HELMHOLTZ-ZENTRUM GEESTHACHT

# COSYNA

## Coastal Observing System for Northern and Arctic Seas

COSYNA

Helmholtz-Zentrum Geesthacht

Centre for Materials and Coastal Research

# COSYNA Mission

**Develop an integrated observing and modelling system suitable for the operational and synoptic description of the environmental status of the North Sea and Arctic coastal waters. COSYNA aims to provide data and knowledge tools to help authorities, industry, and the public to plan and manage routine tasks, respond to emergency situations and to evaluate trends. Scientific products and infrastructure are developed to foster scientific knowledge of the "global coast" and its regional manifestations.**


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

# COSYNA Partners

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.

BSH
BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

BAW Bundesanstalt für Wasserbau
Kompetenz für die Wasserstraßen

Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein

AWI
Alfred-Wegener-Institut für Polar- und Meeresforschung in der Helmholtz-Gemeinschaft

marum
The ocean in depth!

ICBM

NLWKN

HPA
Hamburg Port Authority

# 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 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, or morphology changes due to sediment transport. 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 thus contributes to national and international programmes, 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 processes, improve operational models, provide products for various interest groups, and support technological 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 and retrieving data, products, and infrastructure.

# COSYNA Research Questions

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

## Questions of Operational Oceanography

- What are the key regions that have the largest influence on coastal seas and what is the ideal instrumentation and observing strategy?
- How can an observing system be optimized to provide relevant and high quality information in a cost effective way?
- How can the large range of relevant spatial and temporal scales from minutes to decades and meters to hundreds of kilometers be captured simultaneously?
- 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 in situ and remote sensing observations be combined to yield realistic large-scale measurements, e.g., when observing and distinguishing different algal groups?
- How can the data be made publically available in an easily accessible and comprehensive way?

## Scientific Questions

- What are the relevant short-term physical processes of the North Sea and Wadden Sea and how do they influence their biogeochemical and biological dynamics?
- How important are extreme events (e.g. storms, extreme winters) for the hydro-physical environment in comparison to regular tidal dynamics or general trends?
- What impact have long-term anthropogenic changes on natural processes, 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 Wadden Sea and North Sea?
- What are the driving factors for algal blooms?
- What are the effects of offshore wind farms on the physical dynamics, mixing, sediment transport, or biogeochemical processes of the North Sea?

# Implementation of COSYNA

The Helmholtz-Zentrum Geesthacht received about 9 M€ of investment capital from the German Federal Ministry of Education and Research for construction and development of 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 maintenance is provided entirely by the Helmholtz-Zentrum Geesthacht and its partners.

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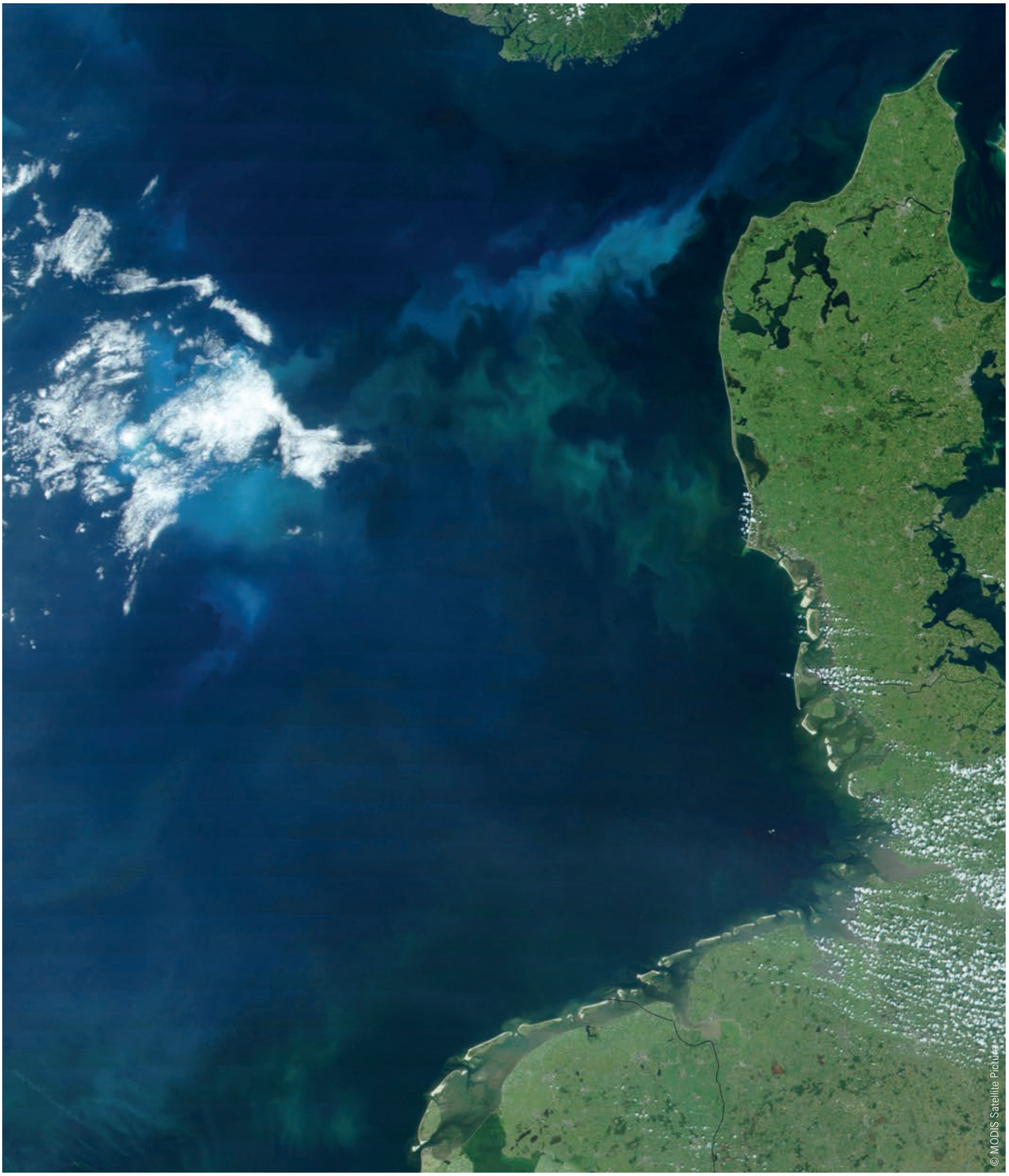
# Integrated Approach – from Data to Information

COSYNA is a unique system that offers a new level of marine monitoring methods. Its main characteristic is the integrated approach combining observations and numerical modelling in order to reliably deliver quality-controlled data as well as model predictions. It is used to answer scientific questions and to help inform political decision makers. COSYNA is run as a pre-operational system, i.e., it is not experimental but geared toward a later operational use.
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 centre 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 nested models with different grid sizes for hydrography (temperature, salinity, waves, currents), for suspended matter and for biogeochemical and ecosystem processes. By using sophisticated data assimilation procedures, i.e., continuous corrections of the models by observations, the reliability of now-casts and short-term forecasts is improved substantially.

One important motivation for COSYNA 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 marine state. The data and plots are available through a data portal (www.cosyna.de/data). To further reach out to stakeholders and the wider community an app has been developed for the most common platforms (see figure below).
This integrated approach provides a versatile tool for understanding and predicting processes and the state of the North Sea and the Arctic coasts. By providing infrastructure as well as various information products, COSYNA has immediate benefits for coastal management and for marine science: COSYNA's components are not only available to and accessible by German research institutes, that already take significant responsibilities in setting-up, maintaining and working with individual components, but are also available to the worldwide science community. By bringing together the expertise of the main institutions ('marine excellence pool') COSYNA also plays an outstanding role in the integration of marine sciences in Germany.


An interactive COSYNA app provides short texts and pictures on the COSYNA measuring systems, models and products. A highlight is that users can access the near-real time data from the various stations with one click via internet. The app was developed and commissioned together with the Public Relations department at HZG.

# COSYNA Focus Regions – German Bight



# The North Sea

The North Sea is a shallow shelf sea in Northern Europe characterized by complex interdisciplinary processes taking place on 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, balances, 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. Especially the extensive development of offshore wind farms requires sound environmental statistics and improved forecasts for planning and operation, while their influence on the hydrodynamics of the North Sea is still poorly understood.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# Arctic Coasts

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.

At Spitsbergen, COSYNA is using methods that have been developed and proved in the North Sea. Automated measurement stations, such as underwater nodes and stationary FerryBoxes are used to measure turbidity, oxygen, coloured dissolved organic matter (CDOM), and methane, as well as temperature, salinity, and pH. Such automated systems allow measurements in harsh environmental conditions year-round that are otherwise almost impossible and very expensive to carry out.


