MONITORING HYPOXIA:

DIVERSE APPROACHES TO ADDRESSING A COMPLEX PHENOMENON WITH FOCUS ON THE BLACK SEA

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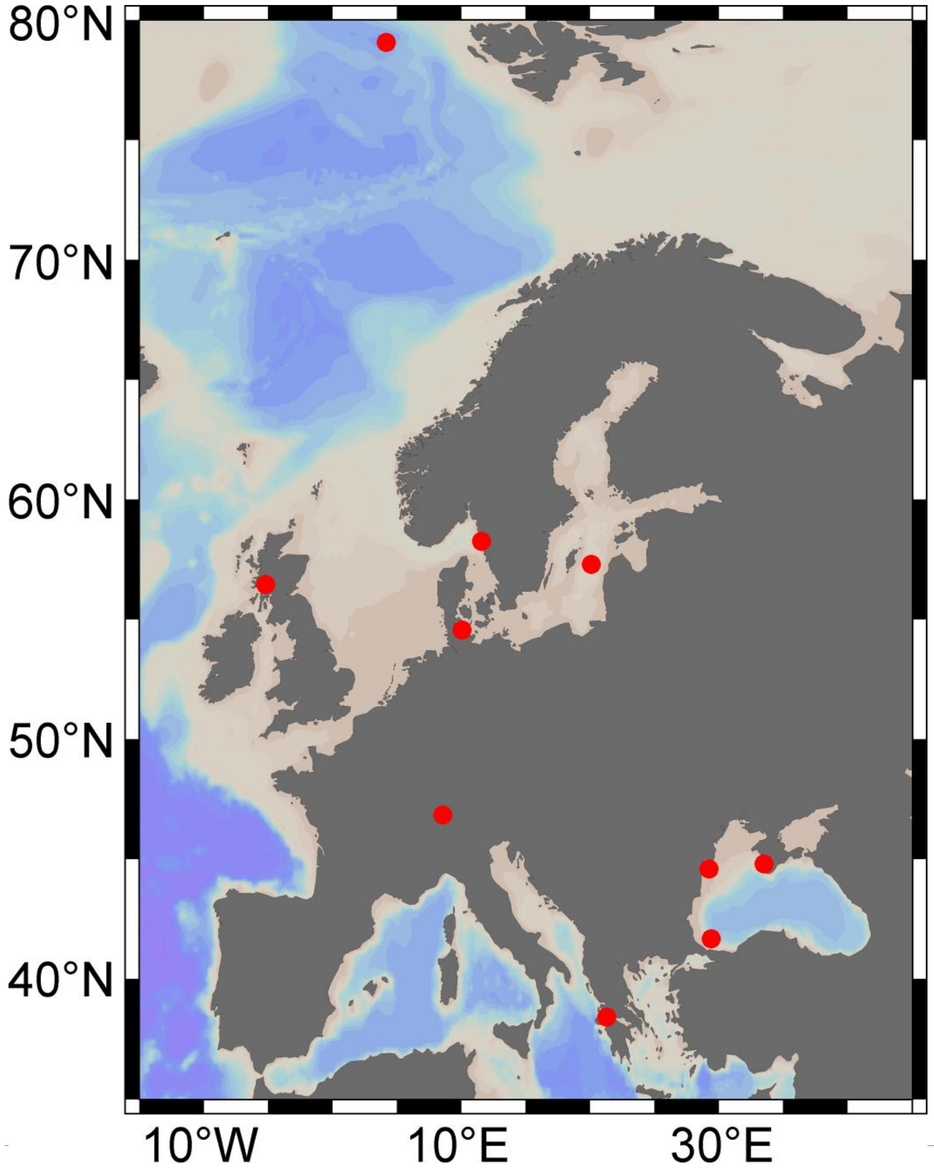
EXAMPLES OF HYPOX STUDY SITES

EC FP7 "HYPOX - In situ monitoring of oxygen depletion in hypoxic ecosystems of coastal and open seas, and land-locked water bodies" (2009-2012)



Take-home message

„The challenge in any kind of monitoring is to choose the appropriate approach that is suited to resolve the temporal and spatial scales on which the phenomenon you wish to monitor, occures."

Biogeosciences Discuss., 10, 12655–12772, 2013
www.biogeosciences-discuss.net/10/12655/2013/
doi:10.5194/bgd-10-12655-2013

Biogeosciences Discussions
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Investigating hypoxia in aquatic environments: diverse approaches to addressing a complex phenomenon

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EXAMPLES OF HYPOX STUDY SITES

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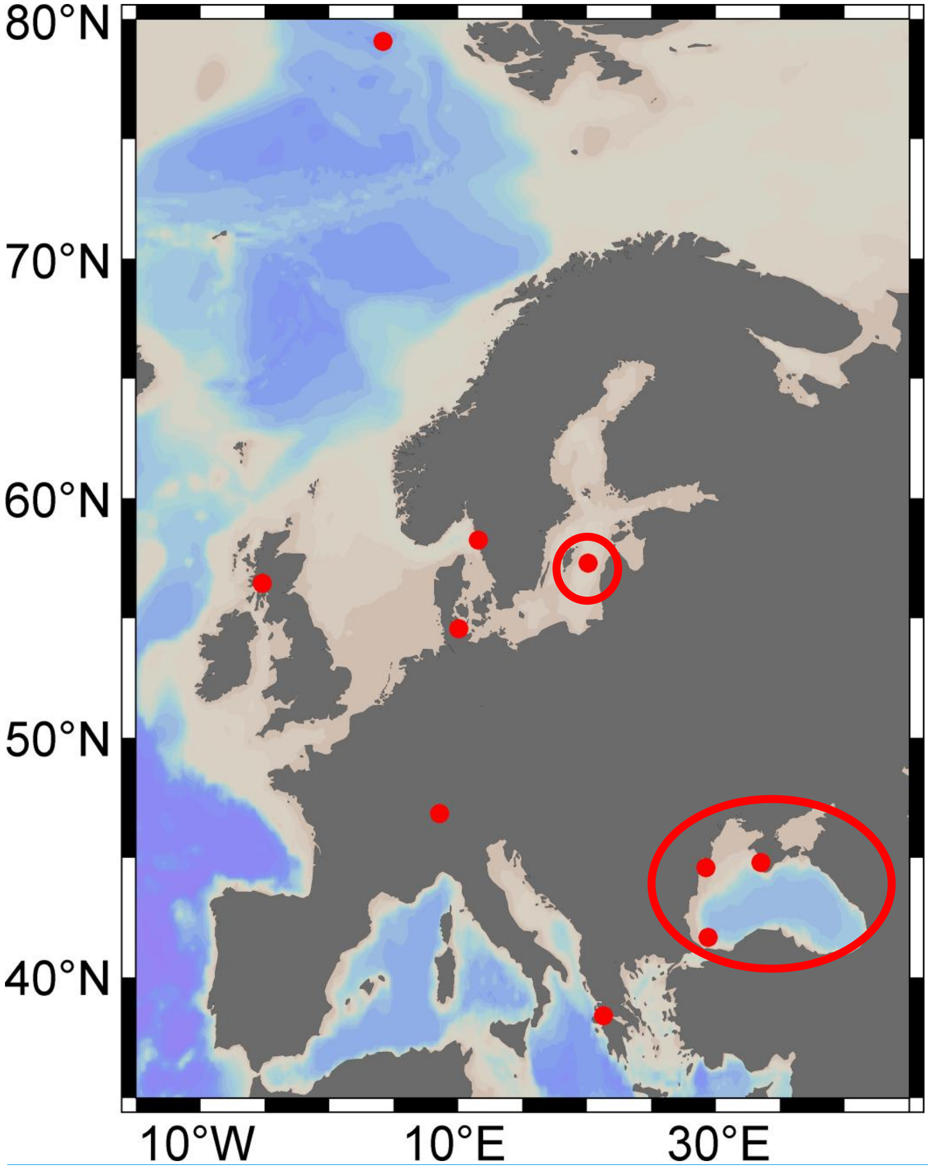


