Benthic oxygen flux observations as a measure of ecosystem state and impacts: strengths, limitations, and available technologies

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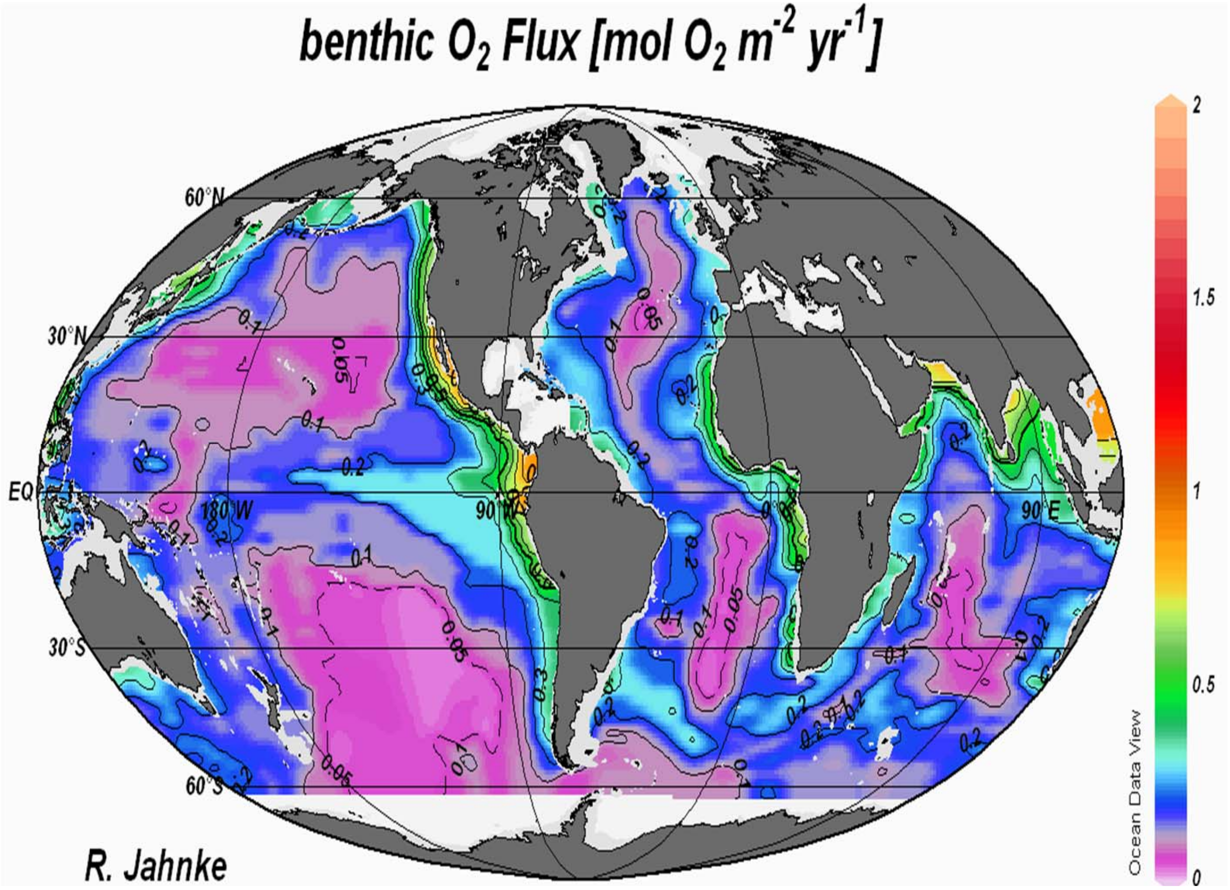
Introduction:
Why monitor seafloor oxygen fluxes?

- Measure of organic matter remineralization, i.e. the antagonist of the biological pump & burial
  > key function of benthic ecosystems (i.e., compartment most impacted by mining) with high relevance for large scale element fluxes
- Global estimates of carbon mineralization at the seafloor are built on O_2 flux measurements



Jahnke, R. (2003)

