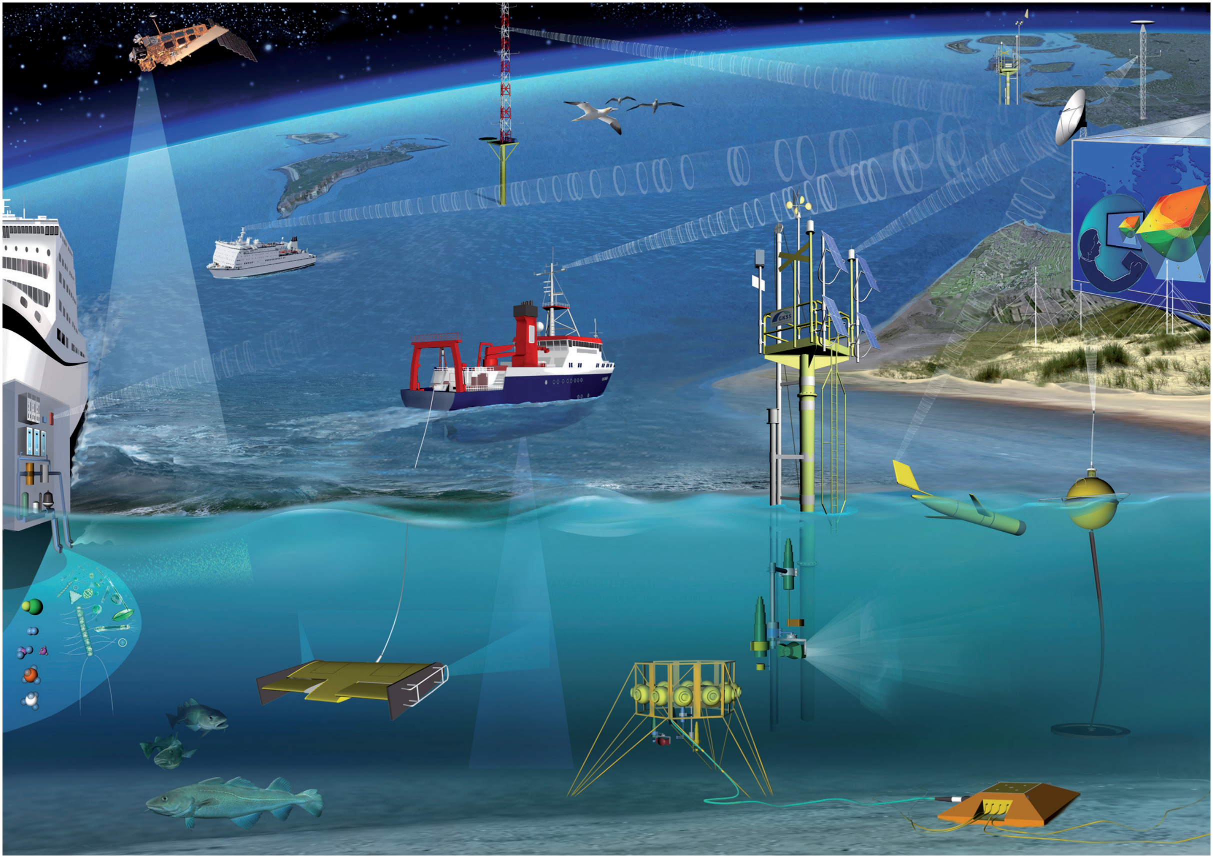
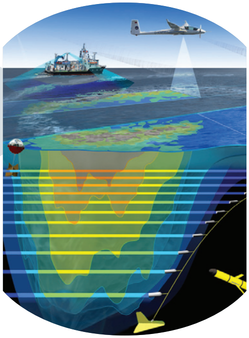
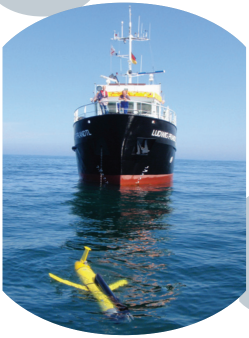
Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

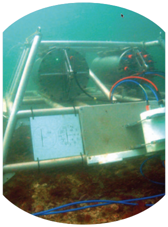
Instrument Development

Research Unit *Operational Systems*










EXPEDITION
UHRWERK
OZEAN
Helmholtz-Zentrum
Geesthacht

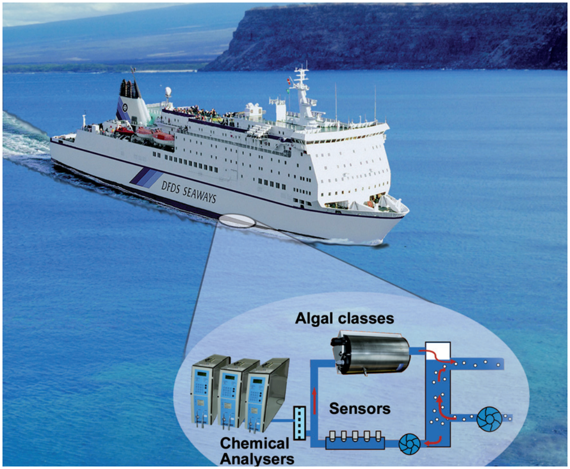
Motivation

The Institute of Coastal Research develops and modifies innovative sensors, instruments and platforms in order to improve the capabilities of its Coastal Observing System for Northern and Arctic Seas (COSYNA) or for observations of small-scale physical and biogeochemical processes. Many of the instruments are developed in cooperation with other research institutions or companies and are highlighted in this brochure.