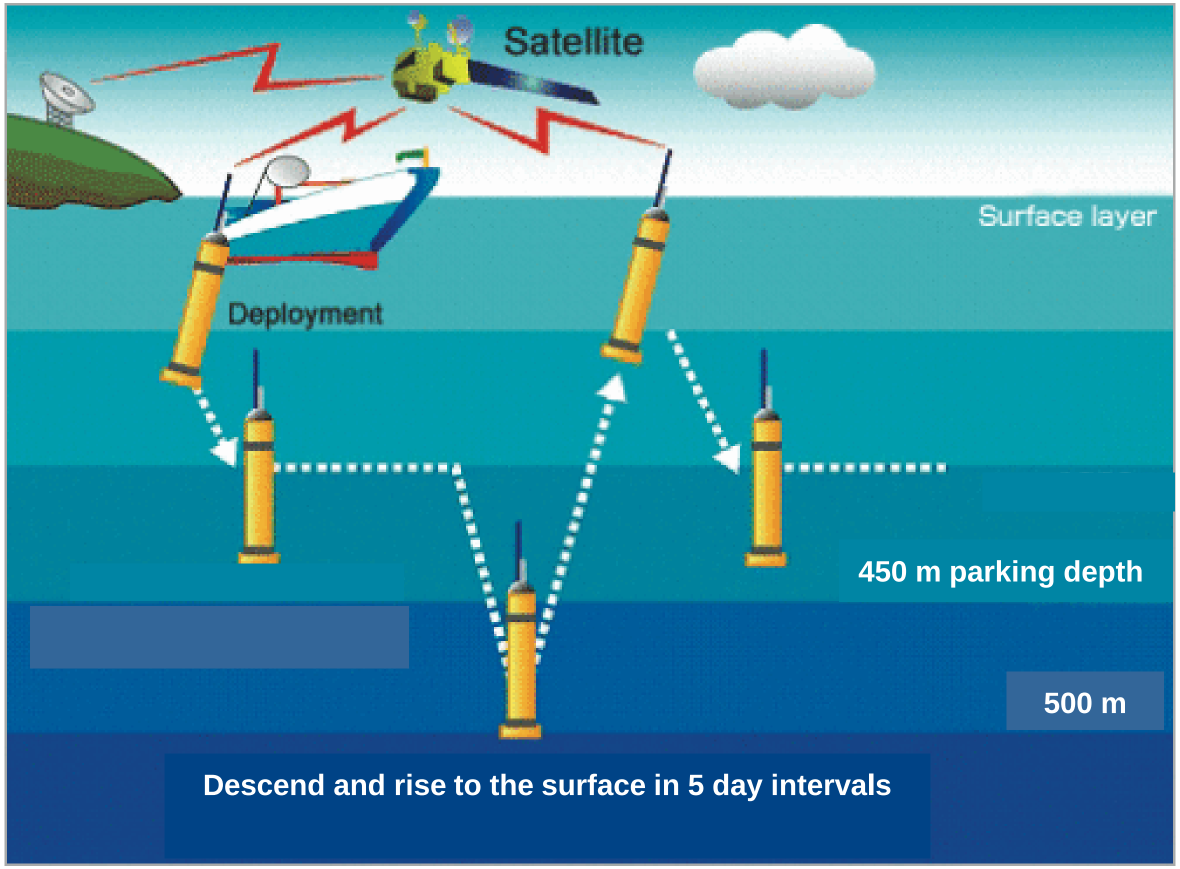
Site	duration/ frequency of hypoxia/anoxia
Central Black Sea, deep basin	persistent anoxia
Bosporus outflow	episodic oxygen injections into permanently anoxic deep waters
Crimean shelf	Oxygen concentrations oscillating, timescales from hours to weeks, longer?
Northwestern shelf	seasonal bottom water hypoxia
Gotland Basin/ Baltic Sea	anoxia >110m, wind driven oxycline dynamics at time scales of hours to weeks persistent anoxia >200m, during stagnation periods

Central Black Sea:
Mesoscale patterns in water column oxygenation

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

APPROACH

ARGO - Navigating European Marine Observer (NEMO) profiling floats (Optimare Sensorsystems) equipped with oxygen optodes (model 3830, AADI), conductivity, temperature, pressure



For the first time in the Black Sea equipped with oxygen optodes!

…see presentation by Emil Stanev on Thursday

Central Black Sea:
Mesoscale patterns in water column oxygenation

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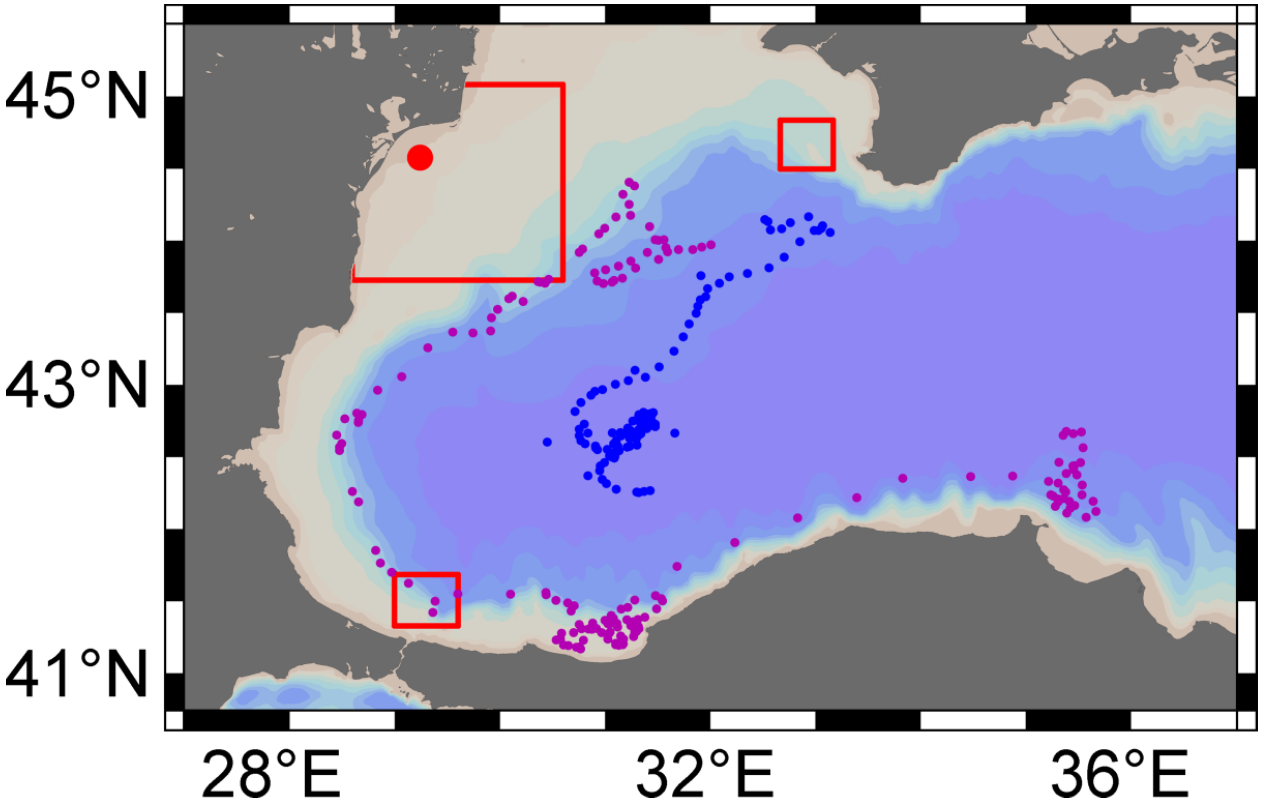
NEMO float trajectories