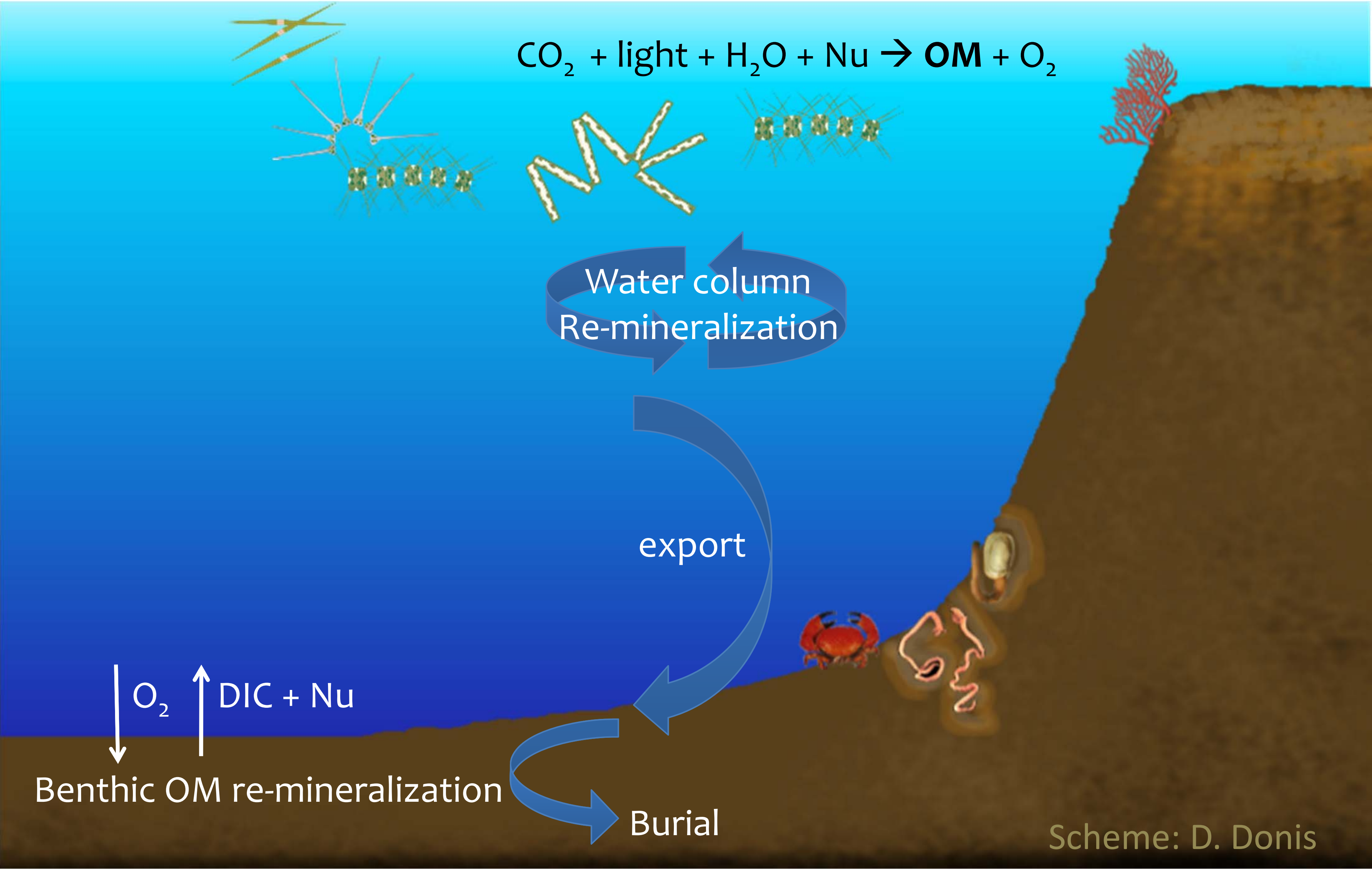
Introduction:
Potential and implementation for monitoring

- High potential for monitoring
  > Well established indicator to characterize ecosystems with potential for autonomous (i.e., continuous & 'low cost') observations
  > good sensors for precise oxygen flux measurements available
  > Instruments can be bought off the shelf (for discrete observations during expeditions)
- Application restricted to basic science
  > rarely used in routine ecosystem monitoring
  > hardly mentioned in ISA recommendations
  > (one) reason: specialist technology (sophisticated instruments, delicate sensors)