Baschek, B., Schroeder, F., Brix, H., Riethmüller, R., Badewien, T. H., Breitbach, G., Brügge, B., Colijn, F., Doerffer, R., Eschenbach, C., Friedrich, J., Fischer, P., Garthe, S., Horstmann, J., Krasemann, H., Metfies, K., Merckelbach, L., Ohle, N., Petersen, W., Pröfrock, D., Röttgers, R., Schlüter, M., Schulz, J., Schulz-Stellenfleth, J., Stanev, E., Staneva, J., Winter, C., Wirtz, K., Wollschläger, J., Zielinski, O., and Ziemer, F., (2017): The Coastal Observing System for Northern and Arctic Seas (COSYNA), Ocean Sci., 13, 379-410, doi:10.5194/os-13-379-2017

Content

FerryBox

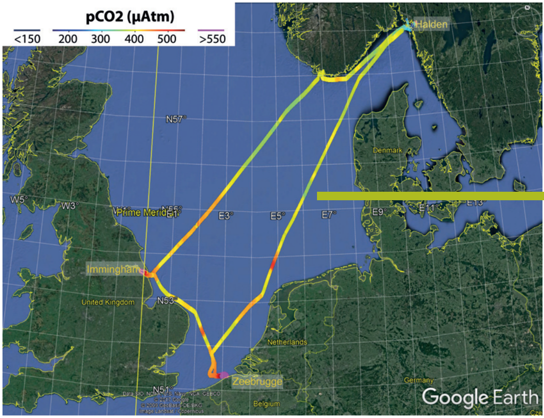


Principle of a FerryBox

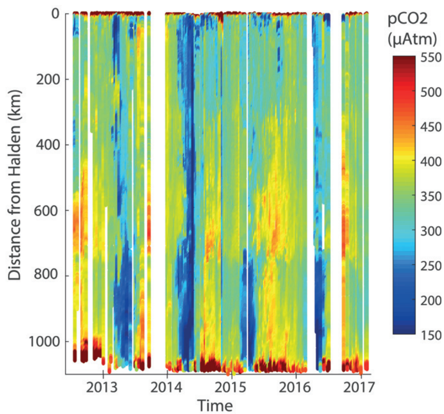
SPECIFICATIONS

Parameters: temperature, salinity, turbid, chlorophyll, pH, oxygen, nutrients, algal groups, pCO_2, alkalinity

Dimension: 50 x 120 x 60 cm



FerryBox routes



Time series of pCO2 from a Ferry>Box (south route)

RATIONALE FOR DEVELOPMENT

A cost-effective and reliable instrument was needed for unattended long-term monitoring of oceanographic and biogeochemical parameters in order to assess the environmental state of coastal waters, such as eutrophication or the carbon budget.

DESCRIPTION

FerryBoxes are flow-through systems that are either mounted on ships of opportunity, or are operated as fixed installations. Ocean water is pumped into a measuring circuit containing multiple sensors. The system is equipped with an automated self-cleaning and antifouling mechanism so that even complex physical and chemical instruments can be used.

The instruments are controlled remotely via mobile phone or satellite connection. Data are regularly transmitted to the COSYNA database and made publically available.
The FerryBox data enable detailed investigations of physical and biogeochemical processes and are also assimilated into models.

TYPICAL RESULT:
Seasonal pCO_2 concentrations

Weekly pCO_2-transects across the North Sea between Norway and Belgium in the years 2013 to 2017 show pCO_2-deficits (blue) in spring when CO_2 is taken up by growing algae (CO_2-sink). In late summer, when algae blooms break down, CO_2 is released (CO_2-source). The results can be used in climate models to assess the role of shelf seas in the carbon budget.

Achievement: Reliable instrument for unattended long-term measurements, broad international use, establishment of European FerryBox data base at HZG.

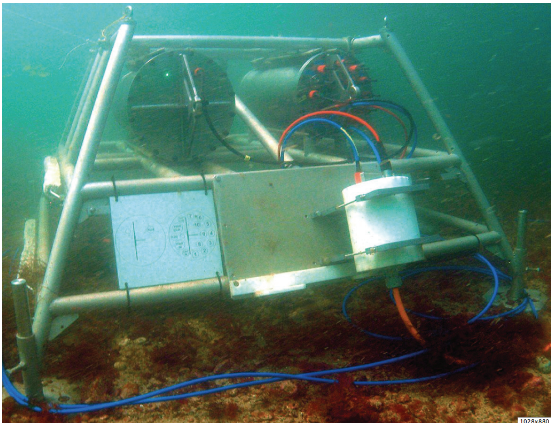
Status: In-house development, commercially available

Partners: 4H jena engineering (license)

Technology Readiness Level 9

Petersen, W. (2014): FerryBox systems: State-of-the-art in Europe and future development. Journal of Marine Systems. doi: 10.1016/j.jmarsys.2014.07.003.

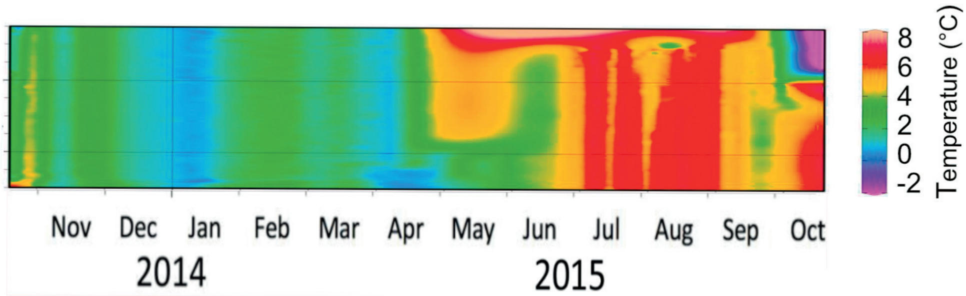
COSYNA Underwater Node System



COSYNA Underwater Node System deployed off the island of Helgoland (photo: P. Fischer, AWI).