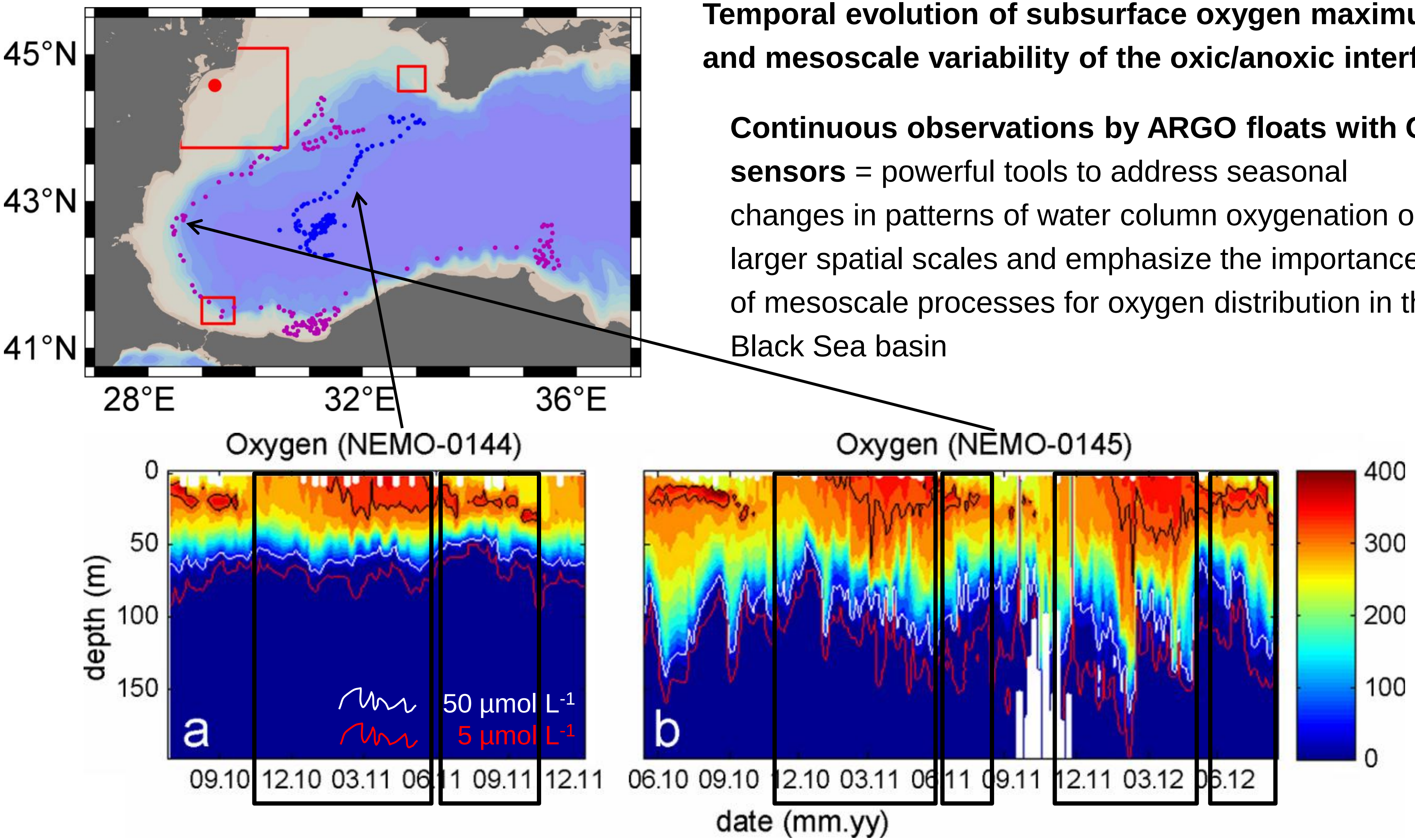
May 2010 until Dec 2011/Nov 2012

Central Black Sea:
Mesoscale patterns in water column oxygenation

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

Temporal evolution of subsurface oxygen maximum and mesoscale variability of the oxic/anoxic interface

Continuous observations by ARGO floats with O_2 sensors = powerful tools to address seasonal changes in patterns of water column oxygenation on larger spatial scales and emphasize the importance of mesoscale processes for oxygen distribution in the Black Sea basin



graphs by E. Stanev & Y. He

Central Black Sea:
Multidecadal hypoxia trends in stratified basins

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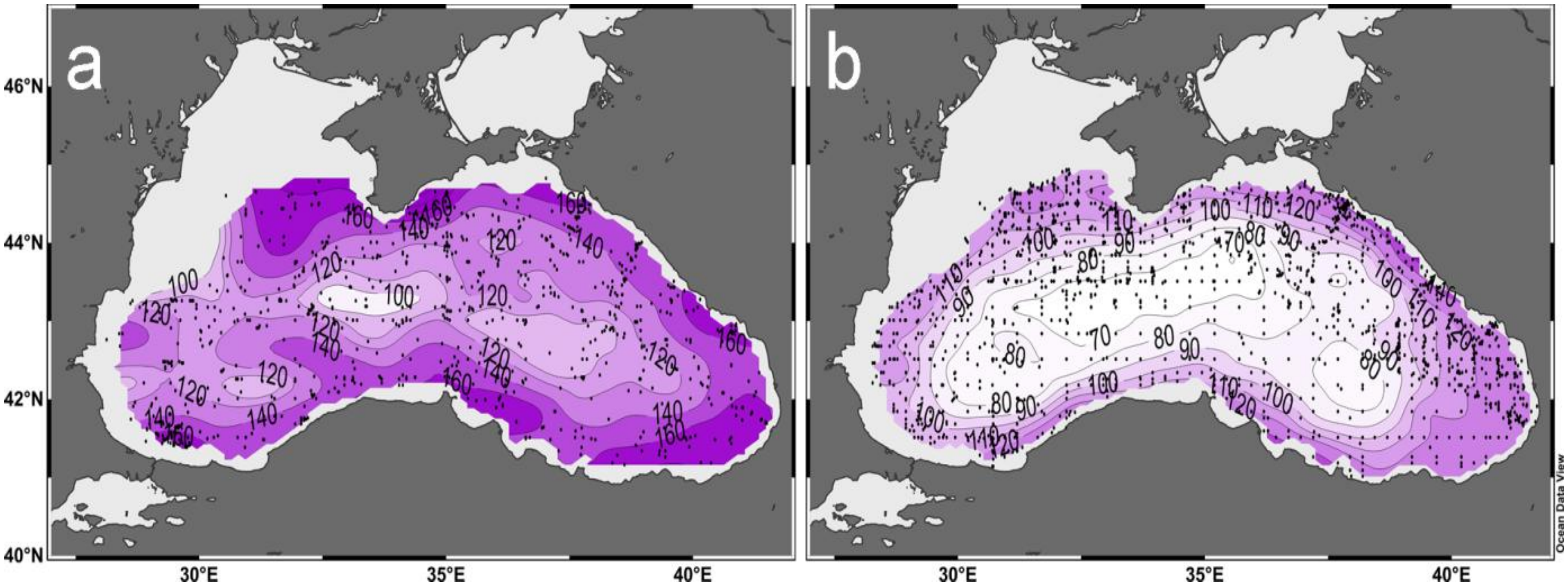
APPROACH

Analysis of standard CTD measurements in the central Black Sea over the last 6 decades to demonstrate the imprint of climate change and eutrophication on long-term oxygen distributions

Mean depth of the upper boundary of the suboxic zone (UBSOZ = 20 µmol O_2 L^{-1} isopleth)



1955-1976 1987-2011

Shoaling in 1970s and 1980s due to eutrophication, in the 1990s and 2000s due to NAO forcing

Shoaling of the UBSOZ from 1955 onwards in the range of 20 - 50 m!

graphs by S. Konovalov

Central Black Sea: Multidecadal hypoxia trends in stratified basins

Helmholtz-Zentrum Geesthacht
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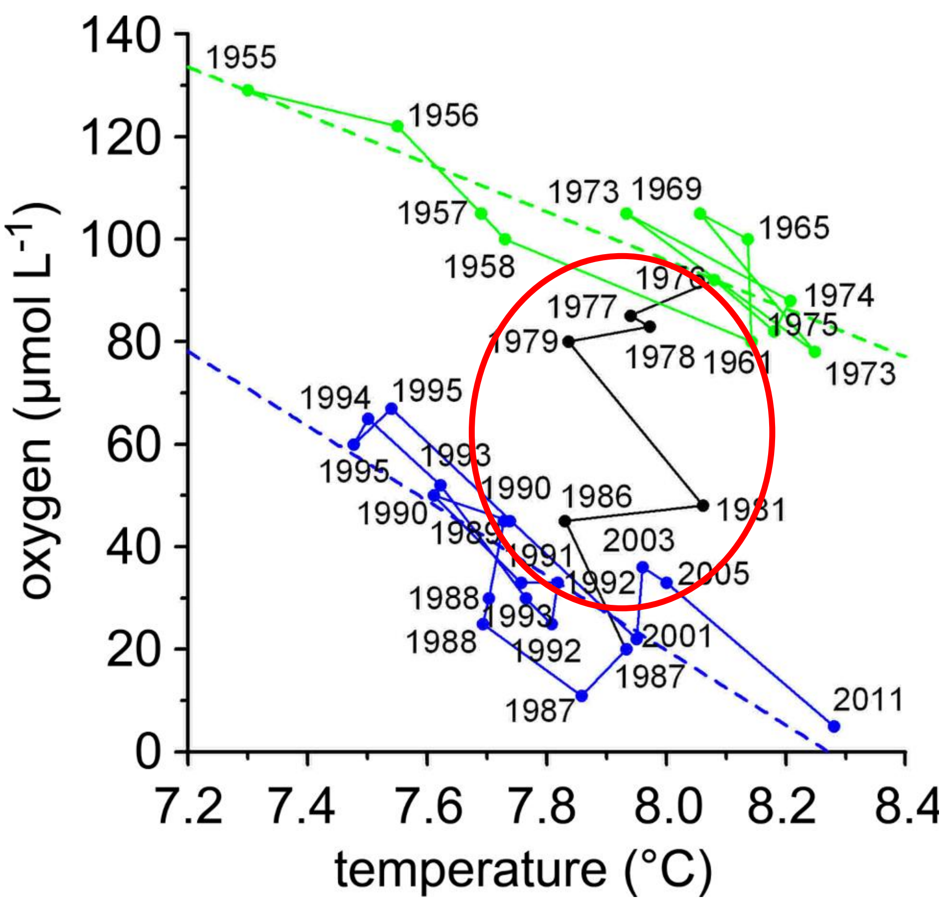
Multi-decadal time-series data allow separating out the effects of climatic forcing and eutrophication on oxygen depletion