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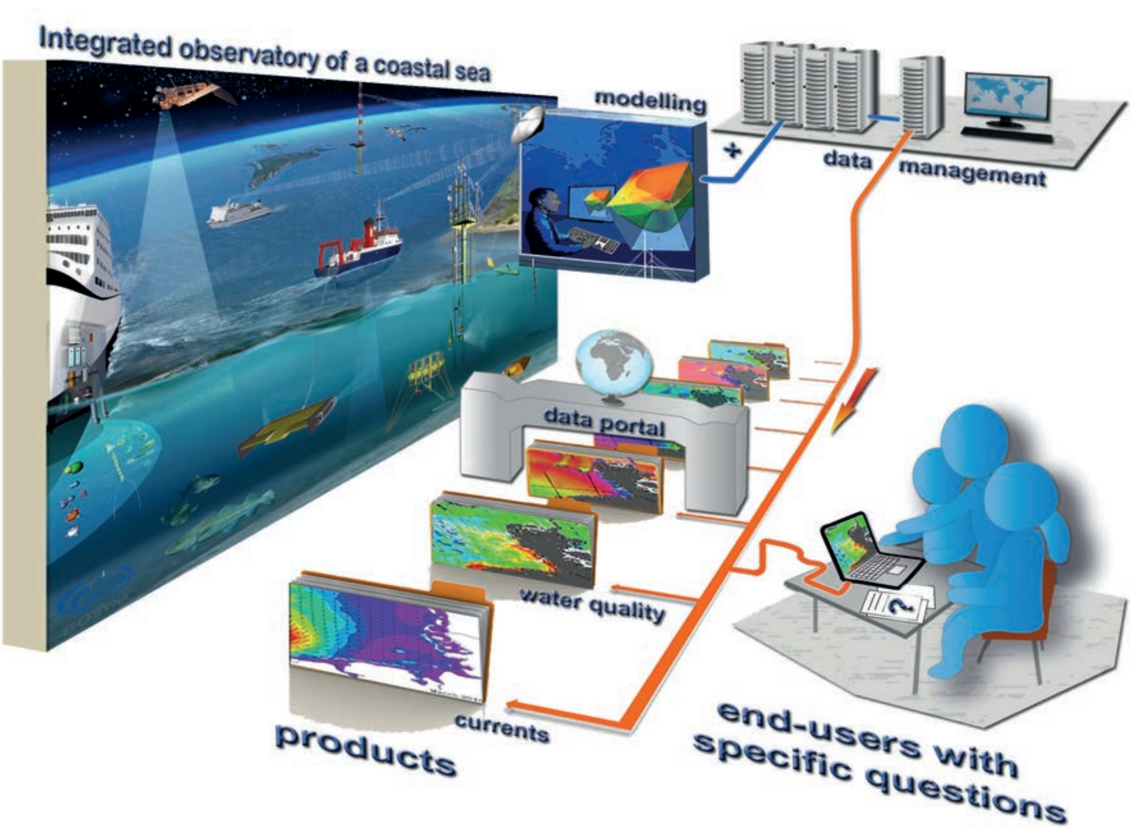
# COSYNA Products

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.

Future products will include wind fields, ship detection, 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 cooperates with government agencies, which, at some stage of the product development, could convert the pre-operational to operational products.

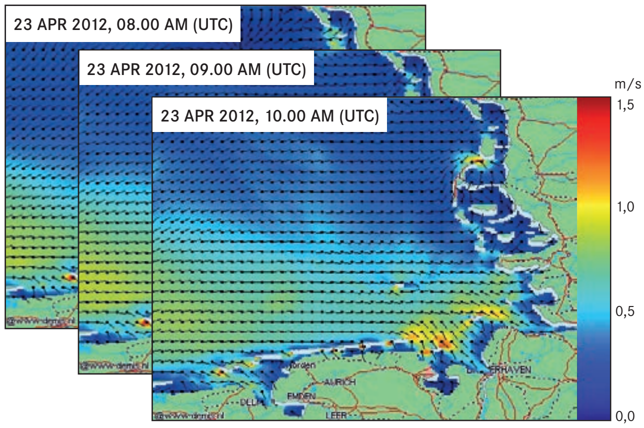
One of the first COSYNA products is the pre-operational analysis system for current fields in the German Bight based on real-time HF radar data.



# COSYNA Products

## Surface Current Fields in the German Bight

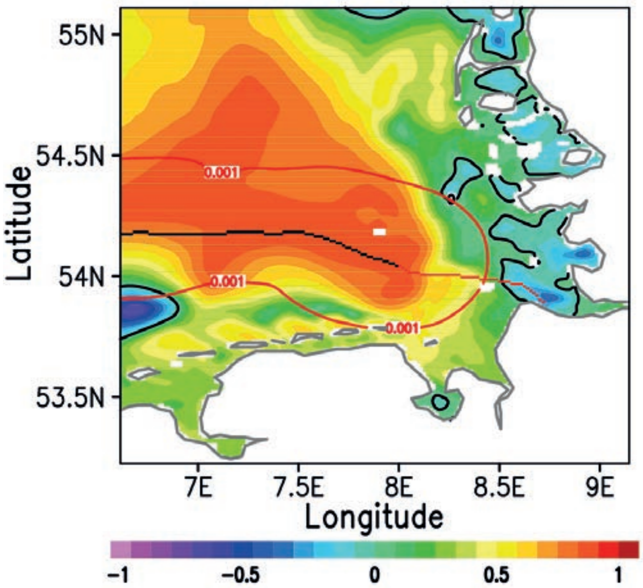
Surface current data from three high-frequency (HF) radar stations at Wangerooge, Büsum, and Sylt is continuously measured and transmitted in "real time" to the Helmholtz-Zentrum Geesthacht. After automated quality control, current vectors are calculated. Every hour, these data are linked to and assimilated 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 tidal signal is well represented.
The deviation from the measured HF radar current data is typically about 0.1 m/s, with large spatial variantions. Time series of current maps are publicly available for download from the COSYNA data portal. They can be utilized, for instance, for ship traffic safety, for the spreading of pollutants, or for rescue operations.




COSYNA Product: Currents in the German Bight, snapshots from 23 April 2012.

## Temperature and Salinity

Automated FerryBox systems provide valuable information on the spatial distribution of sea surface temperature (SST) and salinity (SSS) in the North Sea. In order to obtain a two dimensional picture of SST and SSS the observations taken along ship tracks are extrapolated to larger areas using additional information from numerical models. For example, data from the route Cuxhaven-Immingham are assimilated into a three-dimensional circulation model. An assimilation step is performed every 24 h. The output is validated against an independent data set (the MARNET Deutsche Bucht station). Misfits of SST and SSS in the free run are corrected almost completely after data assimilation. FerryBox data can locally enhance SST fields of the German Bight (up to ± 40 km apart from the track).




COSYNA Product: Temperature and Salinity. Skill of the SST data assimilation (in best case skill =1). The red line indicates the area beyond which the influence of FerryBox observations was reduced with a filter to avoid unrealistic SST fields.

## Waves

The pre-operational COSYNA wave forecast model system runs twice a day at 0 and 12 UTC and provides a 24 hour forecast on the regional scale for the North Sea and on the local scale for the German Bight. With boundary information from the regional wave model EWAM of the DWD a number of wave parameters such as significant wave height, period, and total wave direction are calculated. Wave rider buoys serve for validation of the model outputs.

# Stationary Platforms

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, existing and planned offshore platforms (e.g., FINO3; photo on right), and wind energy installations provide power and broadband capacities to operate FerryBoxes and wave radars. Smaller, self-contained poles in the Wadden Sea (see figure below) and at the mouth of the Elbe record data used to study the exchange of energy and matter between the shallow, intertidal near-coastal basins and the German Bight.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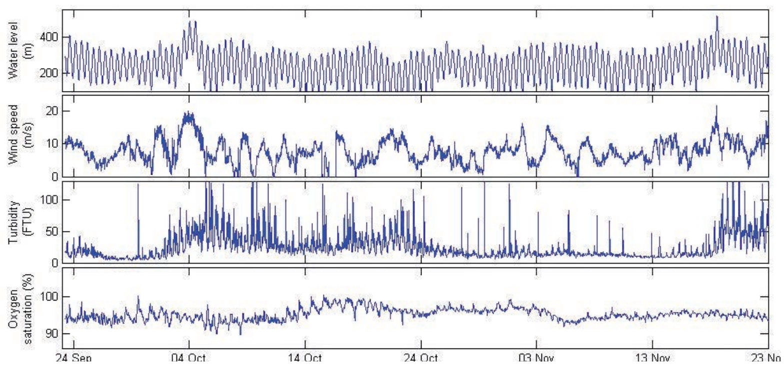
**Parameters**

**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 in the Hörnum Deep, south of Sylt Island. From top to bottom, water level, wind speed, turbidity, and oxygen saturation are shown for two months.
High wind speeds, on 4 October 2009 and 19 November 2009, influence the water level (inflow of North Sea water into the Hörnum Deep), and led to higher erosion rates that are mirrored by an increase in turbidity.



# Surveys with Research Vessels

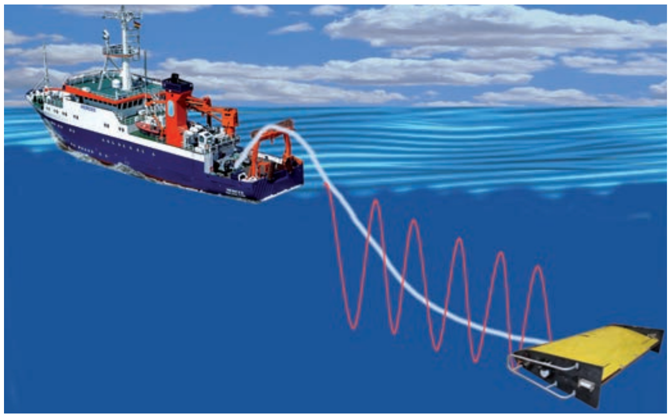
Research cruises across the German Bight complement the regular in situ stationary and ship of opportunity observations. They provide a quasi-synoptic overview of the German Bight. The regular repeated ship-tracks criss-cross the North Sea (see figure of results below) passing by the stationary COSYNA and state 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 equipped with a FerryBox, profiling water samplers and an undulating towed instrument carrier ('Scanfish',™ see on right).

