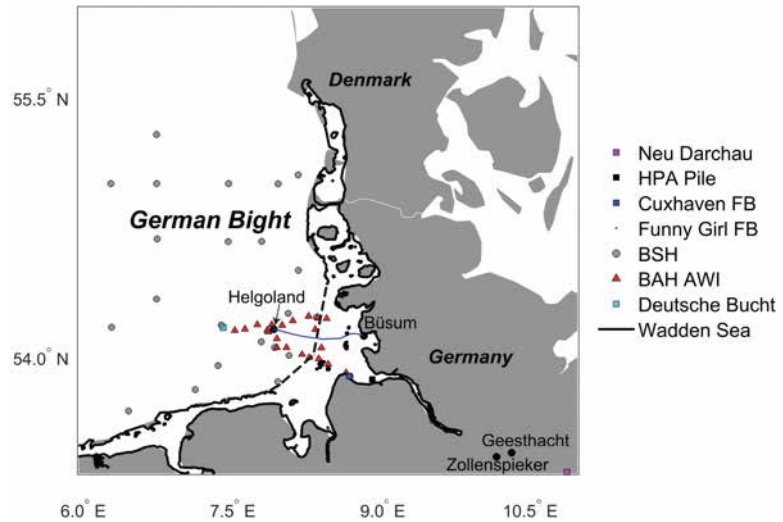

Map of German Bight, Elbe estuary, Wadden Sea and the continental regions around them. Stations are indicated with different symbols: Neu Darchau discharge gauging station (magenta square), operated by the German Federal Waterways and Shipping Administration (WSV); HPA pile (black square), operated by Bundesamt für Seeschifffahrt und Hydrographie (BSH) and Helmholtz-Zentrum Geesthacht (HZG); Cuxhaven FerryBox (FB, blue square), operated by HZG; M/V Funny Girl FB transect (blue line) between Büsum and Helgoland, operated by HZG; BSH discrete sampling stations (grey circles); Biological Station Helgoland at the Alfred Wegener Institute (BAH AWI) discrete sampling stations (red triangles); Deutsche Bucht MARNET monitoring station, operated by BSH (cyan square).
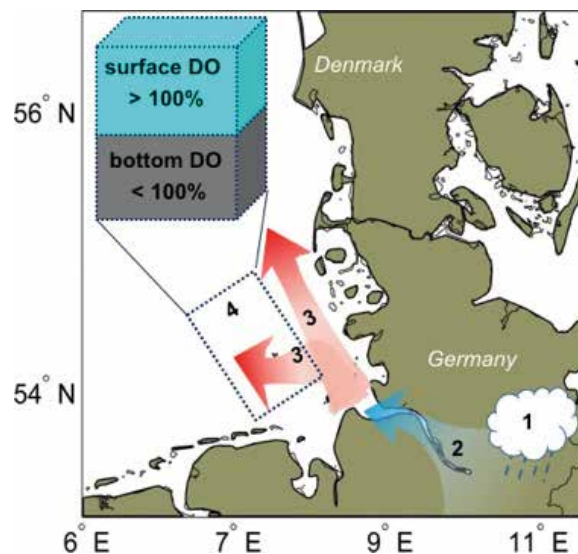