strong impact of eutrophication while the effect of climate forcing was less pronounced

long-term monitoring data allow the quantification of spatial and temporal changes in the distribution of oxygen

projections of climate driven trends become possible

long-term monitoring remains crucial for timely warning of dramatic changes

Relationship between basin-averaged oxygen concentration and water temperature in the main pycnocline of the Black Sea (sigma-t = 15.4) from 1955 to 2011

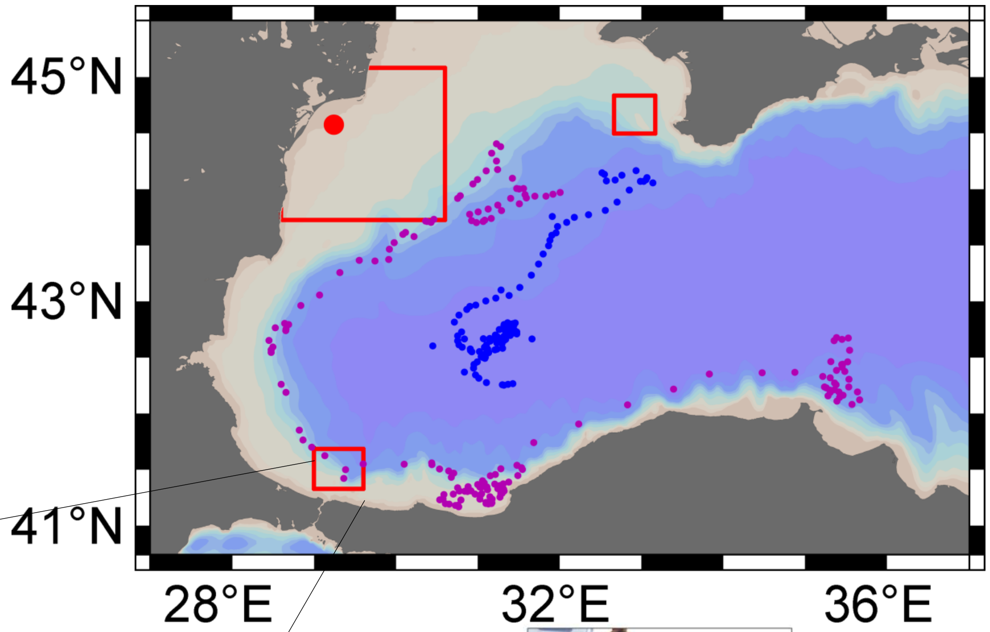
graph by S. Konovalov

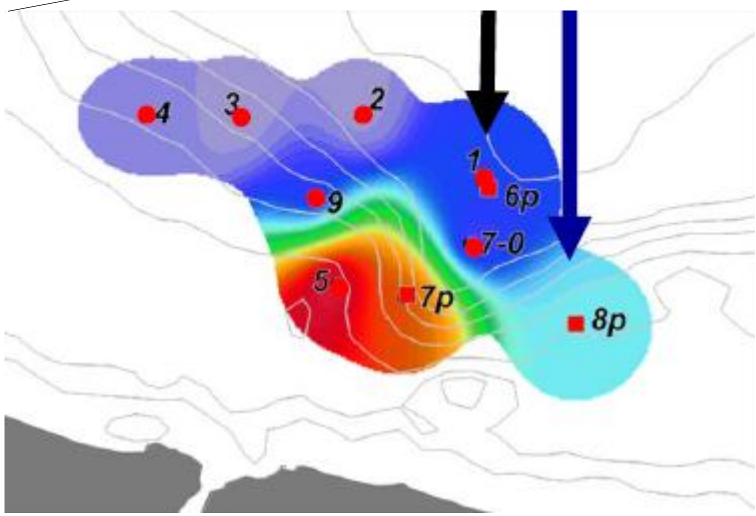
Bosporus outflow:
Oxygen intrusions into highly stratified systems

APPROACH

Repeated free-falling pump CTD surveys

- In free-falling mode the pump CTD descends slowly along a wire that runs through the center of the instrument
- sensors for temperature, salinity, and oxygen, and the inlet of the pump, protrude out of the downward-facing cone





Bosporus outflow:
Oxygen intrusions into highly stratified systems

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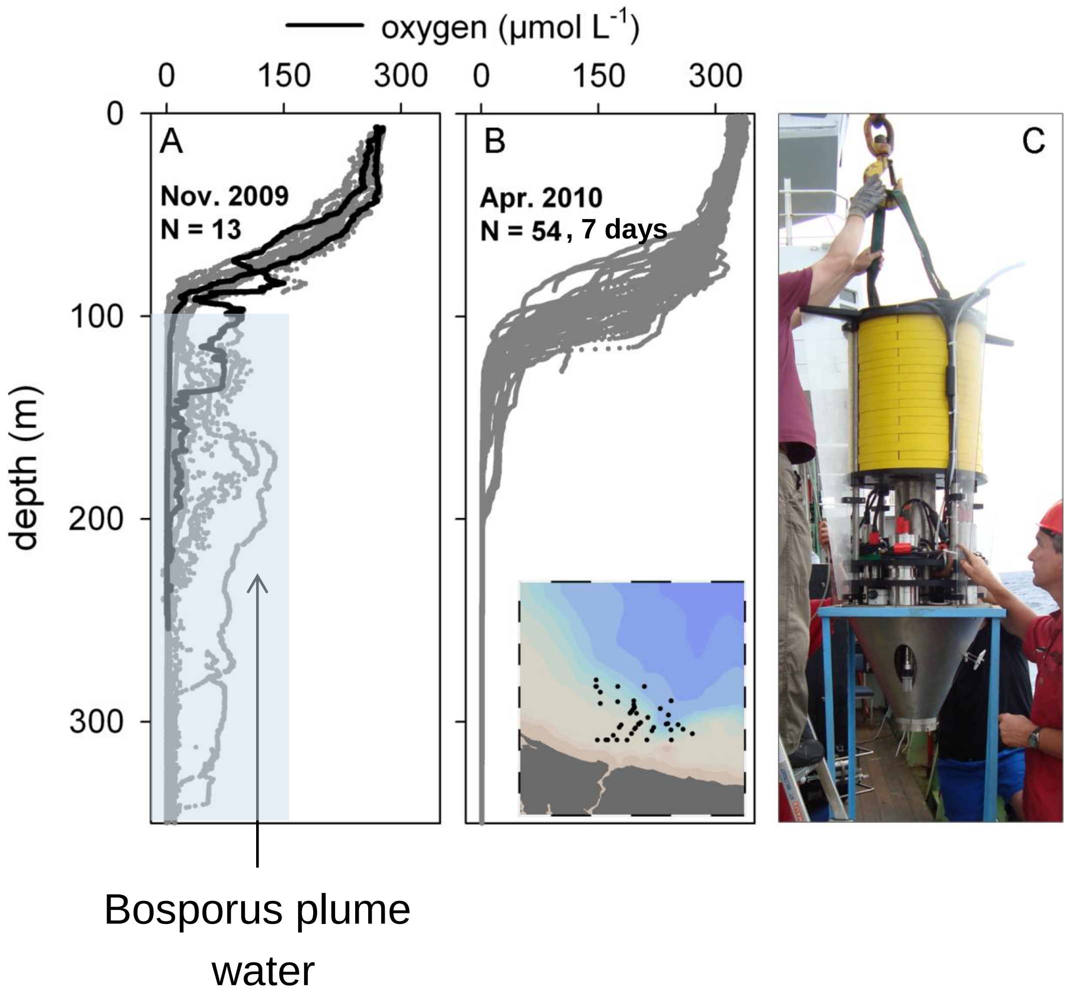