Introduction:
Aim of the talk

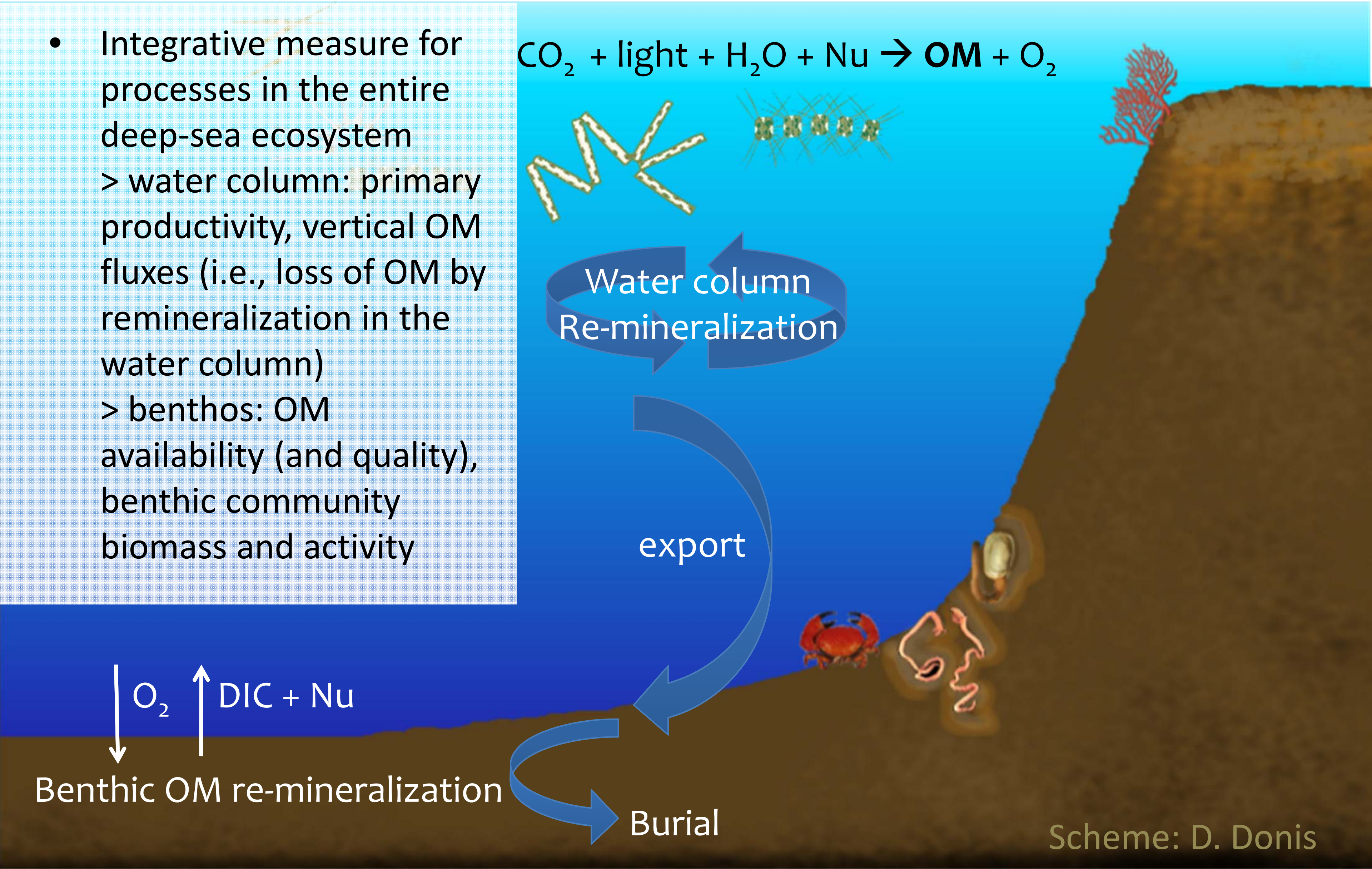
- Assess the appropriateness of benthic oxygen fluxes as parameter for deep-sea environmental monitoring and impact assessment
  > what processes / functions are addressed?
  > how do measurements take place?
  > what is the oxygen uptake of healthy ecosystems?
  > scales and levels of natural variations?
  > are natural gradients resolved, i.e., can we expect that impacts are?
  > improved technologies

Introduction:
Processes addressed



Introduction:
Processes addressed

- Integrative measure for processes in the entire deep-sea ecosystem
  > water column: primary productivity, vertical OM fluxes (i.e., loss of OM by remineralization in the water column)
  > benthos: OM availability (and quality), benthic community biomass and activity