These surveys serve several purposes simultaneously:

- Spatially interpolate observed variables between the locations of the 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.

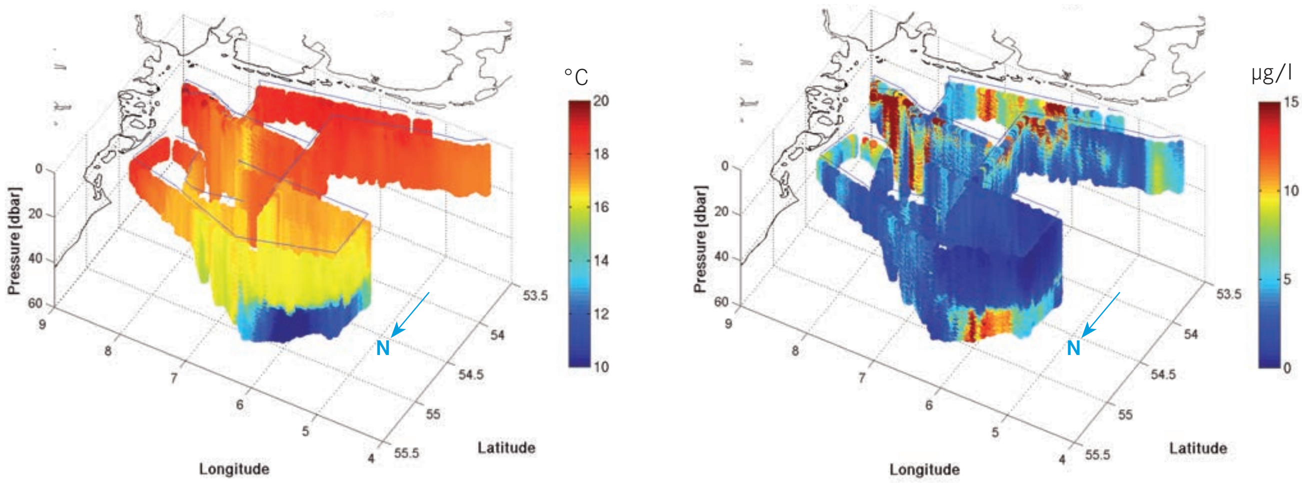
## Scanning the water column

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).



**Parameters**

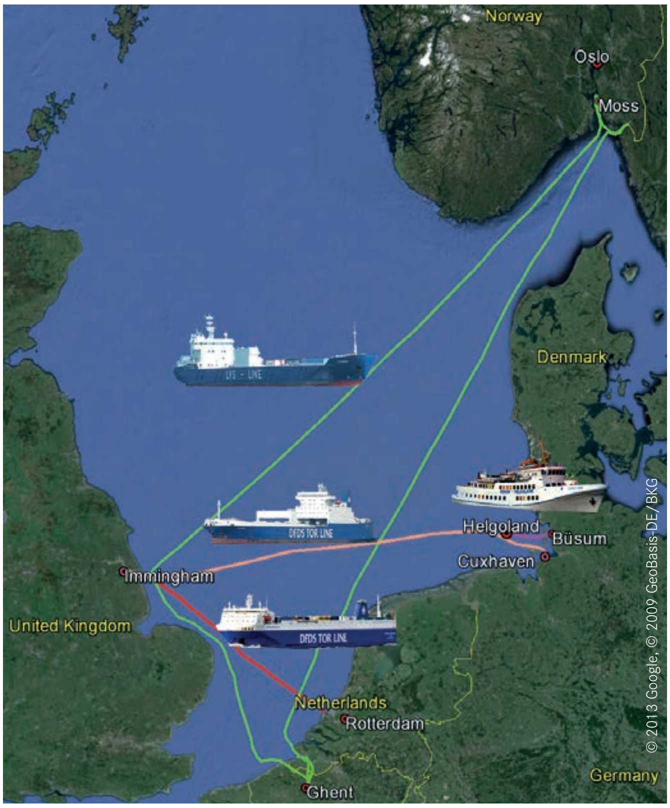
Temperature, salinity, suspended matter, chlorophyll, oxygen, local water depth




Quasi-synoptic view of water temperatures (left) and chlorophyll a-fluorescence (right) from Scanfish™ data during a 10-day cruise in the German Bight, 28 July to 5 August 2009. Note the high fluorescence values in the cool deeper water layer in the north-west corner of the survey area indicating large phytoplankton concentrations in the lower and darker water column. (Note: Map not adjusted to north.)

# 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 across the North Sea (see picture, right) or are operated as fixed installations (Cuxhaven, Spitsbergen, and the measurement platform FINO3). 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. All processes can be controlled remotely via satellite from land. Data are transmitted and made publically available after each transect. The automated regular recordings by the FerryBoxes enable detailed investigations of physical and biogeochemical processes and are, for instance, assimilated into models.

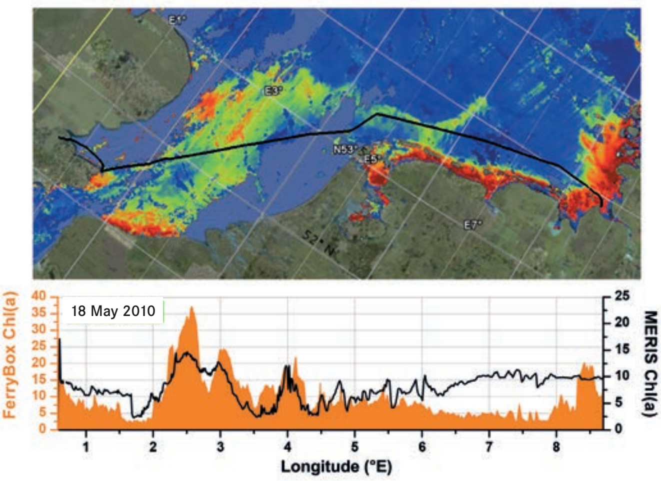



### Parameters

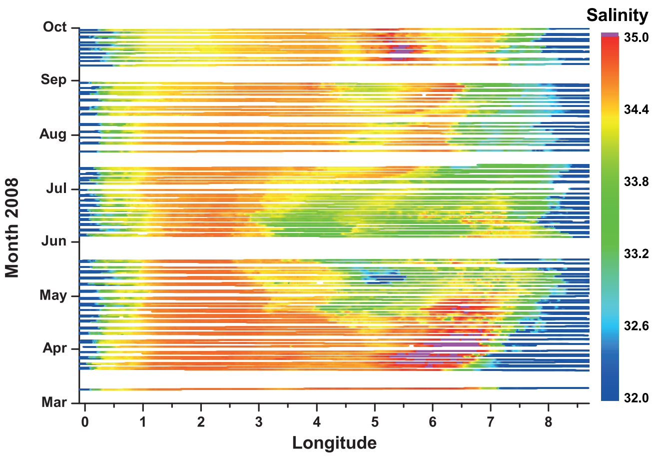
Temperature, salinity, turbidity, chlorophyll, pH, oxygen, algal groups, nutrients, automatic water samples for further lab analysis

### Future

pCO2, alkalinity, flow-cytometer, gene-probes




Measurement of Chlorophyll: Comparison between FerryBox and MERIS satellite data (relative units, 18 May 2010, time difference between the measurements is less than half a day). Differences can be explained by the different methods: MERIS: light absorption; FerryBox: Chlorophyll-fluorescence.



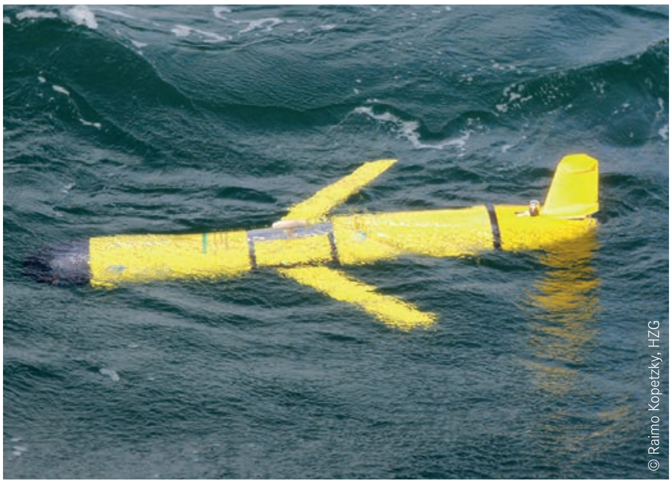

Salinity on transects between Immingham (UK) and Cuxhaven (D) in 2008. Differences in salinity are governed by river discharge, precipitation, and evaporation. In May, low salinity represents inflow of Rhine river discharge.