Oxygen intrusions

- shift in the position of the oxic/anoxic interface / redoxcline
- lateral intrusions mix oxic and reduced compounds, e.g., oxygen, nitrate and sulfide
- lateral mixing plays a significant role in maintaining a permanent suboxic zone in the Black Sea

- **high-resolution profiles highly suitable for identifying and localizing processes in complex redoxclines**

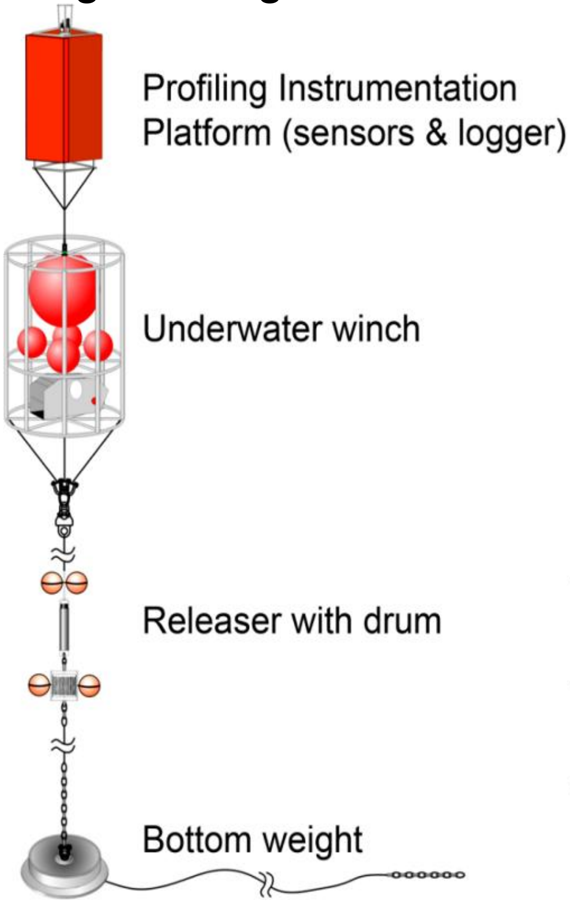
- **even in highly stratified systems, redoxclines can be highly complex and dynamic in space and time**

graphs by M. Holtappels

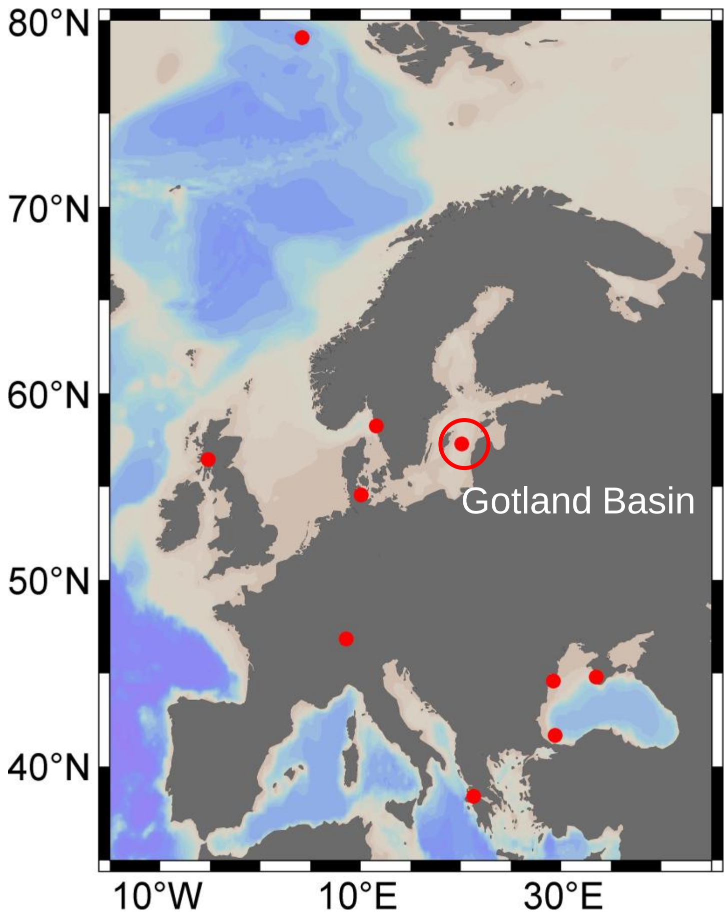
… but a profiling mooring would have been more appropriate…

APPROACH

Profiling mooring GODESS



Monitoring the temporal evolution of redox conditions



Parameters

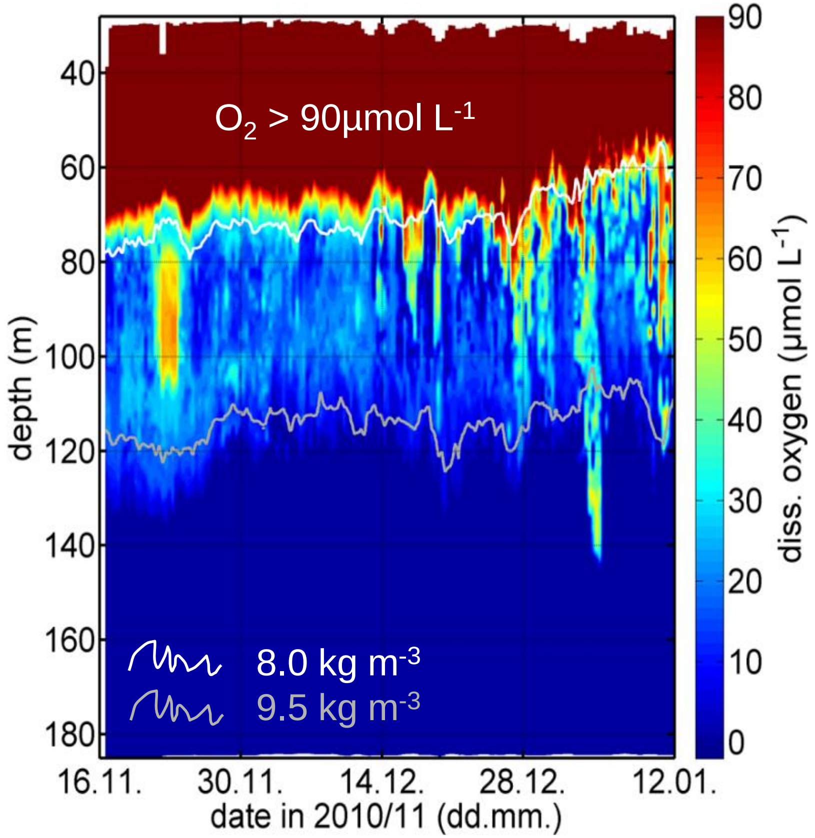
oxygen, CTD, chlorophyll *a,* fluorescence, turbidity, oxidation reduction potential, pH

figure by R. Prien

Gotland Basin / Baltic Sea: Short-term changes of oxygen in the pelagic redoxcline

Characterization of oscillating redoxclines as temporally dynamic, three-dimensional systems

O_2 in a 56-day deployment of GODESS



graph by R. Prien

High temporal variability is indicative of a complex three-dimensional structure of the redoxcline, created by lateral import of different water masses due to e.g.,

- baroclinic and barotrophic inflows
- breaking internal waves
- Upwelling
- boundary mixing

Dynamic properties of pelagic redoxclines cannot be addressed by traditional ship-based monitoring; require continuous measurements