SPECIFICATIONS

Power supply, total:	1000 V, 2000 W
Deployment:	near-coast (< 30 km), water depth: <200 m
Data connection:	to internet, 1 Gbit/s
Users:	10 (48 V, 200 W each)



Year-round temperature measured with a profiling CTD connected to a COSYNA Underwater Node System off Spitsbergen, Svalbard.

RATIONALE FOR DEVELOPMENT

Continuous year-round monitoring of hydrographical and biological data with high-frequency and in real-time is required, in particular during extreme conditions, such as storm events or sea-ice. Because cabled deep-sea under-water observatories are not suitable for shallow water applications, due to high costs and harsh environmental conditions, the COSYNA Underwater Node System was developed. It was designed to allow the operation of complex instruments with high power consumption.

DESCRIPTION

The Node is designed for water depths of 10 m to 300 m and comprises land-based power unit and server providing 1000 VDC, a Gbit-network connection, and virtual computer technology for different users. The land-based control system is connected to the underwater units via a fibre-optic and power-hybrid cable of up to 30 km length.
Up to 10 instruments can be connected in a surrounding of 70 m. A secondary and tertiary underwater node unit can be connected thus extending distance from shore.
For this task a development of a new instrument that can be used for unattended operation.

TYPICAL RESULT: Under-ice observations at Spitsbergen (79° N)

A profiling CTD connected to an Underwater Node System delivers year-round data off Spitsbergen. During closed ice cover from November 2014 to March 2015, stratification is weak and temperatures range between 0 and 3 °C. In April, the ice cover breaks up and warmer water from the ocean enters the bay, accompanied by larger turbidity.

This was the first time that continuous observations have been carried out during the winter below the ice.

Achievement: Innovative underwater connection for multiple underwater instruments. Worldwide unique for shallow-water applications.

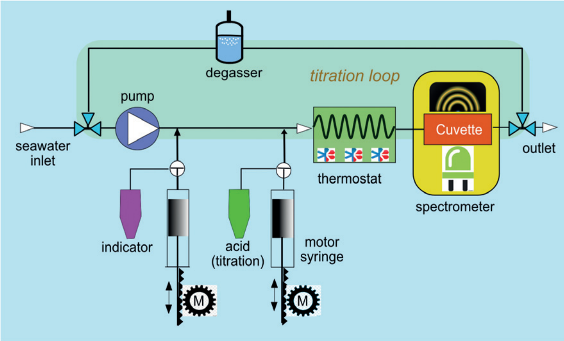
Development: In-house development

Partners: Alfred-Wegener-Institute,
4H Jena engineering GmbH, Loth-engineering GmbH

Technology Readiness Level 8

Fischer, P., Schwanitz, M., Loth, R., Posner, U., Brand, M., and F. Schroeder (2017): First year of practical experiences of the new Arctic AWIPEV-COSYNA cabled Underwater Observatory in Kongsfjorden, Spitsbergen, Ocean Sci., 13, 259-272. doi:10.5194/os-13-259-2017

pH and Alkalinity Sensors



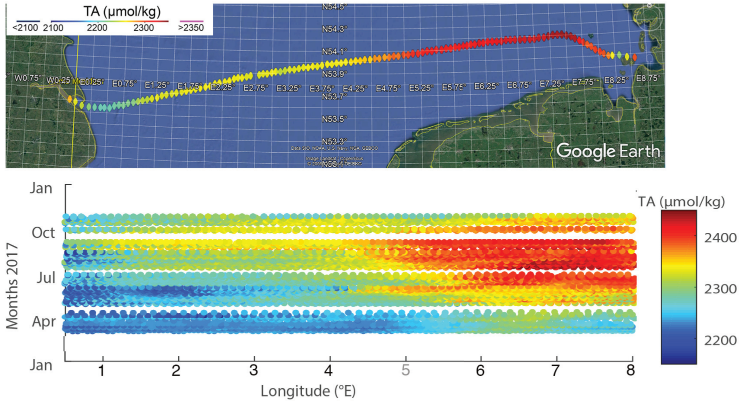
Process scheme of the alkalinity sensor

SPECIFICATIONS

Parameters: alkalinity, pH

Deployment: on FerryBox or fixed station

Resolution: Alkalinity: ±1 mol/kg
pH ± 0.002



Time series of alkalinity, measured from a FerryBox

RATIONALE FOR DEVELOPMENT

The *Total Alkalinity* represents the ability of seawater to resist pH change upon addition of acid. Alkalinity and pH determine how much CO_2 can be absorbed by sea water. For the assessment of the capacity of shelf seas to store or release carbon, a precise measurement of pCO_2, pH and alkalinity is therefore necessary. A new sensor system was developed as no automated instrument for continuous alkalinity detection existed and pH methods were not precise and stable enough over time.

DESCRIPTION

The pH analysis system adds an acid-base indicator dye to a seawater sample. The indicator dye's optical extinction coefficient changes with the acidity of the water sample which can be measured with a spectrometer. No drift occurs and no calibration in the field is needed if temperature and salinity are known accurately.

The total alkalinity is determine with a tracer-monitored titration with a strong acid. The tracer *bromocresol green* allows to measure the concentration of the indicator with spectrometer and, hence, the concentration of the acid.

TYPICAL RESULT:

Seasonal Alkalinity of the North Sea

Regular FerryBox transects between Cuxhaven and Immingham in 2017 show that the highest alkalinity occurs in the German Bight from June to October. This is probably due to alkalinity production in the summer months in the adjacent Wadden Sea and tidal transport into the North Sea. During this time, the oceanic buffer capacity and the uptake of atmospheric CO_2 is increased.