# Three Dimensional Transects – Gliders

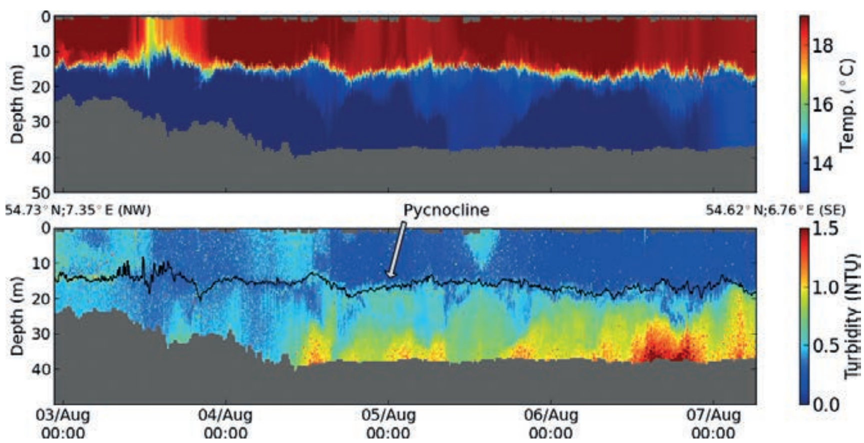
Underwater gliders are autonomous underwater vehicles designed for long-term (weeks to months) survey missions. By actively changing their buoyancy the gliders dive and climb using very little energy. Small wings propel the glider forward, creating a saw-tooth shaped path. Typically, a glider performs 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 sensor data as a proxy for sediment concentration.

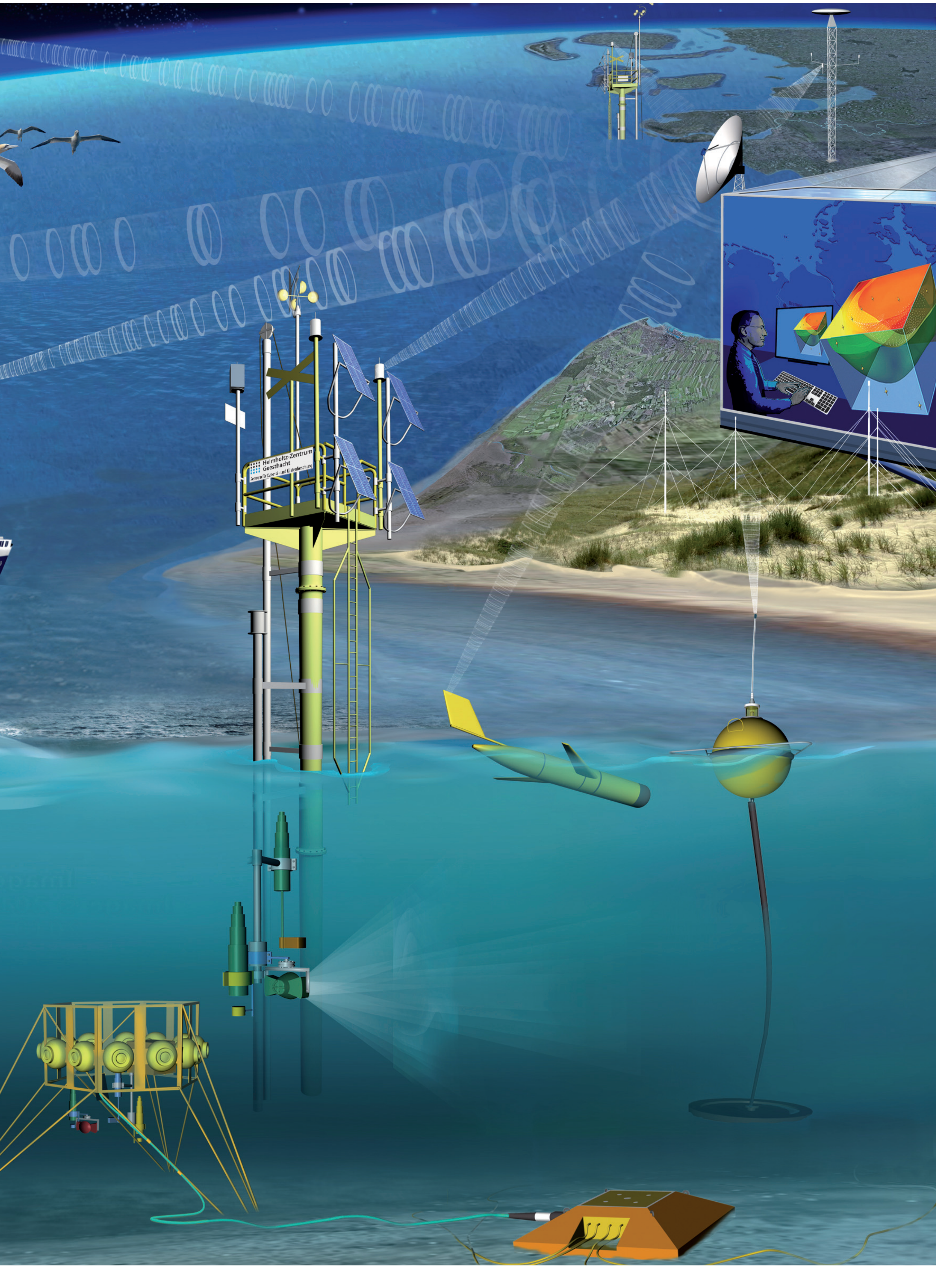
In the future, the gliders will be equipped with turbulence microstructure sensors aiming at providing new insights in the mixing of temperature, salinity and suspended sediment. These highly sensitive sensors need a virtually vibration-free platform to operate from, a requirement the gliders match almost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




**Parameters**
Temperature, salinity, suspended matter (optical backscatter), chlorophyll, depth-averaged currents, microstructure (optionally)



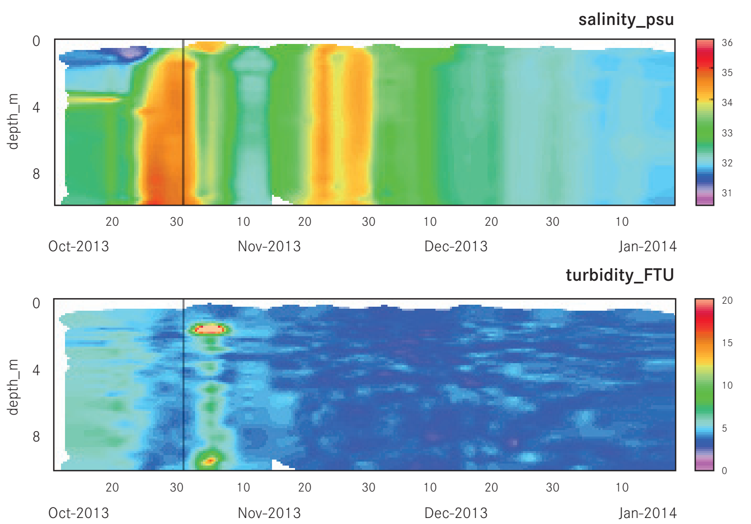

A 30 nm (nautical mile) transect measured in the German Bight during August 2013. The top panel shows the temperature and the bottom panel shows the measured turbidity The water column was stratified with a pycnocline at around 15 m depth (top panel). Sediment resuspended from the sea bed, was well-mixed vertically, but only up to the pycnocline, represented by the black solid line (bottom panel). This is due to the strongly damped turbulence at the pycnocline locally inhibiting the upward transport of suspended sediment.


Helmholtz-Zentrum
Geesthacht

# 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. 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. 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. In 2014, two COSYNA Underwater Node Systems are in operation, one in the Southern North Sea off Helgoland and one in the Arctic Ocean at 79°N off Spitsbergen (see figure below). An additional system is planned for the time-series station Boknis Eck in the Baltic Sea. All data are transferred to the users at 100 MBit/s (max. 1 GBit/s). 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 COSYNA underwater node system at Helgoland (left) and in the Arctic Ocean at Spitsbergen (right).




Salinity and turbidity 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 10 October, 2013, and 20 January 2014.

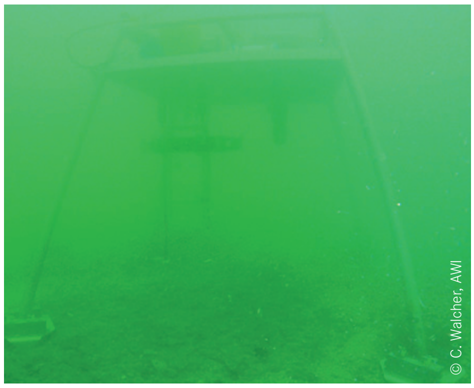
# Seafloor Instrument Frame - Lander

Processes on and in the seabed play an important role in the state and natural dynamics of North Sea habitats. In addition to ongoing ship-borne field, autonomous near bed measurements are required to understand the highly dynamic physical and biogeochemical processes interacting on the seabed. Newly developed in situ sea floor observatories are used to directly measure currents, turbulence, sediment transport and biogeochemical nutrient budgets in and on the sea floor. These 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. They operate autonomously for hours up to several days, allowing measurements in high spatial and temporal resolution even under storm conditions. The "landers" are positioned on the sea floor following hydro-acoustic and photographic pre-site surveys.