Crimean Shelf:
Fast oxygen fluctuations at the sediment-water interface

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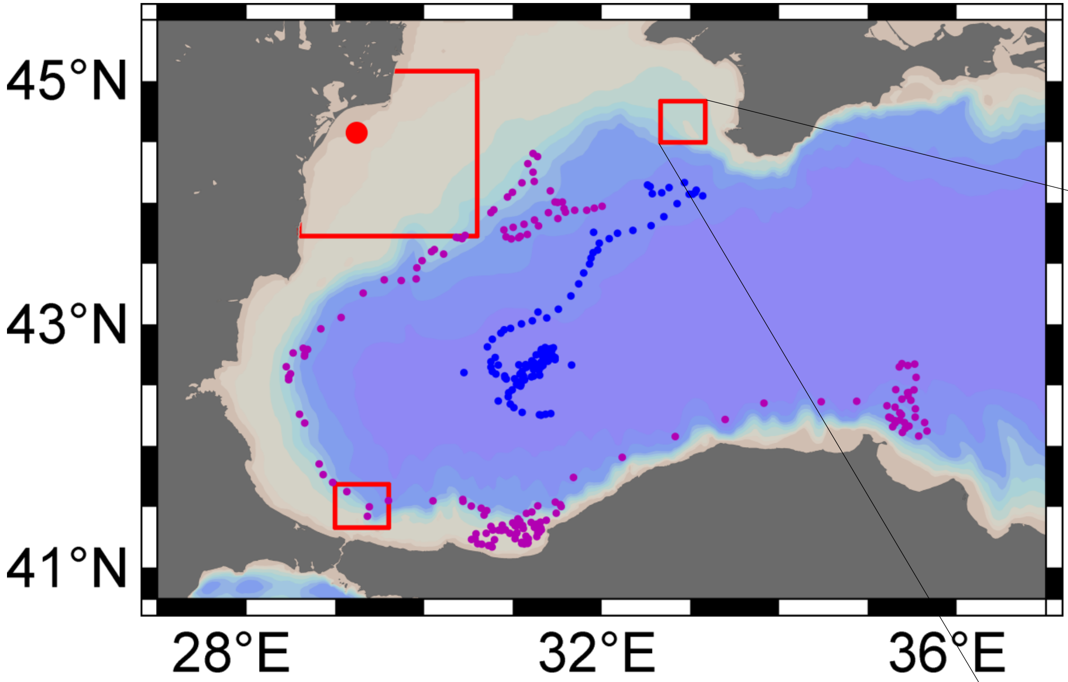
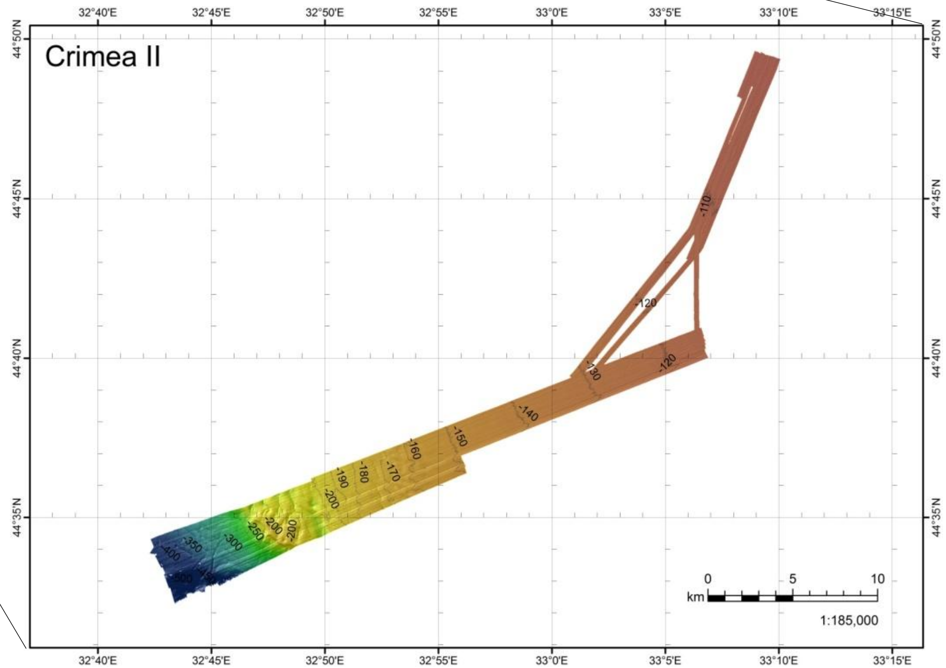


APPROACH

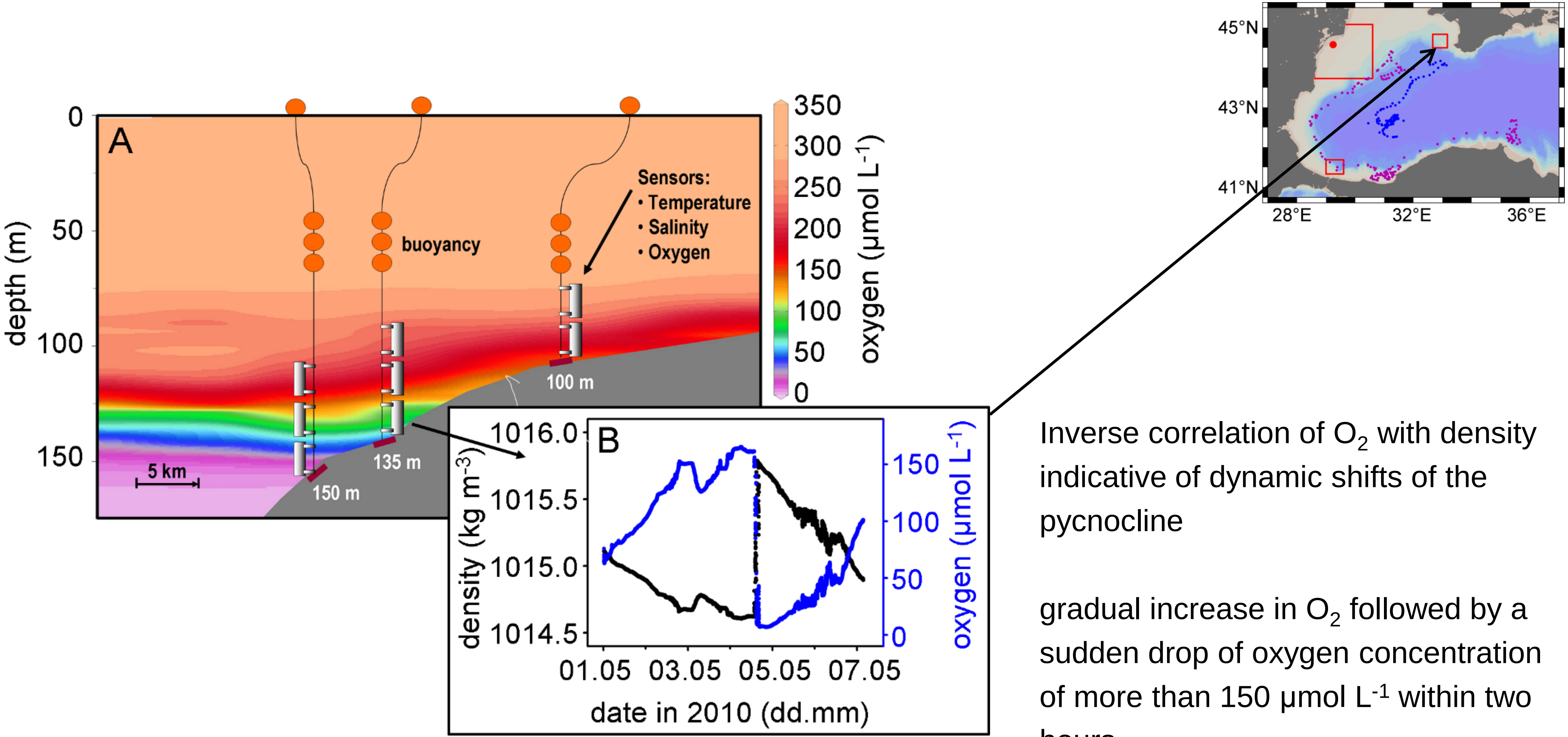
3 stand-alone static moorings (RCM 9 Aanderaa) at 100m, 135m and 150m depth, measuring temperature, salinity, currents and oxygen, & CTD surveys



Drivers of variability in oxygen

- oscillations of chemocline depth (e.g., mesoscale eddies, internal waves, Ekman pumping, atmospheric pressure oscillations and tides)
- interactions with local shelf bathymetry
- locally CH_4 seepage

Crimean Shelf:
Fast oxygen fluctuations at the sediment-water interface



Time series of density and O_2 at 135m depth

Inverse correlation of O_2 with density indicative of dynamic shifts of the pycnocline

gradual increase in O_2 followed by a sudden drop of oxygen concentration of more than 150 µmol L^{-1} within two hours.