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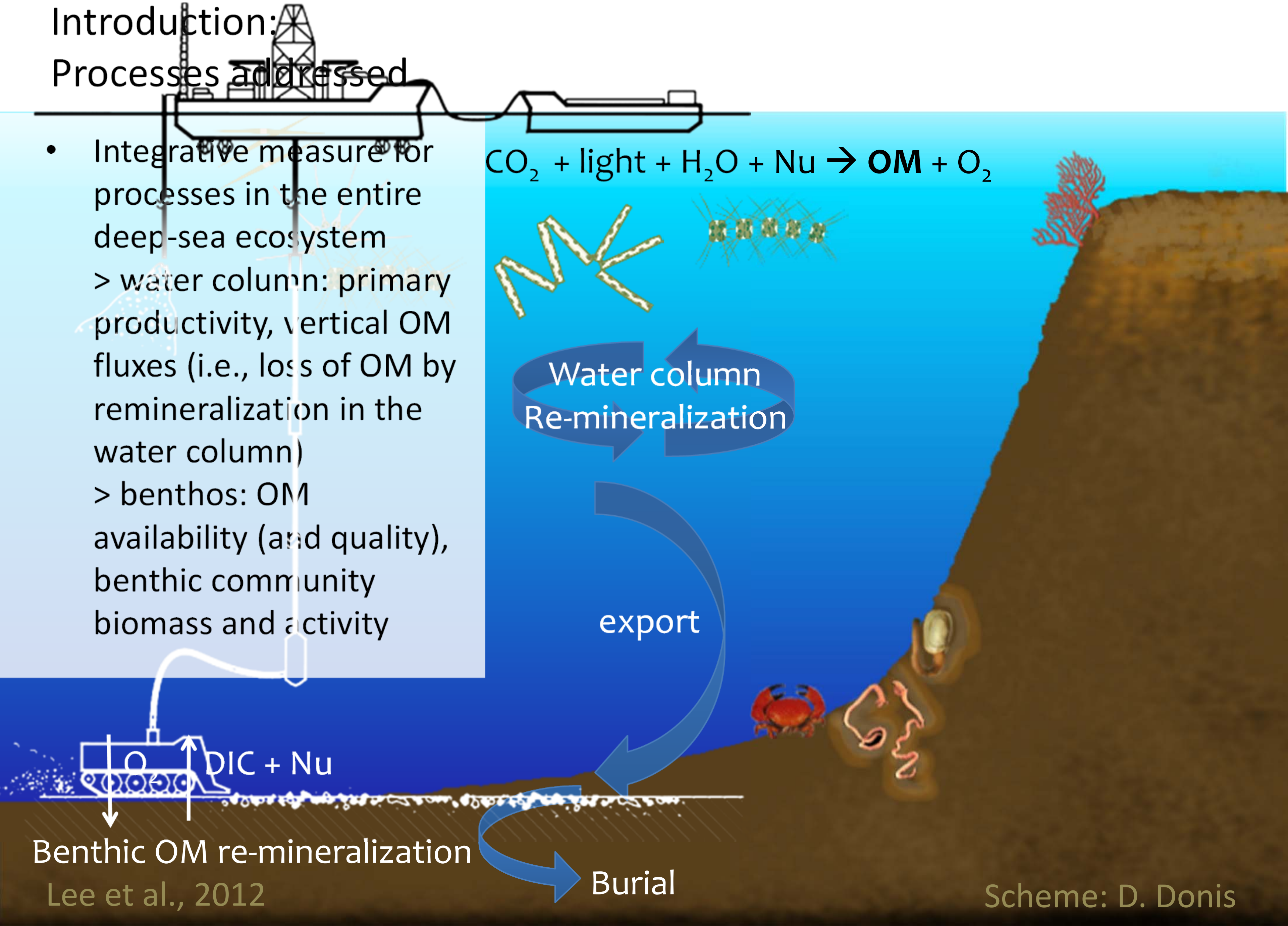
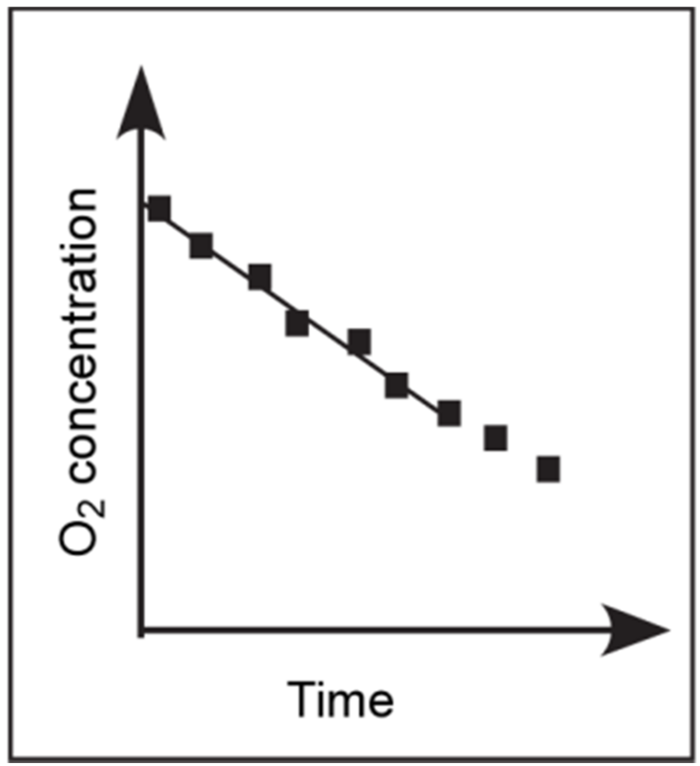


Flux monitoring approaches (1): Chamber incubations

- Principle
  > sediment enclosures, evolution of O_2 in chamber water
  > total oxygen fluxes, integrated over enclosed patch