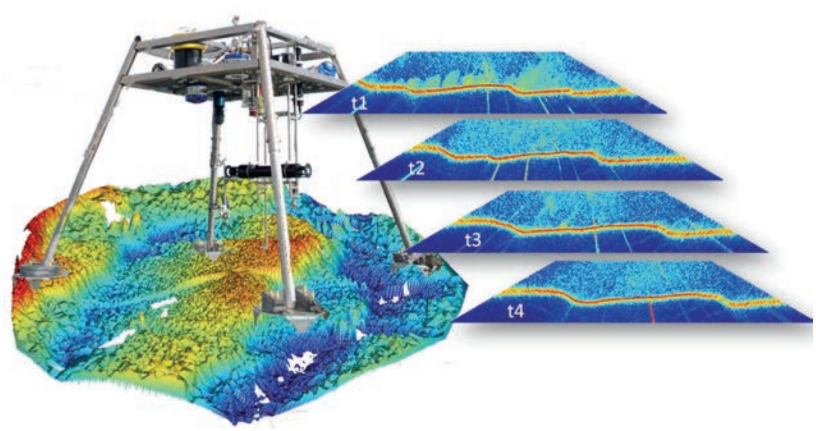
The SedOBS (Sediment Dynamics Observatory) lander has been assembled with the aim of a consistent high-resolution dataset on the interaction of microbathymetry (dynamics of sediments, bedforms, fauna on the seafloor), flow structures (like currents, turbulent patterns), sediment transport on the bed and in the lower water column, and biogeochemical parameters such as oxygen, pH, salinity, fluorescence (see figures below). SedOBS is operated by the Center of Marine Environmental Sciences MARUM in co-operation with the Helmholtz-Zentrum Geesthacht.
The benthic lander NusOBS (Nutrient and Suspension Observatory) was developed to study biological, sedimentological and geochemical exchange processes between the sediment and the water column. It is operated by the Alfred Wegener Institute. The lander is equipped with several sensors and sampling devices for biogeochemical parameters such as nutrients, oxygen and pH. Two benthic chambers carry out in situ incubations at the sediment water boundary.

**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



Underwater photo of the SedOBS lander at a shallow water deployment in a very heterogeneous sedimentary environment near Helgoland, German Bight.

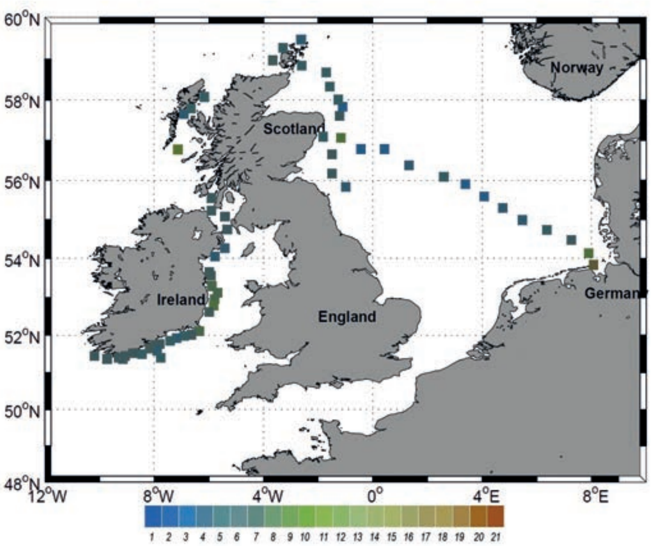


The complex 3-dimensional topography of the seafloor, the interaction of hydrodynamics and small scale bedforms, seen in the local suspension of sediments on the backs of the bedforms (t1) and the rapid adaptation of the bedform geometry to the tidal currents (t2-t4).

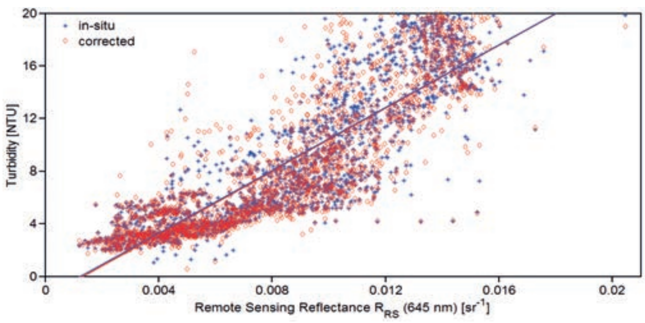
# Hyperspectral Optical Observatory

Ocean colour measurements offer a non-invasive approach to monitoring and assessing marine ecosystems at different spatial scales. This approach is challenging in coastal waters, shelf seas, and polar waters, as they are known to be optically complex. As part of COSYNA, hyperspectral radiometers mounted on stationary and mobile (e.g. ship-borne) platforms are used to investigate the 'bio-optical state' of the sea, i.e., the colour of seawater producing constituents, to improve the interpretation of ocean colour in optically complex waters. The major problems in this environment are surface reflected glint, sea conditions, and meteorological conditions. Mitigating these perturbations will allow us to distinguish different seawater constituents that interact with solar radiation from ocean colour products. Bio-optical models that have been developed using ocean colour products predict e.g. turbidity with good accuracy. The Institute for Chemistry and Biology of the Marine Environment at the Carl von Ossietzky University Oldenburg performs these investigations in co-operation with the Helmholtz-Zentrum Geesthacht.

**Parameters**
Chlorophyll, CDOM, suspended matter / turbidity


Map showing approximated colour of seawater from sampled stations during the field campaign during R/V Heincke cruise HE302 between 21 April and 14 May 2009.

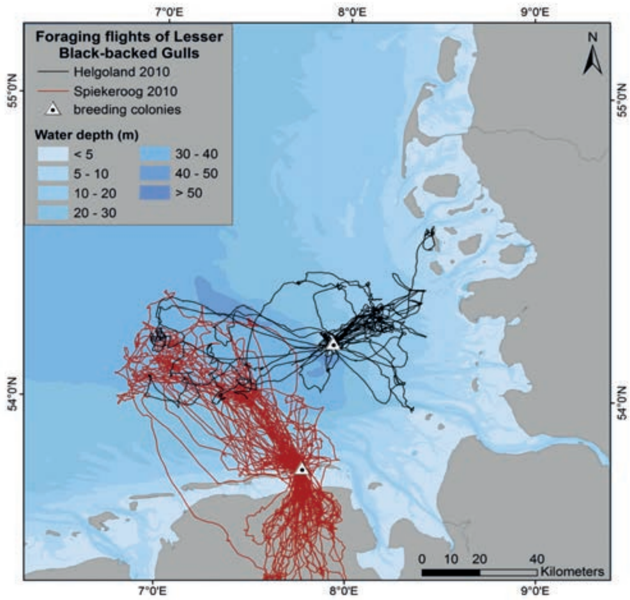



Remote sensing reflectance is correlated to turbidity: Correlation between raw in situ (*) and smooth corrected (◊) turbidity and mean remote sensing reflectance (RRS, 645 nm) between August and October 2013. The linear fits are blue for in situ and red for corrected turbidity.

# GPS Telemetry of Seabirds

As top predators, seabirds depend on marine resources and, accordingly, are sensitive to environmental changes. Thus, any changes in their foraging behavior indicate changes in the marine environment. The use of GPS data loggers allows comprehensive tracking of foraging and flight patterns. Rapid ongoing advances in data logger development offer more and more possibilities: Devices become lighter and more efficient and can be applied to a great variety of seabird species. For instance, solar cells provide long-time tracking for several weeks or even years. Individuals are caught by walk-in traps on their nest and the devices are fixed on the birds' backs by Teflon® tape around their legs or wings. Besides information about seabird flight patterns, e.g., foraging hotspots, flight speed and altitude, data loggers can record the birds' diving depth, pressure and surrounding temperature. Combining these data with environmental parameters from COSYNA measurement stations, e.g., salinity, sea surface temperature or chlorophyll, facilitates the understanding of the seabirds' foraging behavior, their food intake and habitat choice. In turn, the recorded spatial and temporal flight patterns of equipped seabirds can be used as indicator for characterizing the environmental status of the North Sea to a certain extent. The tracking studies are carried out within the COSYNA framework by the Research and Technology Centre at Christian-Albrechts-University of Kiel. Study species are, e.g., Northern Gannets (*Morus bassanus*) and Lesser Black-backed Gulls (*Larus fuscus*).

**Parameters:**
**Bird's diving depth, pressure, and surrounding temperature, foraging hotspots, flight speed and altitude**



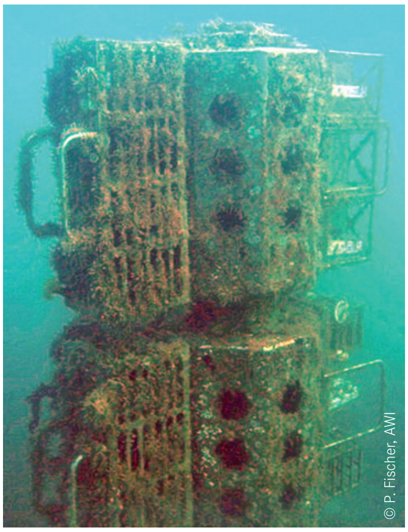

Foraging flights of Lesser Black-backed Gulls (*Larus fuscus*) from Helgoland (n = 5) and Spiekeroog (n = 8), in 2010.



Example of a solar GPS data logger (e-obs, Munich, Germany) attached on an Eurasian Spoonbill (*Platalea leucorodia*) on Oland, Germany, in 2012.

# Instrument Development – Pollutant Sampling

Integrative (over a period of time) observation/sampling is achieved by passive, membrane- based sampling tools (passive sampler) as well as by using immobilized sentinel marine biota such as blue mussels (active sampler). In a „Caged Mussel Approach“ standardized mussels of known origin are continuously deployed at two COSYNA stations, allowing a targeted, spatially resolved monitoring as well as a repetitive sampling for time series or trend analysis. Within this context, the blue mussel (*Mytilus edulis*) represents a well-investigated indicator organism, its body burdens of anthropogenic contaminants reflect the current state of the environment.
Two new experimental platforms (near Helgoland as a part of the underwater experimental site “MarGate”, and at the “Seebäderbrücke” in Cuxhaven directly beside the fixed Ferrybox container) have been developed by the Helmholtz-Zentrum Geesthacht to investigate the potentially hazardous effects of contaminants in coastal and marine environments. The integrative sampling techniques provide information about time weighted average contaminant concentrations. Averaging often generates data that represent the state of the environment better than data generated by conventional spot sampling.