graphs by F. Janssen & M. Holtappels

North-western Black Sea shelf:
Seasonal changes in bottom-water oxygen

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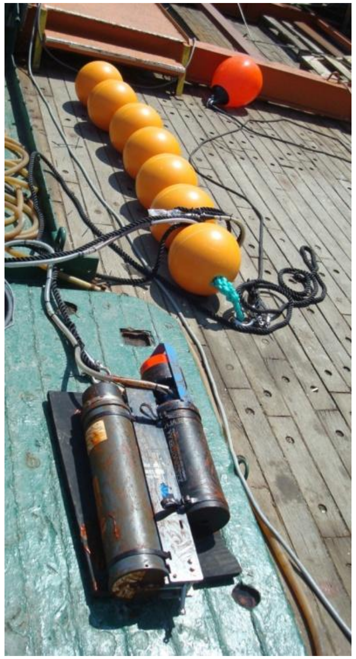
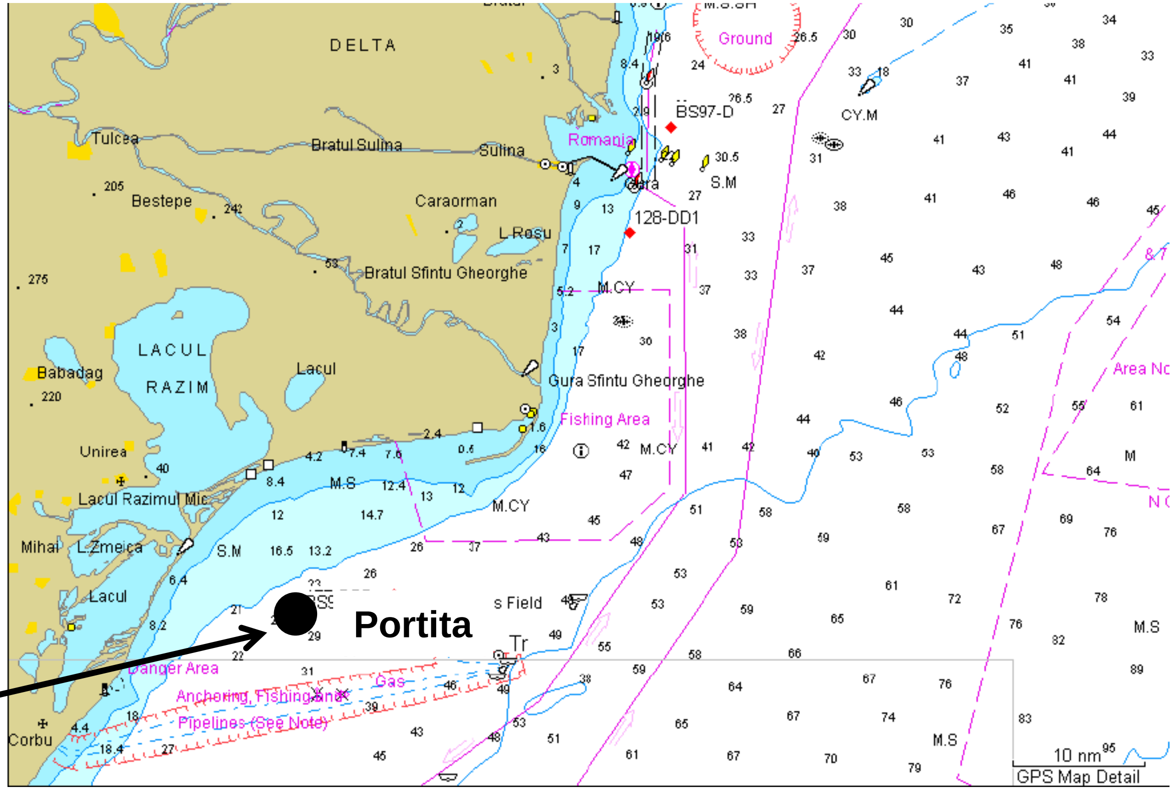
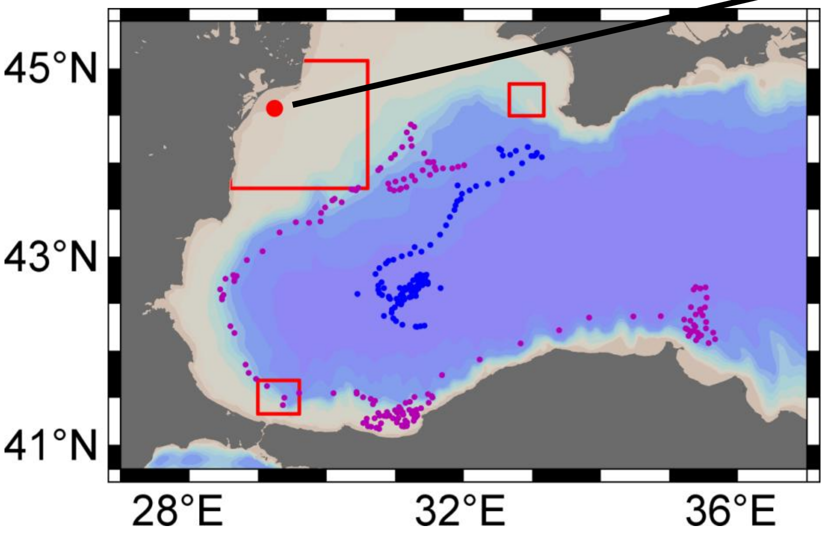
APPROACH
Stand-alone
static mooring

RCM9, AADI:
CTD
optical O_2 sensors
current meters
turbidity sensors







Drivers of Hypoxia

- Seasonal thermohaline stratification due to freshwater-seawater confluence
- eutrophication due to nutrient input from Danube River and non-point sources combined with climate variability
- coastal urbanization, agriculture
- Fisheries