Schematic representation of processes during the 2013 Elbe river flood: (1) Rain saturated soils: (May-June); (2) Extreme Elbe discharge (June); (3). Large freshwater influx, high nutrients, DOC & POC from Elbe River and onto the German Bight (June-July); (4) 2 month stratification; high primary production in surface; widespread DO depletion in bottom waters.
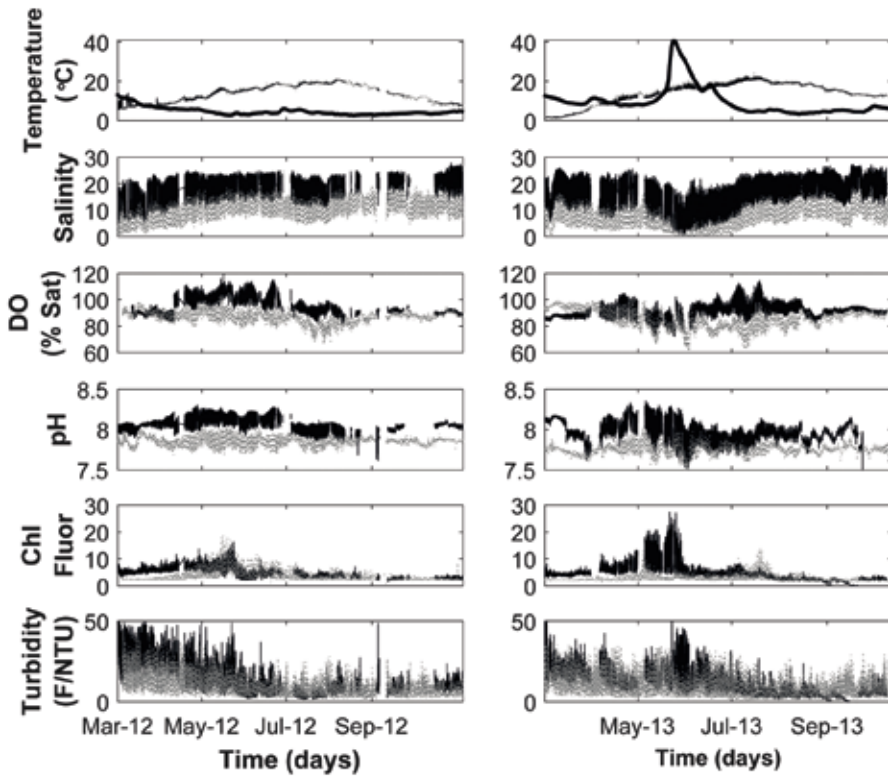
Hourly measurements of temperature, salinity, DO (% saturation), pH, chlorophyll (fluorescence) and turbidity (F/NTU), measured at Cuxhaven (725 river km, black line) and HPA pile (710 river km, gray line) in the Elbe estuary, for 2012 (left panels) and 2013 (right panels). As a reference, the Elbe discharge (m³ s⁻¹ at Neu Darchau station (thick black line), scaled by dividing it by 100, is included in the temperature plots.
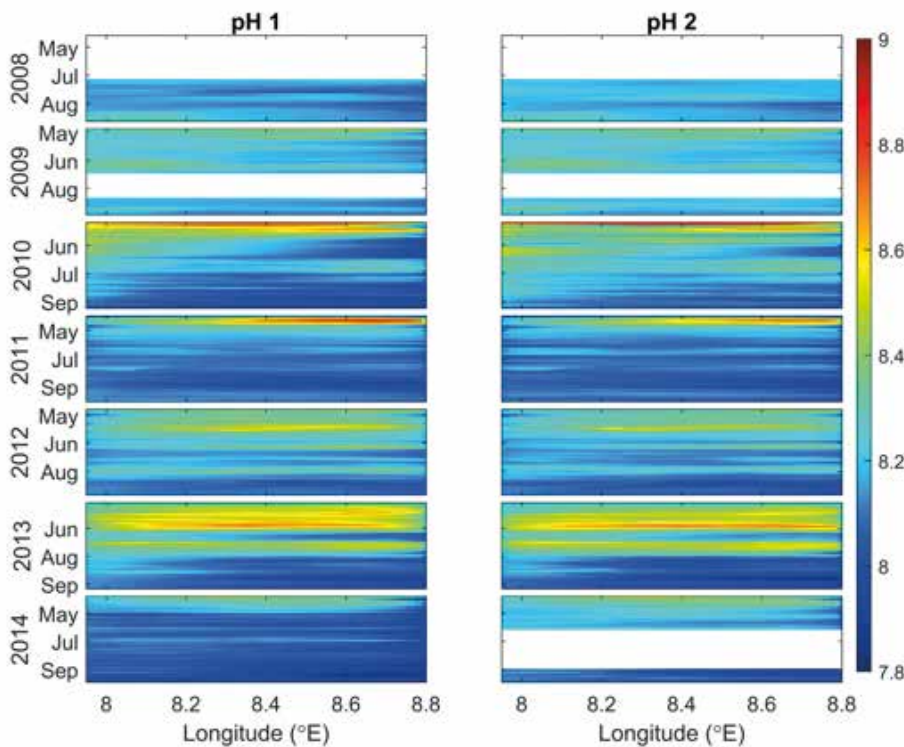
pH ferry data between Büsum and Helgoland for each summer between 2008 and 2014. There were two pH probes available on the ferry M/V Funny Girl. The white sections represent times when data were not available.