**Parameters:**
**Chemical:** Time weighted average concentrations of trace elements and element species, trace element body burdens, trace element water and suspended particulate matter (SPM) concentrations
**Biochemical:** Effect biomarkers
**Technical:** Mussel and passive sampler deployment, SPM collection

# Instrument Development – Zooplankton Recorder (MOKI)

Rapid mapping of plankton abundance in combination with taxonomic and size composition will be undertaken using the zooplankton recorder MOKI (figure right: a predecessor type). The zooplankton recorder can provide high-resolution images of minute objects below 100 µm. Its modular configuration enables the device to be towed by research vessels, to be a component of the FerryBox or to be installed on unmanned platforms, or underwater nodes.

Images of dominant plankton groups can be classified by software and objects can be assigned to their respective environmental parameters: depth, temperature, salinity and oxygen concentration. The instrument has been developed and will be modified and operated by the Alfred Wegener Institute.


**Parameters**
Zooplankton species and size

# Instrument Development – Sensors for pH and Alkalinity

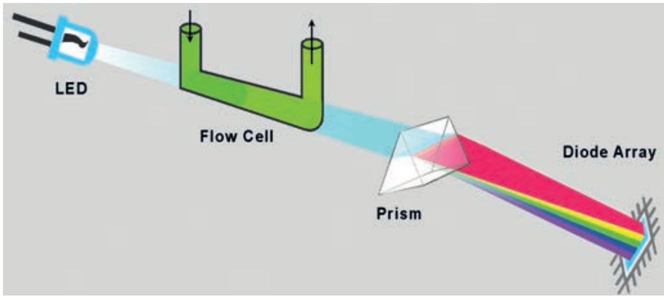
Shelf seas are a critical interface between the land and the open ocean. Consequently, processes in shelf seas play a crucial role in global biogeochemical and carbon cycles and have a significant influence on ocean $CO_2$ storage. Continuous monitoring of the carbon cycle in the ocean is highly relevant to understanding climate change and ocean acidification. To fully quantify the complete carbon system in seawater it is necessary to determine at least two of the five 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.

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. In addition, the pH value can be calculated during the titration procedure, which is needed to determine the alkalinity.

**Parameters**

pH, total alkalinity

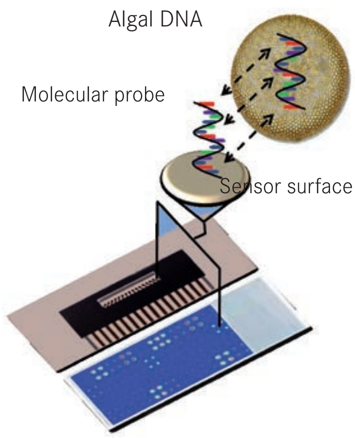



Schematic overview of the measurement principle.

# 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 (sandwich hybridization, figure right). A molecular probe, the detection component, binds to the specific target of interest. In turn, an antibody-enzyme-complex coupled to the signal moiety transforms this detection event into a redox-reaction that can be measured as an electrochemical signal. This technique allows rapid detection and counting of microalgae in complex samples. The main steps are automatically carried out in a portable device.

The detection principle has already been verified. The main challenge for COSYNA is to construct an automated device that (1) reliably filters sea water in order to concentrate algae cells, (2) 'cracks' the cells (lysis) and (3) transports the resulting fluid to the detector. The Helmholtz-Zentrum Geesthacht and the Alfred Wegener Institute operate the instrument jointly.




**Parameters**

Algae taxa and algal groups

# Remote Sensing – Radar

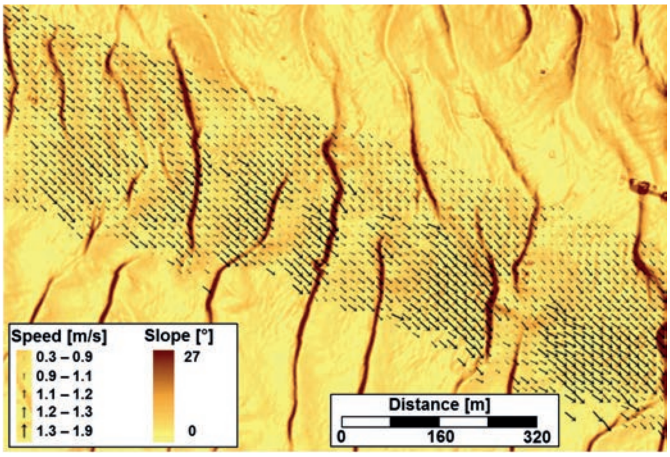
Radar remote sensing is an ideal instrument for monitoring the ocean continuously as it is independent from daylight and weather. Several different types of radar systems are in use at the Helmholtz-Zentrum Geesthacht, Institute of Coastal Research. They are operated from a variety of platforms: Space-borne, 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.

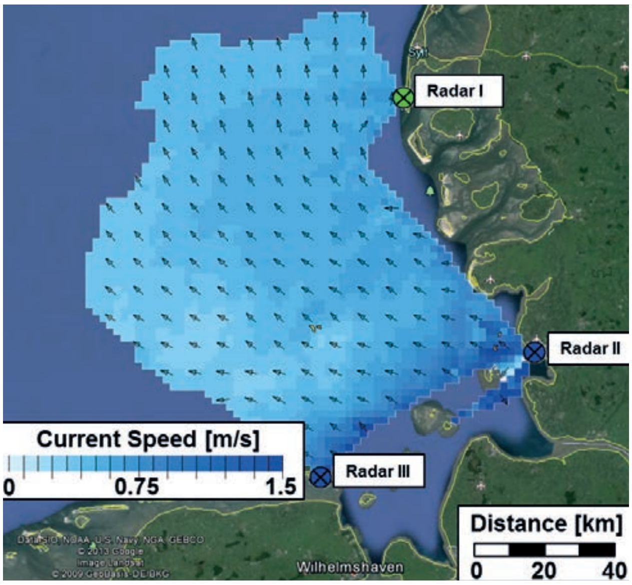
In contrast to the X-band, waves in the high frequency (HF) band (3-30 MHz) propagate along the air-sea interface. This allows the signal to sense the ocean behind the horizon enabling coverage of more than 150 km with a coarse spatial resolution. As part of COSYNA, three HF-radar stations along the 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 m.

**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.

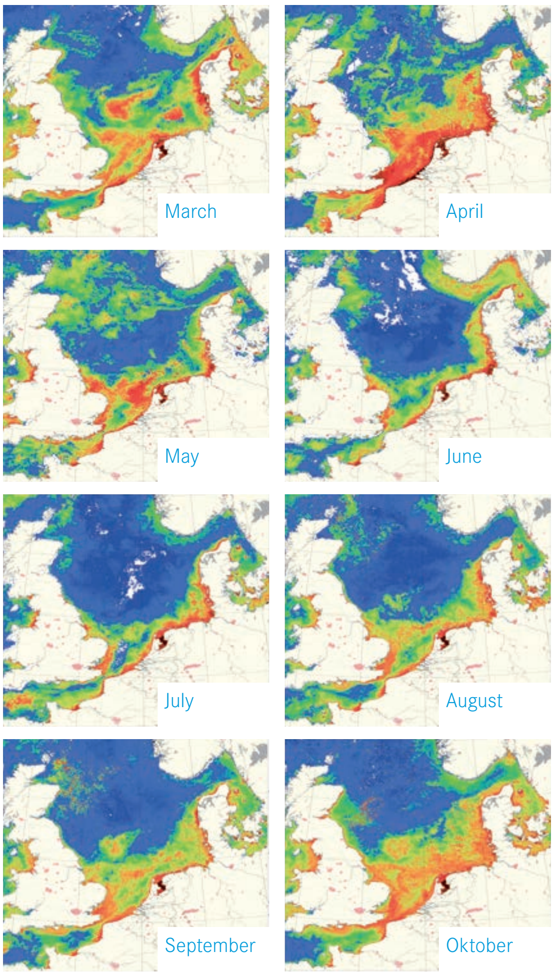
# Remote Sensing – Ocean Colour from Satellites

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 developed at the Helmholtz-Zentrum Geesthacht to reprocess all coastal data from their MERIS 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 17 May 2010 (figure below on the right).