Achievement: Worldwide unique

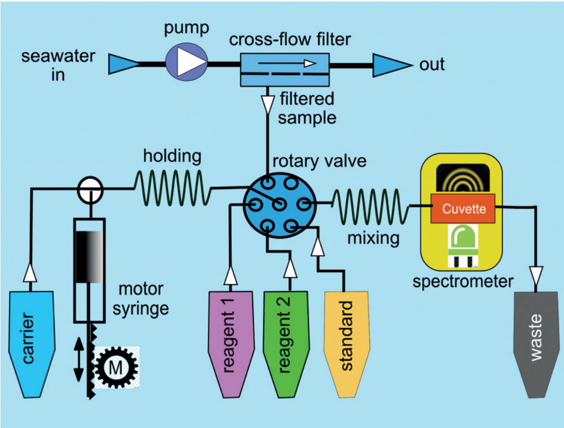
Development: In-house development

Partners: Licensed to Kongsberg

Technology Readiness Level 9

Aßmann, S., Frank, C., and A. Körtzinger (2011): Spectrophotometric high-precision seawater pH determination for use in underway measuring systems. Ocean Sci. 7: 597–607. doi: 10.5194/os-7-597-2011

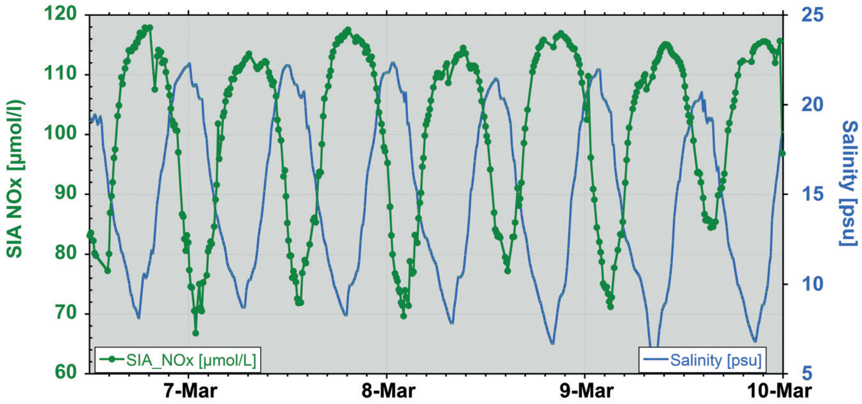
Nutrient Analyser



Process scheme of the nutrient analyser

SPECIFICATIONS

Parameters:	nitrate, o-phosphate, ammonia
Deployment:	on ships or stationary, flow-through system
Resolution:	0.1 µmol/l
Analysis time:	6 samples/h (nitrate) 10 samples/min (ammonia) 50 samples/min (phosphate)
Reagent consumption:	200 µl / measurement



Time series of nitrate (green) and salinity (blue) at the station Cuxhaven in March 2016

RATIONALE FOR DEVELOPMENT

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 20-30 min. 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.

DESCRIPTION

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 1 sample per 10 minutes for nitrate, 1 sample per minute for ammonia and for o-phosphate are achieved.

TYPICAL RESULT: Nitrate concentrations at *Cuxhaven*

A distinct salinity gradient (tidal salinity fluctuations, blue) is observed at the FerryBox station *Cuxhaven*, situated at the mouth of the Elbe estuary.

Since the river water has higher nitrate concentrations than seawater the two curves display opposite trends with the highest nitrate values occurring at lowest salinity. The quick changes can be detected due to the relatively fast analysis times.

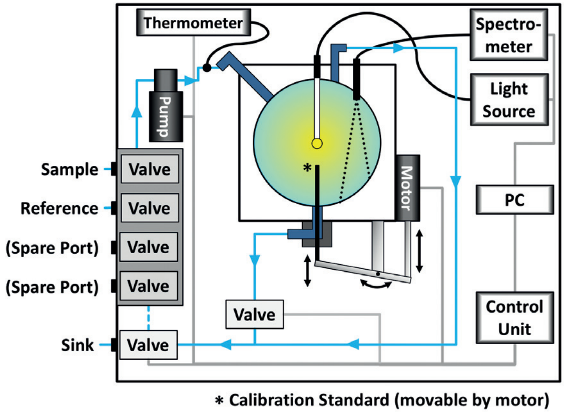
Achievement: flow system for monitoring; fast system suitable for the observation of small-scale structures

Development: In-house development

Technology Readiness Level 5

Frank C. and F. Schroeder (2007): Using Sequential Injection Analysis to Improve System and Data Reliability of Online Methods: Determination of Ammonium and Phosphate in Coastal Waters. Journal of Automated Methods and Management in Chemistry Vol. 2007; Article ID 49535, 6 pages. doi: dx.doi.org/10.1155/2007/49535

Hyperspectral Absorption Sensor

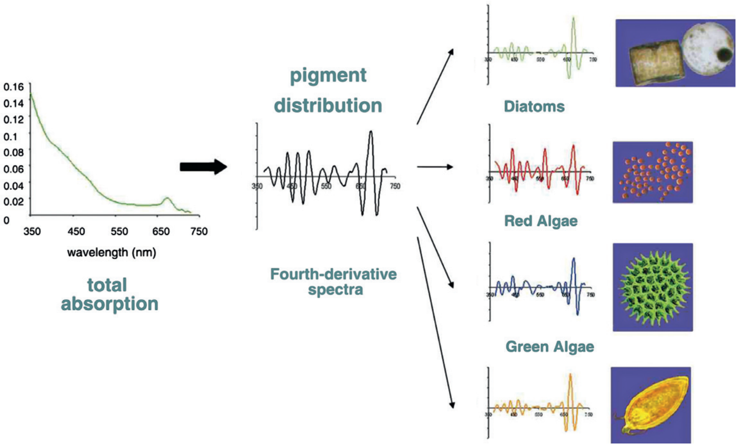


Process scheme of the continuously operating absorption sensor (integrating cavity principle)