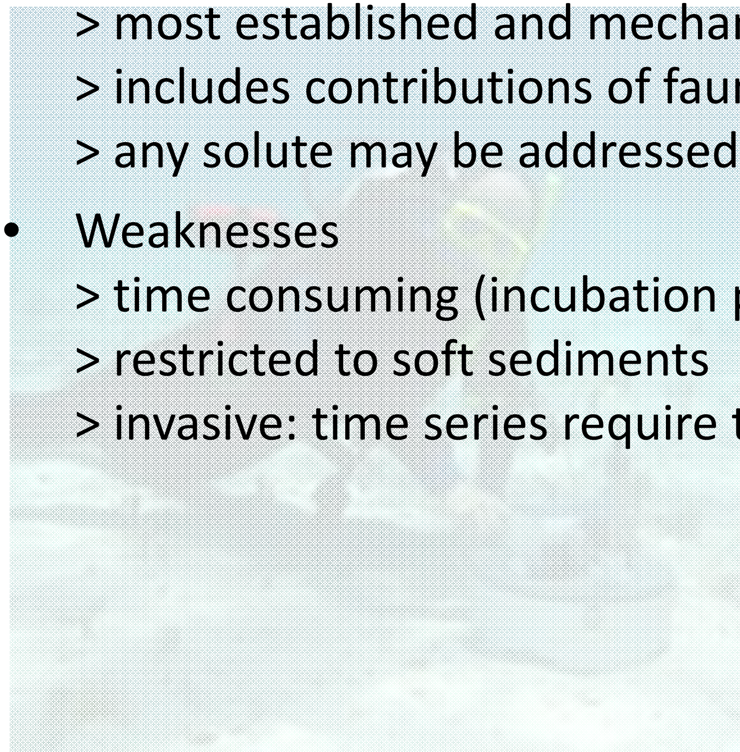
$$TOU = \frac{V}{A}\frac{dC}{dt}$$

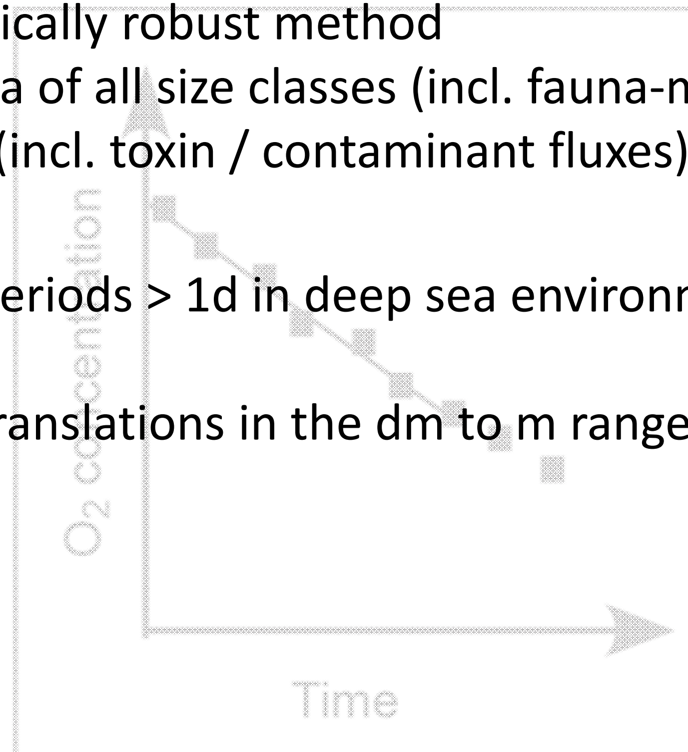
www.esf.edu

Glud, 2008

Flux monitoring approaches (1): Chamber incubations

- Principle
  > sediment enclosures, evolution of O2 in chamber water
  > total oxygen fluxes, integrated over enclosed patch
- Strengths
  > most established and mechanically robust method
  > includes contributions of fauna of all size classes (incl. fauna-mediated uptake)
  > any solute may be addressed (incl. toxin / contaminant fluxes)
- Weaknesses
  > time consuming (incubation periods > 1d in deep sea environments)
  > restricted to soft sediments
  > invasive: time series require translations in the dm to m range