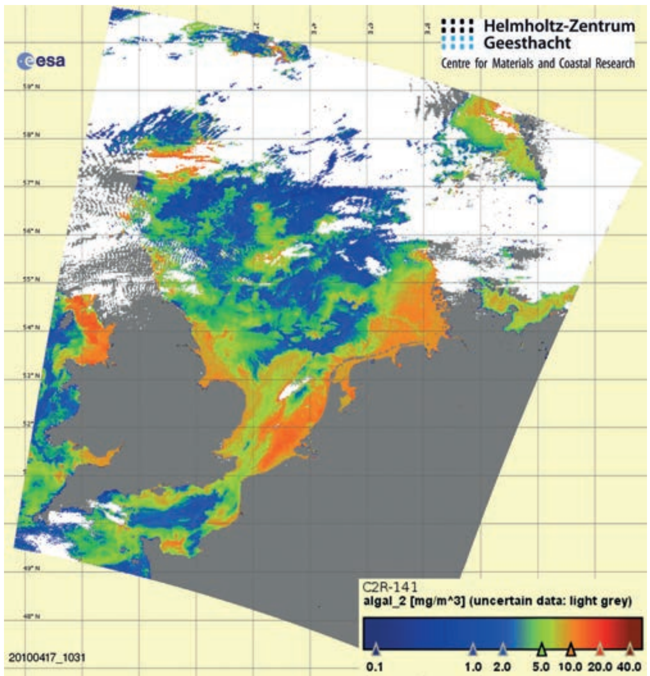
The same algorithm will be used in the future Sentinel-3 mission that is scheduled to launch in 2015.
Monthly means and maxima are derived from the daily fields to obtain an improved understanding of the chlorophyll dynamics and to reduce the effect of cloud coverage on data. The images (below left) show the monthly maximum concentrations of chlorophyll in 2003. They were created by combining many daily scenes for each month. 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



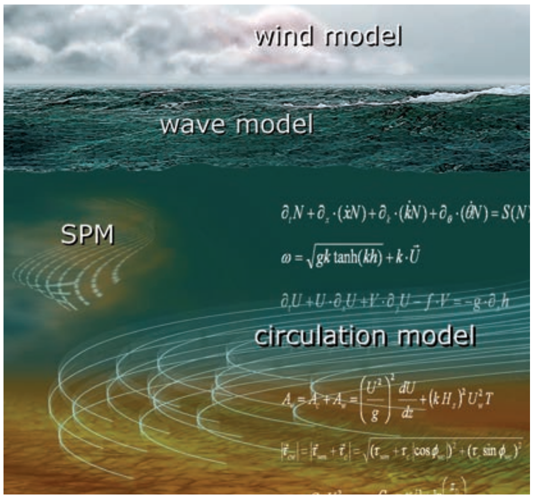

Maximum monthly chlorophyll concentrations in 2003 (from REVAMP Project).




Chlorophyll concentration of the North Sea, 17 May 2010 at 10.30UTC derived from MERIS with the 'Case-2-Regional' Processor. Note that only natural clouds (no contrails) are visible due to airspace closure over Europe.

# Hydrodynamic Modelling

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.

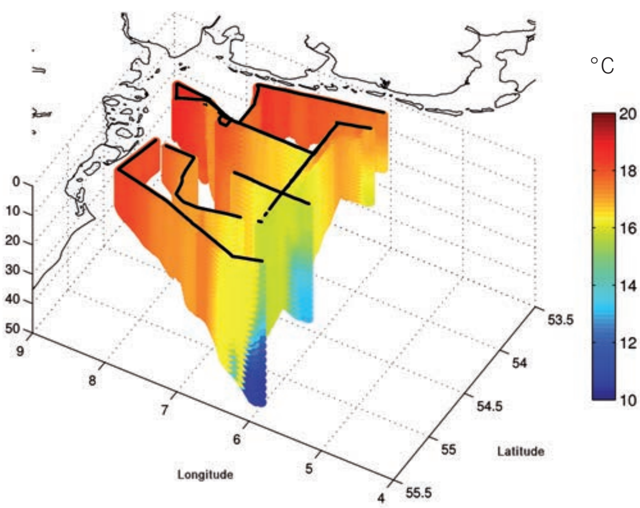



## Circulation Model

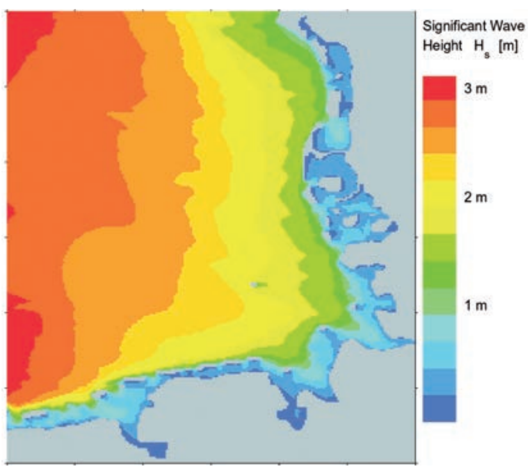
The nested-grid pre-operational circulation model consists of three model configurations: (1) Coarse-resolution outer model for the North Sea-Baltic Sea (grid size about 5 km), (2) fine-resolution inner model (grid size about 0.8 km) covering the German Bight, (3) very fine-resolution model for the Wadden Sea region (grid size about 200 m) resolving the barrier islands and the tidal flats.
Although the simulation of features such as vertical stratification is very complex, the model is in good agreement with observations (figure below).

## Wave Model

The grid-nested COSYNA wave model system provides 24-hour wave forecasts twice a day on a regional scale for the North Sea and on a local scale for the German Bight. Wind fields and boundary information provided by the German Weather Service (DWD) force the forecast runs delivering a number of wave parameters such as wave height, period and direction. As example, the wave heights on 21 April, 2010 in the German Bight at midnight (below) show a typical distribution with low values at the coast and higher values off shore.




Three-dimensional distribution of water temperatures computed with a numerical model. The data are co-located with Scanfish measurements taken between 28 July and 5 August 2009 (see page 11).

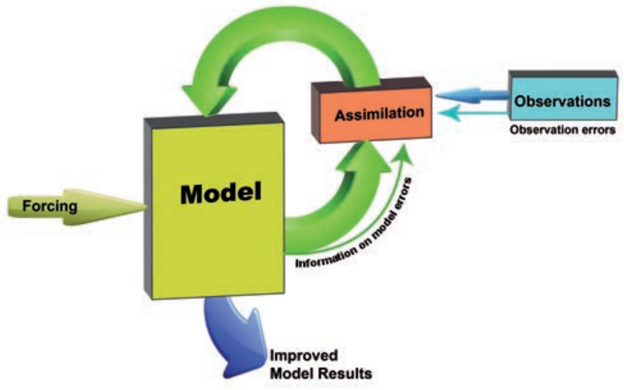



Simulated wave heights in the German Bight (21 April 2010)

# Hydrodynamic Modelling

## Data Assimilation

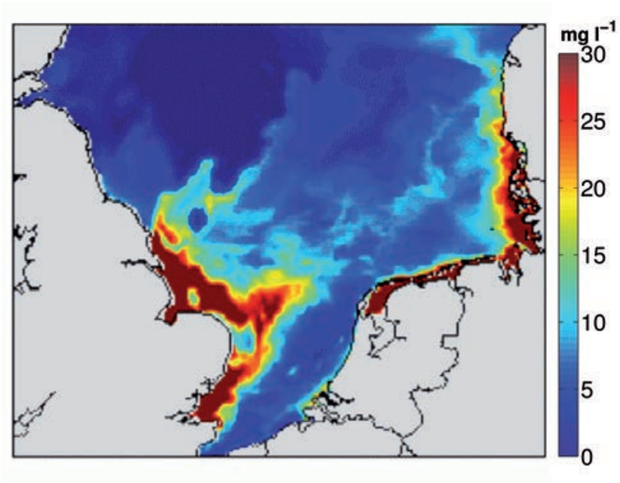
Ocean state estimates provided by numerical models contain errors that increase with prediction time. Errors are due to imperfect model dynamics as well as to uncertainties in the initial state and the forcing fields. Data assimilation is a technique to reduce estimation errors by dynamically consistent combination of numerical models and observations. COSYNA applies different statistical and variational assimilation techniques to correct the model now- and forecasts.



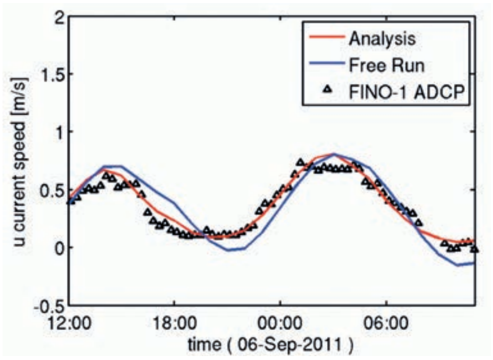

The two figures below contrast model results of the "free" run, i.e., without the use of observations, with the respective data assimilation run using HF radar measurements as additional information. The green arrows in the figure (bottom right) represent observational HF radar data. The data assimilation obviously affects areas beyond the observational coverage. This is nicely demonstrated in the validation at FINO1 (bottom left). Both model results are plotted for two full tidal cycles at the position of the FINO1 platform located outside the HF radar range. Data assimilation forces the tidal phase back in time by about one hour making it more consistent with the ADCP observations. Note that these observations are not included in the assimilation.

## SPM Model

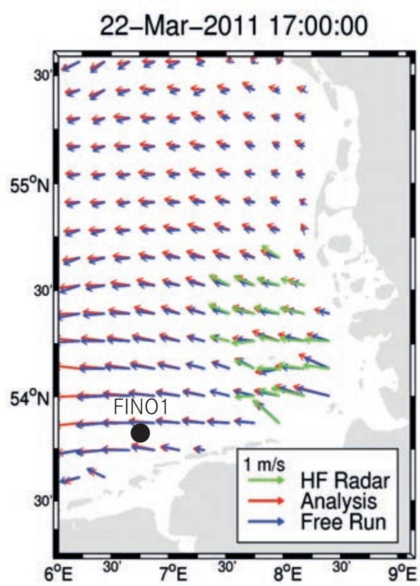
The distribution of suspended particulate matter (SPM) is of primary importance for the ecological status of the sea because it impedes the penetration of daylight into deeper water layers and affects the accumulation of pollutants. The model takes into account advection, vertical exchange processes due to currents and waves, sedimentation, re-suspension, and erosion at the bottom, as well as bioturbation in the sediment.