SPECIFICATIONS

Parameters: chlorophyll-a algal groups (crysophytes, cryptophytes, cyanobacteria; difficult species: diatoms, dinophytes, haptophytes)

Deployment: flow-through system, installed on ships or stationary use



From absorption measurements to algal group identification

RATIONALE FOR DEVELOPMENT

Conventional chlorophyll-a estimation with fluorometry is prone to errors associated with phytoplankton composition, physiological status, and short-term light acclimatization.

A continuous flow-through system was therefore developed for a more reliable estimation of chlorophyll-a from absorption. The absorption spectra are also applied to algal group detection for assessing changing taxonomic compositions.

DESCRIPTION

The *Hyperspectral Absorption Sensor* (HyAbS) is an instrument for continuous and automated flow-through absorption measurements. It is based on measurements in an integrating cavity to overcome two common problems of conventional seawater spectrophotometry: Biases caused by light scattering on particles and low signal-to-noise ratios. From the obtained absorption coefficient spectra, quantitative and taxonomical information on chlorophyll and phytoplankton can be derived. All measurement procedures, such as instrument calibration, are completely automated.

TYPICAL RESULT:
Estimation of algal groups from absorption spectra

Certain phytoplankton groups can be differentiated due to their specific pigments . They determine the shape of the absorption spectra measured with the HyAbS. Mathematical transformation extracts the spectral features and thus group-specific differences. The patterns are compared with spectra of known phytoplankton composition stored in a database allowing estimations of phytoplankton groups dominating a specific water sample.

Achievement: Flow-through method worldwide unique

Development: in-house development
of flow-through system

Technology Readiness Level 6

Wollschläger, J., Voß, D., Zielinski, O., and W. Petersen (2016): In situ observations of biological and environmental parameters by means of optics-development of next-generation ocean sensors with special focus on an Integrating Cavity approach. IEEE Journal of Oceanic Engineering PP (99), 1-10. doi: 10.1109/JOE.2016.2557466

High-Resolution X-Band Radar

X-Band radar antenna

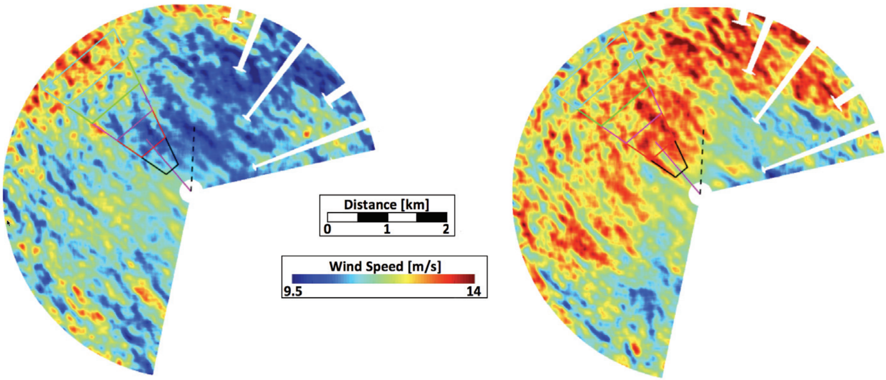
SPECIFICATIONS

Parameters: spectral wave parameters; wind, current and bathymetry maps; detection of fronts, eddies, internal waves and slicks.

Deployment: fixed platforms or ships

Range: 1- 4 km

Resolution: down to 7.5 m
time: 2 KHz
(parameter dependent)



Wind fields, measured at platform FINO-3, at t=0 s (left) and t=120 s (right)

RATIONALE FOR DEVELOPMENT

A method was needed for the remote measurement of wind, waves and currents from moving vessels, and to monitor the bathymetry in coastal shallow water environments under severe (storm) conditions.

DESCRIPTION

An off-the-shelf marine X-band radar was modified to measure Doppler speeds in addition to the intensity of surface scattering. Several algorithms were developed, tested and validated to extract the spectral properties of gravity waves, surface currents, and the shallow water bathymetry from the surface backscatter. Other methods are developed to retrieve the surface wind field and to monitor surface features such as current fronts, eddies, internal waves, and surface slicks.

TYPICAL RESULT: Wind speed at an Offshore wind park

A time series of radar-retrieved wind velocity maps was acquired at the Fino-3 in the North Sea. The maps represent the mean surface wind field calculated from radar backscatter every 60 s. The three time steps show a squall propagating from the Northwest towards the offshore wind park located in the east.

Due to the fast system's response, the method can be used by for offshore wind farms for improved predictive control

Achievement: Broad oceanographic application. Used in many national and international projects.