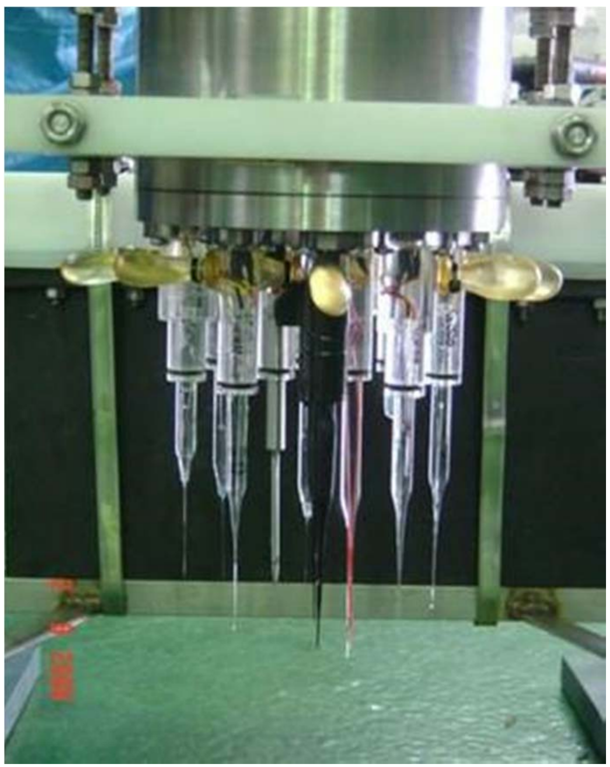


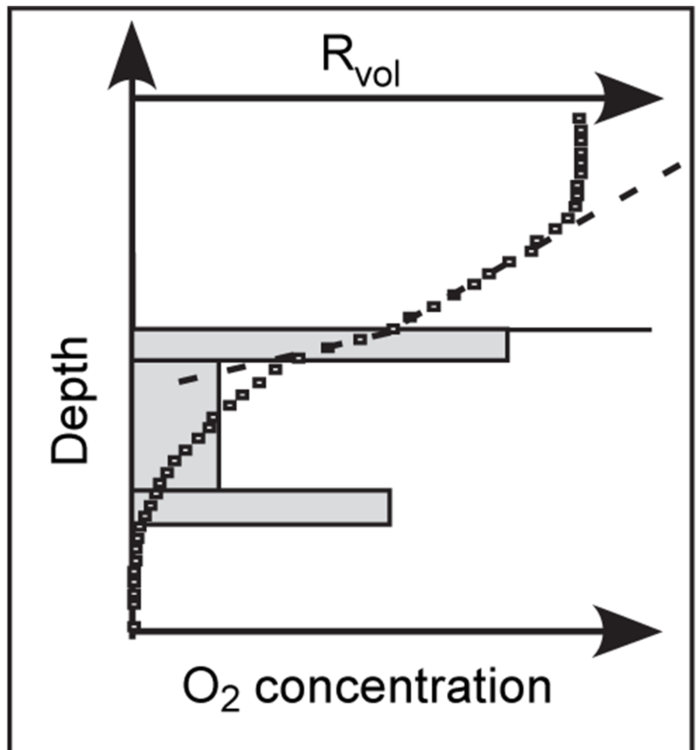
$$TOU = \frac{V}{A}\frac{dC}{dt}$$

Glud, 2008

Flux monitoring approaches (2):
Micro profiler

- Principle
  > high resolution O_2 gradients, transport modelling (DBL or Surface sediment) or transport reaction modeling
  > diffusive flux (DOU) at the profiling spot