Typical distribution of modelled SPM concentrations (improved by assimilated satellite data) in mg/l at the sea surface (22 March 2003, 10:20).



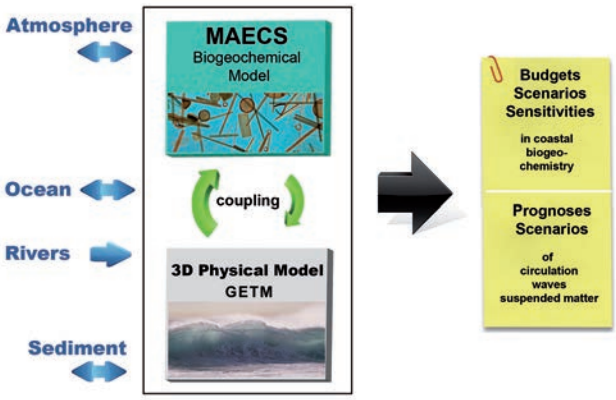

The assimilation of surface current fields derived from HF radar observations. "Free" run and assimilation run (right, 22 March 2011) and validation with FINO-1 ADCP data (left, 6 September 2011).

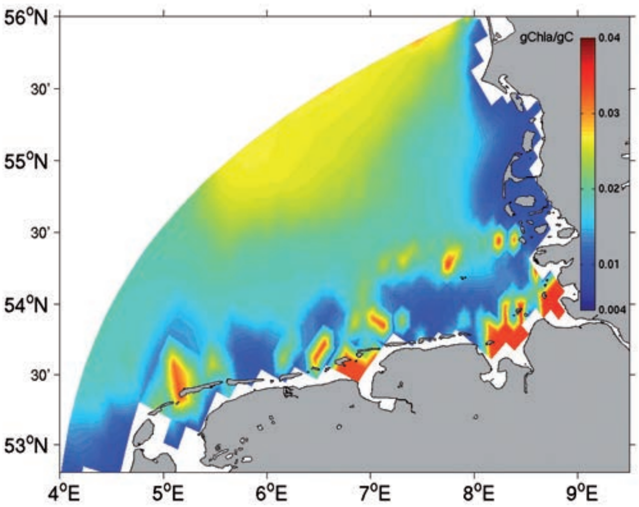


# Biogeochemical Modelling

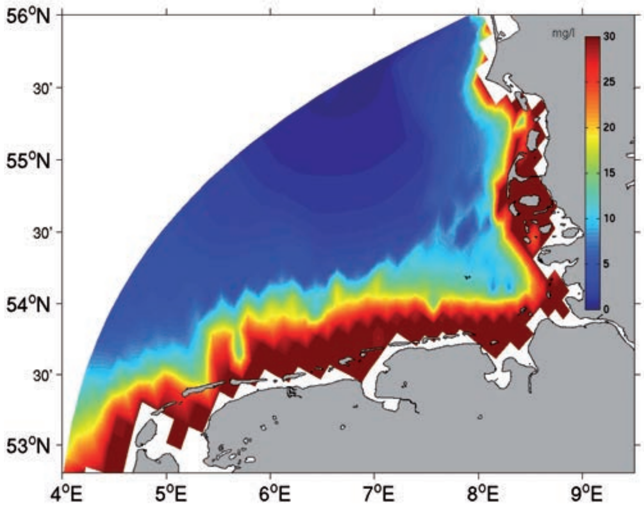
Biogeochemical cycling of matter is characterized by the interaction of physical, chemical and biological processes. Its complexity is enhanced in shallow coastal waters due to a tight coupling of processes in sediments and the water column. Biogeochemical interactions, with various feedback loops, entail highly dynamic carbon, nitrogen, and phosphorus mass fluxes that can be estimated with biogeochemical models. These material fluxes and budgets are of special importance to COSYNA as their contributions to global systems, for instance the role of coastal carbon uptake or release on the oceanic sink for CO2, will become a major research topic.

The Model for Adaptive Ecosystems in Coastal Seas (MAECS) resolves the dynamics of nutrients, phytoplankton, zooplankton, dissolved organic matter, and detritus. Its novelty is the focus on adaptation of biota. MAECS is coupled to the physical General Estuarine Transport Model GETM (see right figure).
In the present version, observations are used to calibrate model parameterisations and to validate the model under a range of boundary conditions. COSYNA observations provide important constraints for flux estimation and magnitudes of spatial and temporal variability. In the future, the assimilation of data into MAECS will improve state estimation, delivering reliable forecasts of ecosystem key-state variables. Two examples of model results are presented in the figures below. First, the models ability to resolve physiological variations of the phytoplankton's cellular Chla:C ratio is relevant when relating nitrogen biomass to observed chlorophyll concentrations. Patterns identify regions with enhanced chlorophyll synthesis, compensating for reduced light availability, e.g., due to deeper mixing or increased light attenuation.  Second, the settling behaviour of suspended matter. Patterns can reflect regions with enhanced aggregation and sinking of algae, exporting organic matter to the sediments.




Chla/C ratio: Surface distribution of Chla:C (gChla/gC) from the shallow Wadden Sea towards the central German Bight.



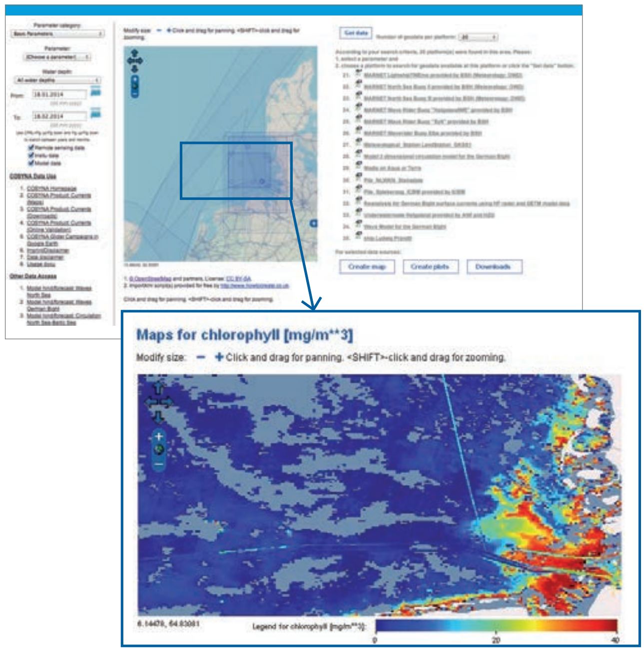

Particulate organic detritus:  Bottom concentration of organic detritus (carbon, nitrogen and phosphorus converted to total mass (mg/l) representing the organic fraction of SPM).

# Data Management

COSYNA data management organizes the data streams between observational and storage systems at Helmholtz-Zentrum Geesthacht and partner sites, the data documentation, and the user interfaces for data retrieval and presentation. The compliance with national and international standards or guidelines for data management and quality control ensures interoperability with other marine/coastal data centres with regard to 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.

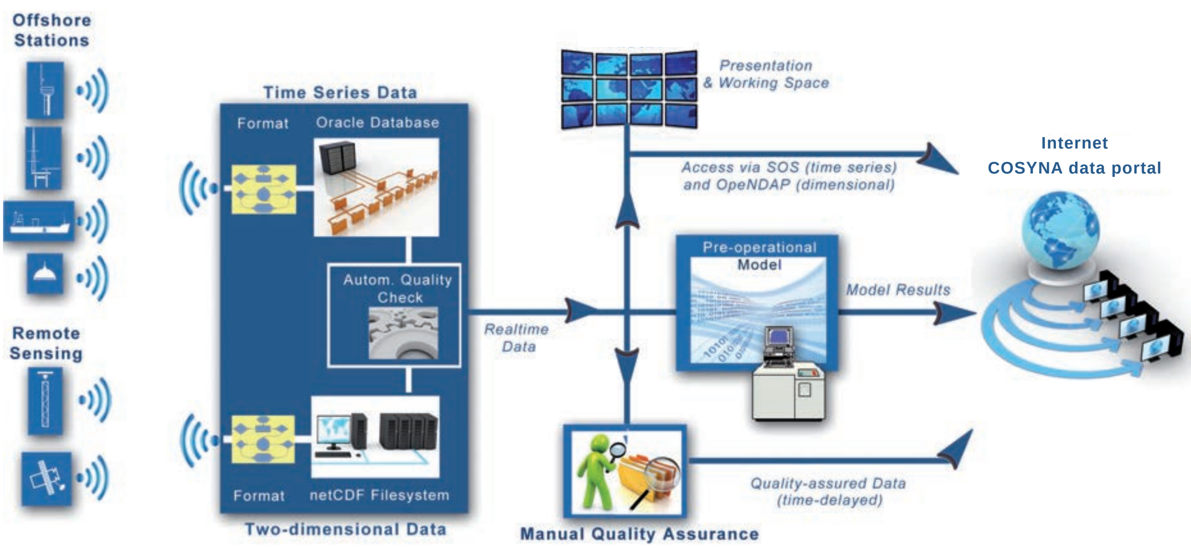
Monitoring the actual state of the ocean and subsequent pre-operational state reconstructions as well as forecasts require fast transmission, automatic quality checks and data assimilation. The COSYNA data portal facilitates the technical aspects of data handling from the data source to the end-user. In the long run, meta, observational and model data will grow into a long-term searchable archive that can be used to detect patterns and trends of physical and biogeochemical quantities in the North Sea 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 data.




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 a combination of FerryBox data and MERIS data for chlorophyll.

## COSYNA data portal: cosyna.de/data



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COSYNA

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