Development: In-house development (radar modifications and algorithms)

Partners: St. Petersburg Electrotechnical University

Technology Readiness Level 5 to 9 (depending on parameter)

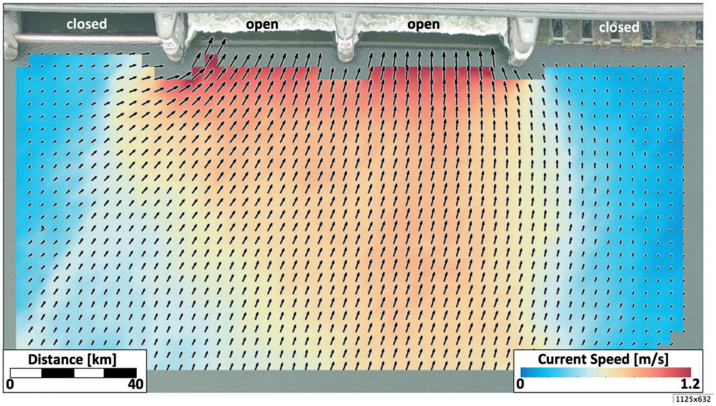
Horstmann, J., Nieto Borge, C., Seemann, J., Carrasco, R. and B. Lund (2015): Wind, wave and current retrieval utilizing X-Band marine radars, chapter 16 in Coastal Ocean Observing Systems, Elsevier, p.281-304

Aerial Current Measurements

Drone (quadrocopter) during investigatiopn (photo: Lippels, HZG)

SPECIFICATIONS

Parameters:	surface current fields
Deployment:	from AUV
Range:	typically 300 m (depends on field of view and altitude)
Spatial resolution:	5 m
Temporal resolution:	minutes
Accuracy:	~0.1 m/s



Current field of the Elbe River at the weir in Geesthacht, Germany, retrieved with a drone.

RATIONALE FOR DEVELOPMENT

Drones can now be used for cost-effective, high-resolution mapping of surface current fields on scales of meters. Non-intrusive methods also allow measurements in environments that cannot be accessed with *in situ* instrumentation.

DESCRIPTION

An off-the-shelf quadcopter was equipped with a 4K video camera and an actively controlled gimbal for video stabilization. It records all flight information for georeferencing of the video data. High-resolution ocean surface currents are retrieved from short video sequences of water surface waves.

The resulting video data allow for measuring surface wave properties such as wave direction, wave length, and phase velocity. These wave properties are used to estimate the surface current vector from the difference of the observed phase velocity and the expected linear dispersion relationship of surface gravity waves. Comparisons to measurements with an acoustic Doppler Profiler have shown that the accuracy is within 0.1 m/s.

TYPICAL RESULT:
Observation of current velocity

The example shows a high resolution surface current field resulting from a video sequence of the Elbe river at the weir in Geesthacht, Germany. The current field was retrieved with a resolution of 5 m utilizing 120 s of video data covering an area of approximately 200 m x 120 m. .

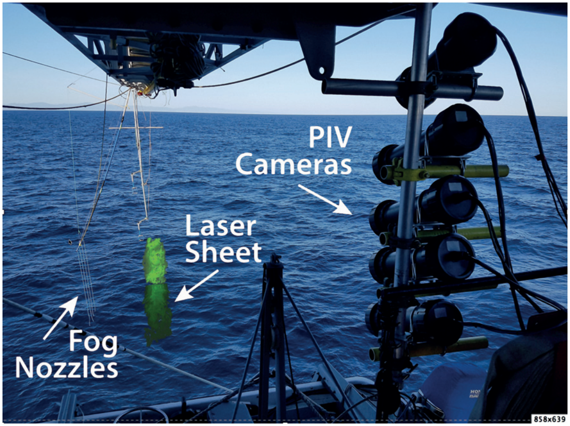
Achievement: Novel low-cost technology to observe surface current fields with very high resolution

Development: In-house development of algorithms

Technology Readiness Level 5

Streßer, M., Carrasco, R., and J. Horstmann (2017): Video-based estimation of surface currents using a low-cost quadcopter. IEEE Geoscience and Remote Sensing Letters, vol.14, issue 11, pp.2027-2031. doi:10.1109/LGRS.2017.2749120

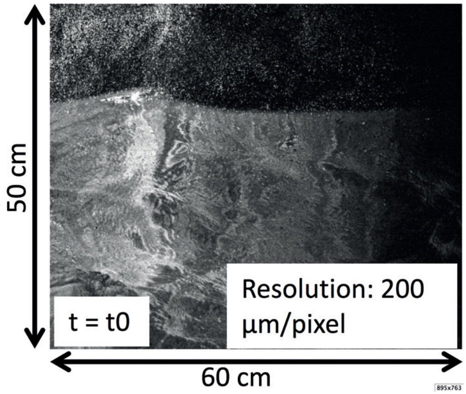
Particle Image Velocimeter



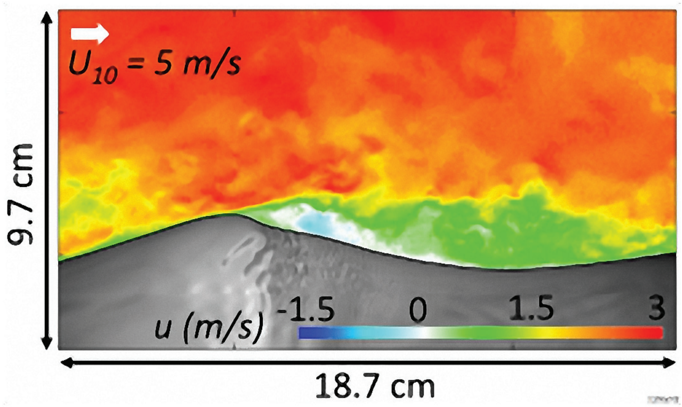
Particle image velocimeter (photo: M. Buckley, HZG)

SPECIFICATIONS

Parameters:	air-flow above water surface	
Deployment:	stationary on mast	
Range:	1 mm to 2 m above sea surface	
Resolution:	pixel:	250 µm
	velocity:	1 mm
	time:	15 Hz



Raw picture used for data processing.



Velocity field measured with the Particle Image Velocimeter.