$$DOU = D_o \frac{dC}{dz}$$

$$DOU = D_s \frac{dC}{dz}$$

$$D_o < D_s$$

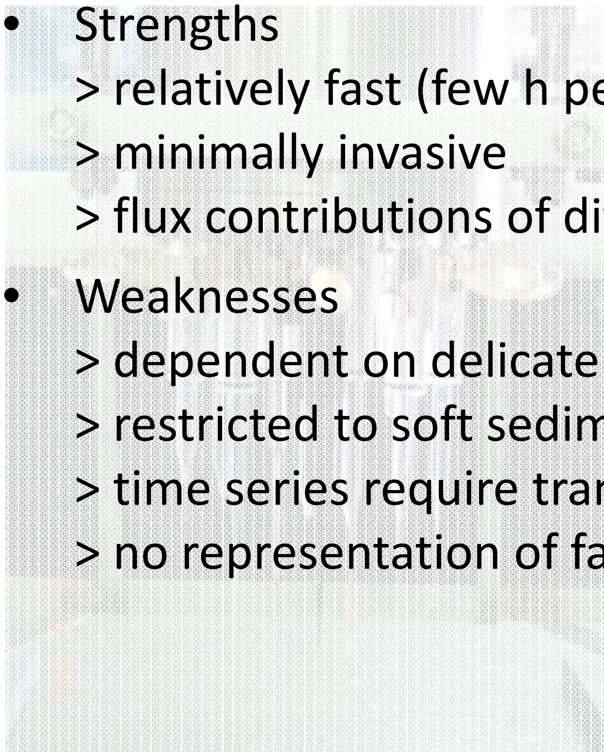
$$R_{vol} = D_s \frac{dC^2}{d^2z}$$

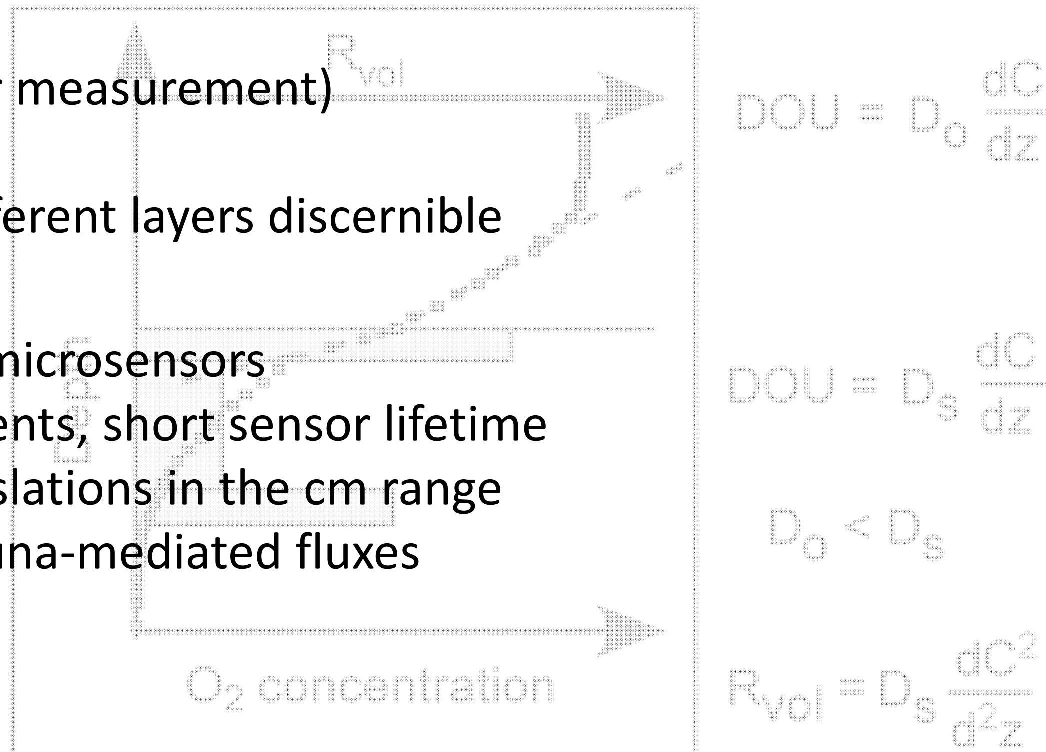
www.planeterde.de

Glud, 2008

Flux monitoring approaches (2): Micro profiler

- Principle
  > high resolution flux gradients, simple transport modelling (DBL) or transport-reaction modeling (Surface sediment)
  > diffusive flux (DOU) at the profiling spot
- Strengths
  > relatively fast (few h per measurement)
  > minimally invasive
  > flux contributions of different layers discernible
- Weaknesses
  > dependent on delicate microsensors
  > restricted to soft sediments, short sensor lifetime
  > time series require translations in the cm range
  > no representation of fauna-mediated fluxes