North-western Black Sea shelf: Seasonal changes in bottom-water oxygen

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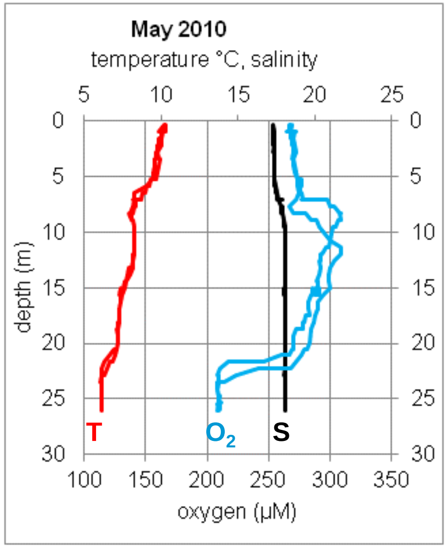
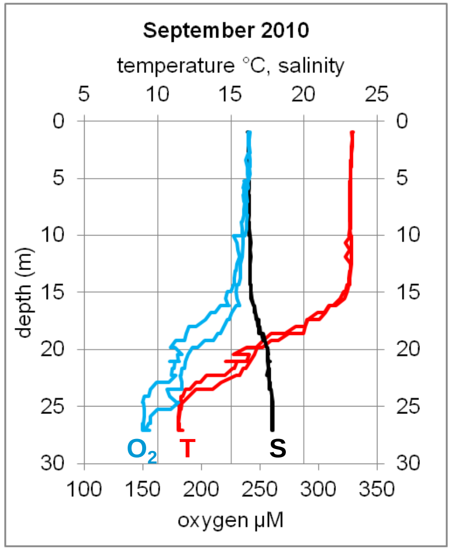
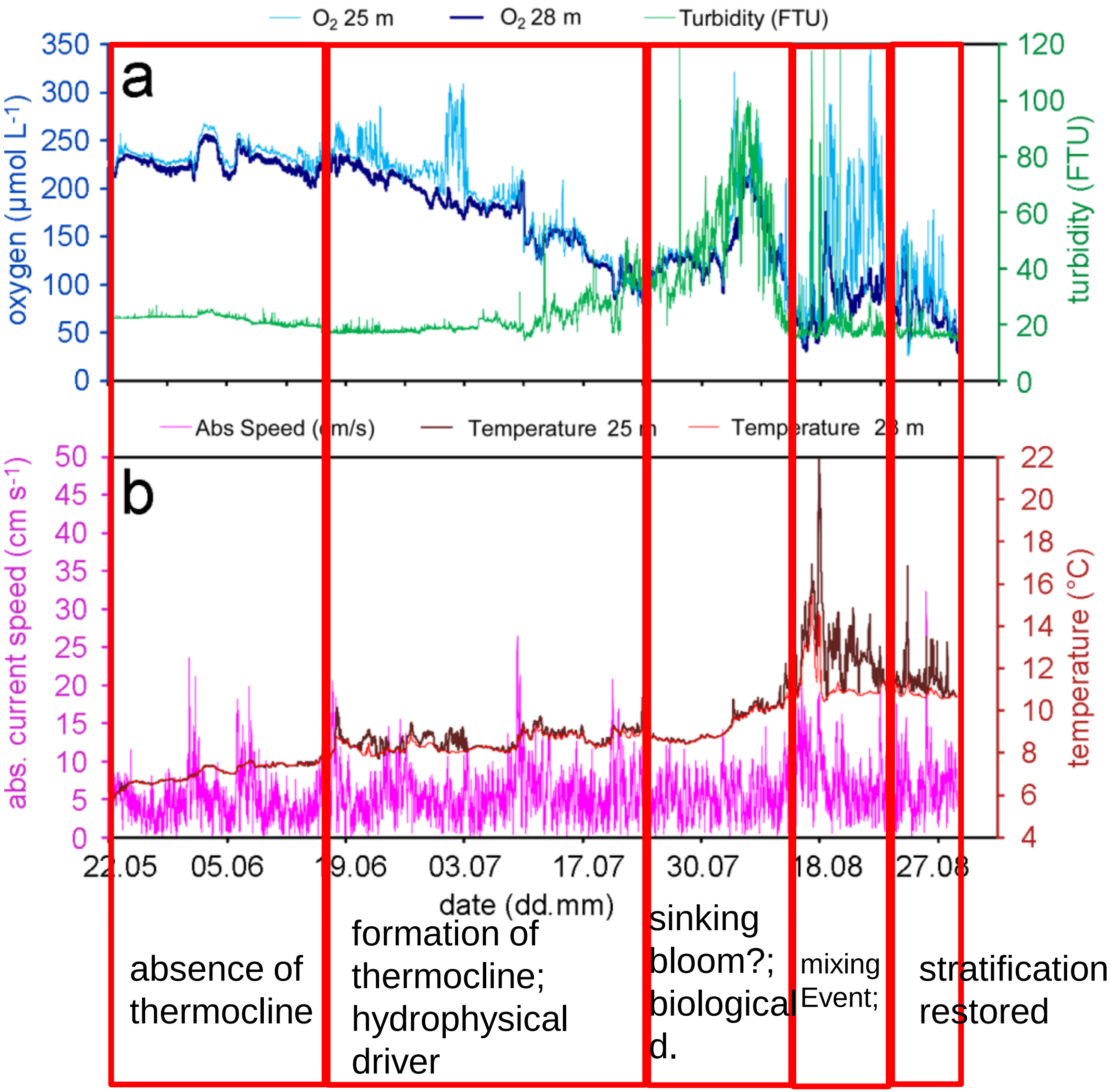
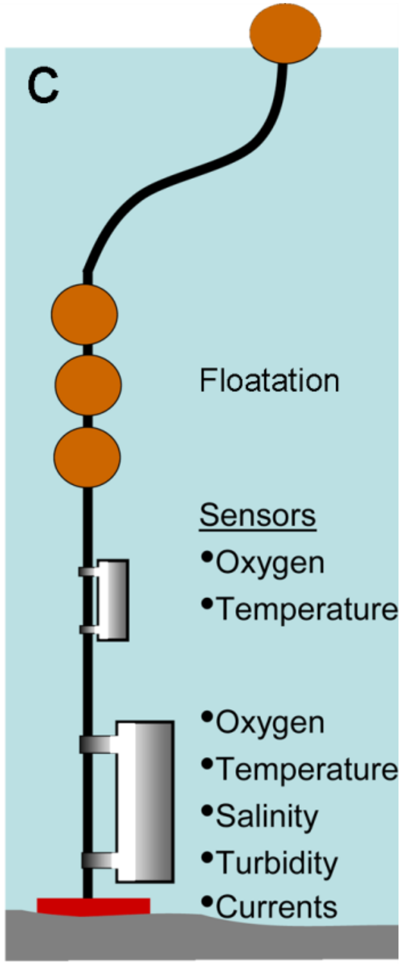
3-months deployment (May – August 2010)









graphs by J. Friedrich

Summary / Conclusions

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- Urgent need for dedicated oxygen monitoring at appropriate spatial and temporal scales with appropriate technology in the Black Sea
- Need for a careful selection of locations, approaches and periods of time for oxygen observations to adequately address the risk for hypoxia formation and ecosystem response

- Oxygen-sensor equipped ARGO profiling floats are powerful tools to address seasonal changes in patterns of water column oxygenation on larger spatial scales

- Analysis of multidecadal CTD data reveal multidecadal changes and allow projections of climate and eutrophication driven trends in water column oxygenation, thus timely warning of dramatic changes, i.e., the development of hypoxia

- Pump CTDs allow to identify oxygen intrusions and investigate effects on water column biogeochemical processes at the same time and at high resolution, repeated CTD surveys revealed that Bosporus plume was not continuous (profiling mooring would be appropriate)

- 2-dimensional high-resolution profiles by profiling instrumentation platforms allow characterization of the three-dimensional structure of complex redoxclines & improve our understanding of diapycnal mixing processes in stratified marine water columns

- Long-term static moorings with oxygen optodes and current meters in hypoxia-prone areas improve understanding of mechanisms of hypoxia formation and, e.g., assessment of descriptor 5 for GES of the MSFD

Take home messages from EC FP7 project “HYPOX” grant 226213 and presentation “Monitoring Hypoxia: Diverse Approaches to Addressing a Complex Phenomenon with Focus on the Black Sea « by J. Friedrich et al.

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- There is an urgent need for dedicated oxygen monitoring at appropriate spatial and temporal scales with appropriate technology in the Black Sea to establish early warning of hypoxia occurrence and adequate risk assessment for ecosystem services.
- A careful selection of locations, approaches and periods of time for oxygen observations is crucial to adequately address the risk for hypoxia formation and ecosystem response.
- The challenge in any kind of monitoring is to choose the appropriate approach that is suited to resolve the temporal and spatial scales on which the phenomenon you wish to monitor, occures.
- The success and efficiency of any long-term monitoring effort, be it autonomous observatories or classical ship-based CTD monitoring, requires the long-term commitment of human and financial resources.
- Due to the inevitable need for validation data, in-situ observatories should always be regarded as supplemental to existing standard monitoring programs rather than as a substitute for such programs.

Challenges in monitoring

(1) the continuation of existing long-term time-series monitoring programs and the set-up of additional programs;

(2) the installation of continuous cabled and autonomous observatories to complement standard monitoring programs;

(3) proper validation of observatory data using data from reference stations;

(4) the development and application of oxygen sensor technologies for monitoring water column oxygen concentrations at trace levels in deep-sea environments, and for monitoring gradual changes in oxygen concentration in the micromolar range;

(5) integrated assessment of the response of ecosystems to hypoxia, including community patterns, the adaptive behavior of organisms, and biogeochemical processes;

(6) the development of model-based forecasting tools;

(7) the setting-up of readily accessible databases for the dissemination of oxygen observations and the integration of these observations into global aquatic system observation initiatives.

Reference

Friedrich J. & F. Janssen et al.: Investigating hypoxia in aquatic environments: diverse approaches to addressing a complex phenomenon (submitted to Biogeosciences Discussions), http://www.biogeosciences-discuss.net/10/12655/2013/

Acknowledgements

Antje Boetius for initiating and supporting the project

The HYPOX team

EC FP7 project “HYPOX” grant 226213

Additional funding by:
Max-Planck-Society
Helmholtz Zentrum Geesthacht Center for Materials and Coastal Research
Alfred Wegener Institute Helmholtz Center for Polar and Marine Research

This study is a contribution to the project "Land-Ocean Interactions in the Coastal Zone" (LOICZ)

Further reading

Friedrich J. & F. Janssen et al.: Investigating hypoxia in aquatic environments: diverse approaches to addressing a complex phenomenon (submitted to Biogeosciences Discussions)
http://www.biogeosciences-discuss.net/10/12655/2013/

http://www.hypox.net/