RATIONALE FOR DEVELOPMENT

Air-sea fluxes of momentum, energy, heat and mass are crucial boundary conditions for weather, climate and oceanic motions. These fluxes are affected by the complex dynamics at the ocean surface, and in particular by the interactions between the wind and surface waves.

In order to understand the complex feedback mechanisms between waves and the airflow dynamics, we have developed a novel air-sea interfacial Particle Image Velocimeter (PIV).

DESCRIPTION

Fog is artificially generated with several fog nozzles and is illuminated with a laser. Five high-resolution cameras record the small-scale motion of the fog particles above waves. 2D-airflow velocity fields are obtained as low as 1 mm above the air–water interface.

TYPICAL RESULT:
Air speed above waves

Artificial fog is blown by the wind from left to right over a wave crest. The air velocity field is then derived from the propagation of the fog particles.

While the air speed at the wave crest exceeds 10 m/s, the velocity decreases to 3-4 m/s behind the crest revealing turbulence.

Achievement: Worldwide unique for ocean deployments

Development: Further development of instrument system of the University of Delware

Partners: University of Delaware

Technology Readiness Level 6

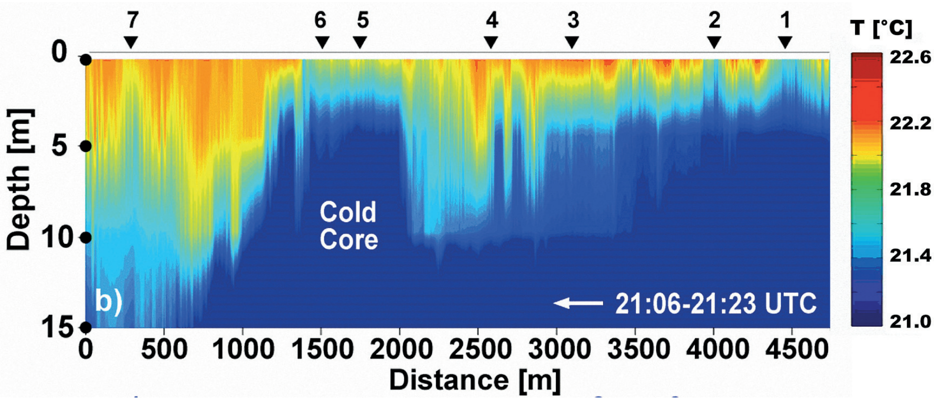
Buckley, M. P., and F. Veron (2016): Structure of the airflow above surface waves. J. Phys. Oceanogr. doi: doi.org/10.1175/JPO-D-15-0135.1

Towed Instrument Chain

Tow-chain ready for deployment (photo: M. Heineke, HZG)

SPECIFICATIONS

Parameters:	temperature, salinity, depth, oxygen, chlorophyll	
Deployment:	towed behind small vessel	
Speed:	10 Knots (5 m/s)	
Depth range:	0-40 m	
Resolution:	Temp.	0.001 °C
	Salinity	0.001
	Depth	0.002% FS
	Chl.	0.008 µg
	horizontal:	< 0.5 m
	vertical:	2-10 m
Frequency:	10 Hz (O_2: 1 Hz)	



First in situ measurements of a submesoscale eddy off California accomplished with the Towed Instrument Chain

RATIONALE FOR DEVELOPMENT

To better understand small-scale processes it is essential to observe them with sufficient horizontal and vertical resolution. The stratification and tilt of ocean fronts are dynamically important and can only be adequately sampled with sensors at multiple depth. Rapid repeat sampling is needed to keep up with the fast evolution over only a few hours. For this purpose, a Towed Instrument Chain was developed.

DESCRIPTION

The Towed Instrument Chain is built as an array of ten to twenty CTDs placed at different locations on a string. A depressor keeps the Tow Chain at depths of up to 45 m, even at a tow speed of 10 Knots. The Instrument Chain can be deployed from small vessels within 5 min.

Currently, self-recording Sea&Sun CTDs with 4-channel probes are used. A next-generation Towed Instrument Chain with real-time data transmission is currently under development.

TYPICAL RESULT: Submesoscale temperature transects

The use of the Towed Instrument Chain resulted 2009 in the first *in situ* measurement of a submesoscale spiral eddy. The figure shows a temperature transect through the eddy. The cold core is visible between 1200 m and 2000 m. Cold temperatures are shown in blue, warm temperatures in orange.

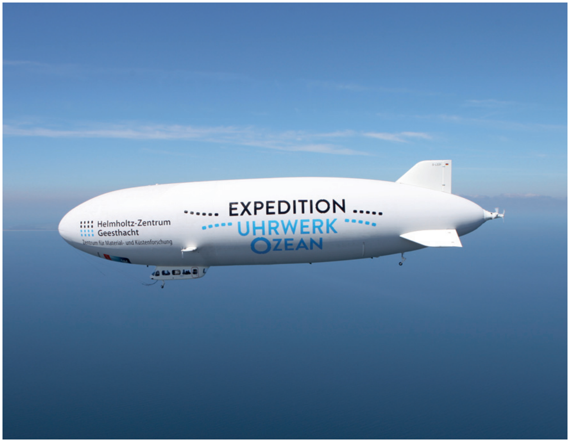
Achievement: Worldwide unique for small vessels, cost-effective.