OBSERVATIONS: IN SITU

Using COSYNA Data: Example Carbon Budgets in the North Sea

Many global problems influence in particular the ecosystems and communities along the coasts. Coastal regions on the other hand provide the 'boundary conditions' for the deep ocean. As part of our research focus area Global Coast, COSYNA will investigate the relevance of coastal waters for global processes, such as carbon exchange processes with the open ocean as well as carbon budgets.

The observation of the oceans' fast-changing carbonate chemistry is of paramount importance since the oceans take up great quantities of CO_2 from the atmosphere. Acidification of sea water is one of the consequences of this uptake with far-reaching implications for marine ecosystems. The role of the shelf seas and coastal regions with their high biological activity as a source or sink of CO_2 is, however, still not well quantified. The North Sea has so far been regarded to be an efficient carbon dioxide conduit from the atmosphere to the North Atlantic Ocean. The variability in the carbonate system in this region, however, necessitates high-frequency measurements of these parameters as well as numerical analyses to be able to understand its workings and vulnerabilities.

FerryBox measurements of pCO_2, pH and alkalinity have been carried out on several routes across the North Sea. The left picture shows pCO_2 concentrations between Norway and Belgium for the years 2013 to 2017. pCO_2 data in the central North Sea regularly depicts under-saturation (<400 µAtm) against atmospheric CO_2 concentrations in spring and early summer due to consumption of carbon dioxide by algae blooms and slight oversaturation in late summer and autumn due to remineralization processes releasing carbon dioxide again.

The right graph depicts the seasonal alkalinity variability in the North Sea in 2017. The highest alkalinity occurs in the German Bight from June to October, probably due to alkalinity production in the summer months in the adjacent Wadden Sea and tidal transport into the North Sea. A steep alkalinity gradient between the near-shore and adjacent coastal regions was observed, likely driven by total alkalinity inputs from the Wadden Sea. This high total alkalinity in the southeastern North Sea, could significantly affect the local carbonate buffer, and thus the regional capacity for pCO_2 sequestration.
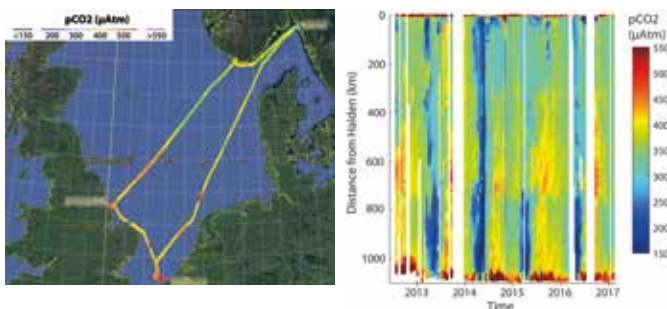
Left panel: Map of the route of the cargo vessel Lysbris. Right panel: Time series of pCO_2 data from 2012 to 2017 (pooled data from all transects between Halden (Norway) and Zeebrugge (Belgium).
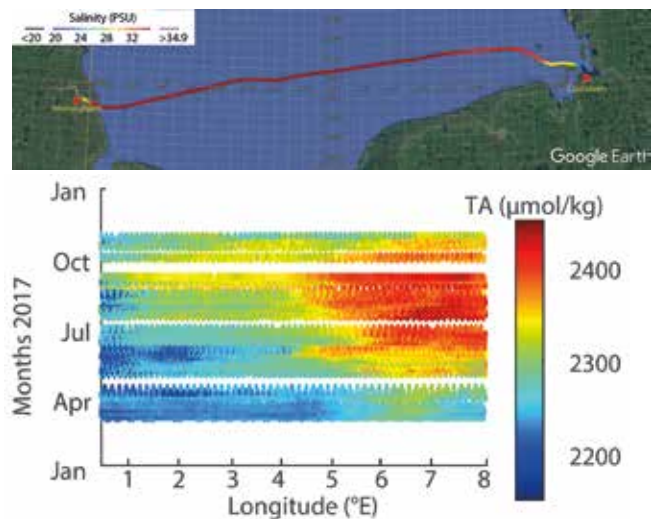
Weekly FerryBox measurements of alkalinity on the route Cuxhaven-Immingham in 2017.

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