Development: In-house development

Partners: University of California at Los Angeles, Sea & Sun Technology GmbH, MBT GmbH (MacArtney Deutschland)

Technology Readiness Level 4 (7)

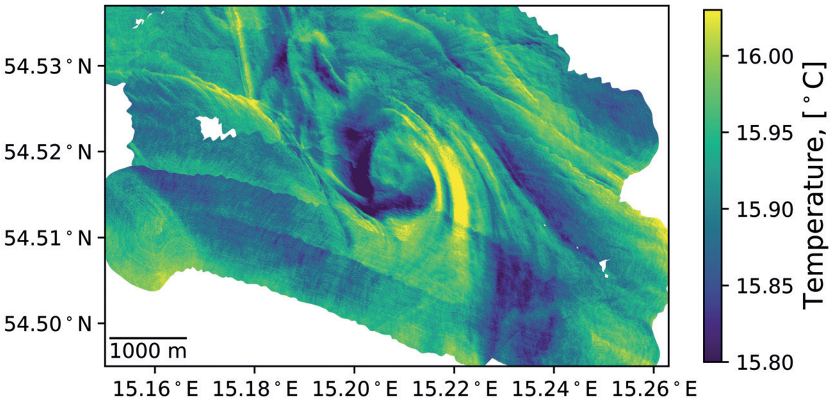
Infrared Camera for Detection of Small-Scale Dynamics



SPECIFICATIONS

Parameters:	temperature maps	
Deployment:	Zeppelin or airplane	
Swath Width:	typically 600 m	
Resolution:	temp.:	< 35 mK
	range:	< 1 m
	time:	50 Hz
Georeferencing:	online	
Data transmission:	near-real time	

Zeppelin during the experiment ’SubEx’ at the Baltic Sea (photo: G. Seidel, HZG)



A small ocean eddy in the Baltic Sea identified by the IR camera

RATIONALE FOR DEVELOPMENT

Submesoscale eddies, fronts and filaments on a scale of 10 m to 10 km play an important role for coastal and oceanic processes. They are responsible for strong mixing and for approximately half of the global phytoplankton production. Due to their small size and short lifetime, these structures are mostly hidden from satellites.

For the detection of small-scale structures and to observe their evolution, a system is needed that detects small temperature differences from the air, provides a spatial overview and allows for rapid repeat measurements.

DESCRIPTION

A commercially available infrared FLIR camera has been adapted for use in a zeppelin. A software was developed for exact real-time georeferencing of the pictures. The information is transmitted to vessels as essential guidance during the experiments.

The map shows small relative temperature differences of $< 0.1\,°C$. Due to the path length through the atmosphere the absolute temperature has to be determined with in situ methods.

TYPICAL RESULT: Detection and Temperature Map of Small Ocean Eddy

From a zeppelin, the temperature structures of a small ocean eddy in the Baltic Sea, was measured. The eddy has a lifetime of only few hours. By transmitting the data to accompanying ships, detailed in situ observations have been carried out.

Achievement: Unique combination of very high-resolution and real-time temperature mapping, georeferencing, and data transmission to vessels.

Development: In-house development

Partners: Company IGI, Naval Research Laboratory, University of California at Los Angeles

Technology Readiness Level 6

Mobile Dome and Virtual Reality

Mobile Dome for 360° presentations (photo: B. Baschek,HZG)

SPECIFICATIONS OF MOBILE DOME

Parameters:	diameter: 9 m height: 7 m
Deployment:	easy to assemble and disassemble
Visitors:	40

Immersive videos presented in the Mobile Dome
(photo:B. Baschek, HZG)

360° video shown in Virtual Reality glasses
(photo: G. Seidel, HZG)

RATIONALE FOR DEVELOPMENT

To fascinate the public about cutting-edge research and let them participate in an ocean expedition.

DESCRIPTION

Novel, immersive technologies available since a few years allow for an innovative dissemination of results to the general public and to decision-makers. They enable an intensive participation in ocean experiments as the viewer is virtually integrated into the film, looking around the presentation. For public shows an inflatable mobile dome has been equipped with six high-quality projectors, server, and audio system.

The production process of immersive content consists of recording of video material during the experiments with a *cube* of 6 cameras, *stitching* of the 6 simultaneous video clips generating a 360°-clip, cutting the material, and adding spatial sound and speaker.

The Mobile Dome has been used for presentations at festivals, such as the central celebrations for the German Day of Reunification or the climate conference COP23 reaching typically 1200 visitors per day. The HZG movies *Clockwork Ocean* and *Mysterious Oceans – the Eddy Hunt* are shown in national and international planetariums. They are also publically available for virtual reality glasses and can be watched with smartphones and a new HZG 360°-App .

EXAMPLE:
the Expedition Clockwork Ocean

The Expedition Clockwork Ocean is presented in two unique fulldome shows. The immerse media allows visitors to immerse in this thrilling hunt for ocean eddies with Zeppelin, planes and speed boats and to explore locations they would not be able to visit otherwise.
For more information on this award winning science communication and movie downloads visit www.clockwork-ocean.com.

Achievement: World-wide unique. Presented at several different locations and festivals.

Development: In-house development

Partners: tat team

Technology Readiness Level 9

Technology Readiness Level (TRL)

Development status based on the Technology Readiness Levels of the European Commission

	DESCRIPTION
TRL 1	basic principles observed
TRL 2	technology concept formulated
TRL 3	experimental proof of concept
TRL 4	technology validated in lab
TRL 5	technology validated in relevant environment
TRL 6	technology demonstrated in relevant environment
TRL 7	system prototype demonstration in operational environment
TRL 8	system complete and qualified
TRL 9	actual system proven in operational environment

https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

FOR PEOPLE AND THEIR
FUTURE ENVIRONMENT

Helmholtz-Zentrum
Geesthacht
Centre for Materials and Coastal Research

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research GmbH
Max-Planck-Straße1 | 21502 Geesthacht
Germany

Telefon: +49 (0)4152-87-1534
Telefax: +49 (0)4152-87-1403
www.hzg.de

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