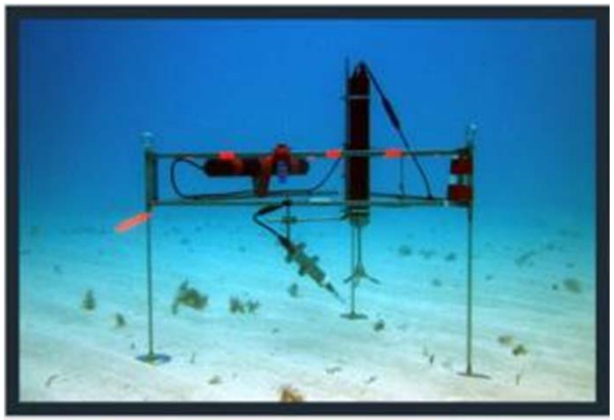


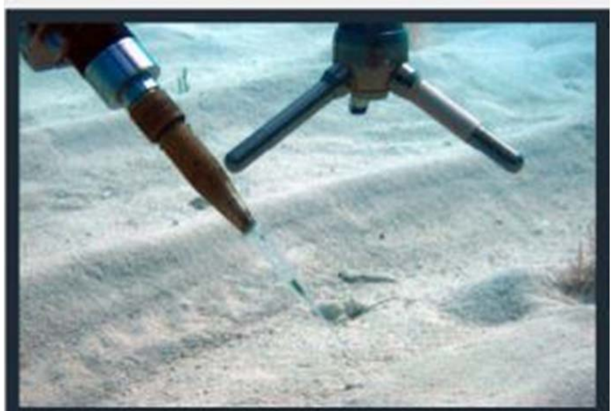


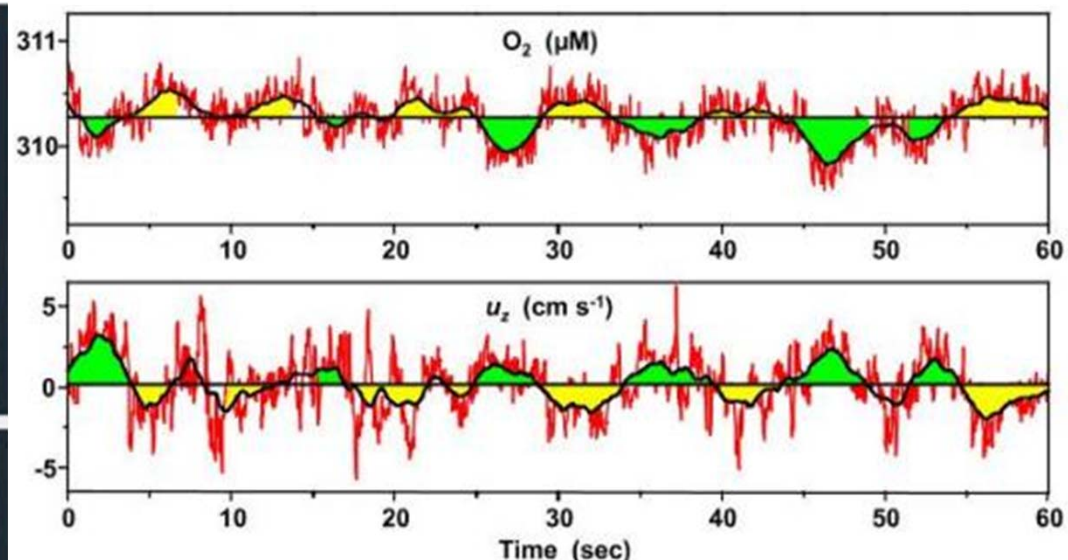
Glud, 2008

Flux monitoring approaches (3):
Eddy correlation

- Principle
  > simultaneous observations of oxygen concentration and vertical flow velocity, assessment of eddy transport (C x v)
  > total flux of a larger area upstream







Markus Hüttel

www.faculty.virginia.edu/berg

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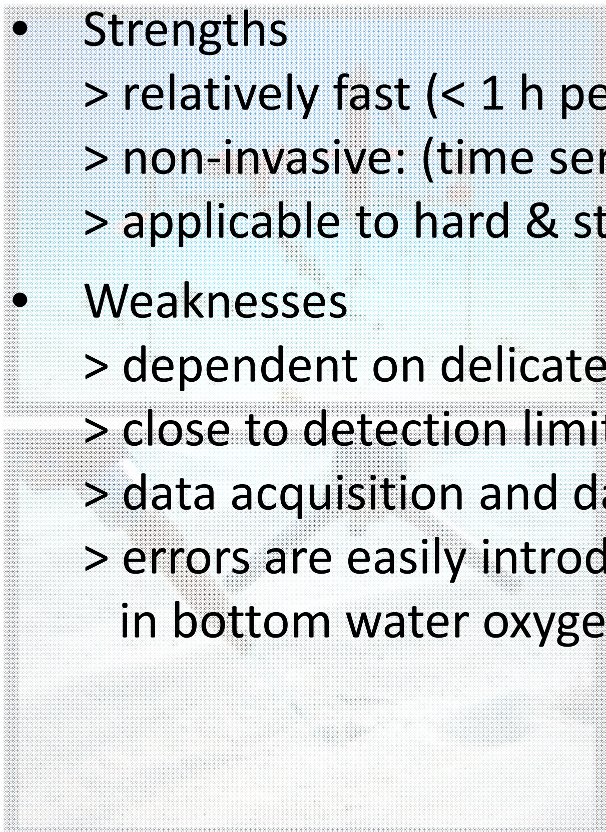
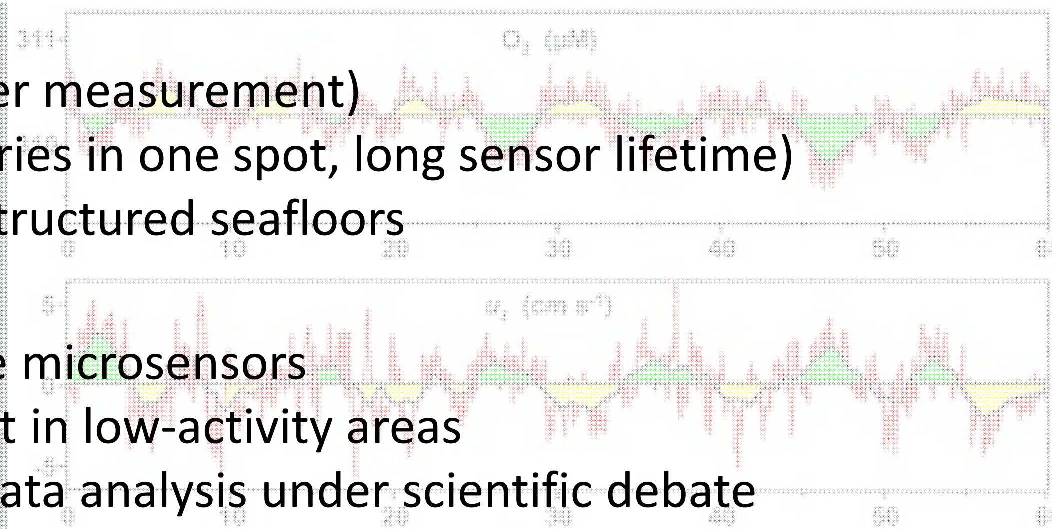


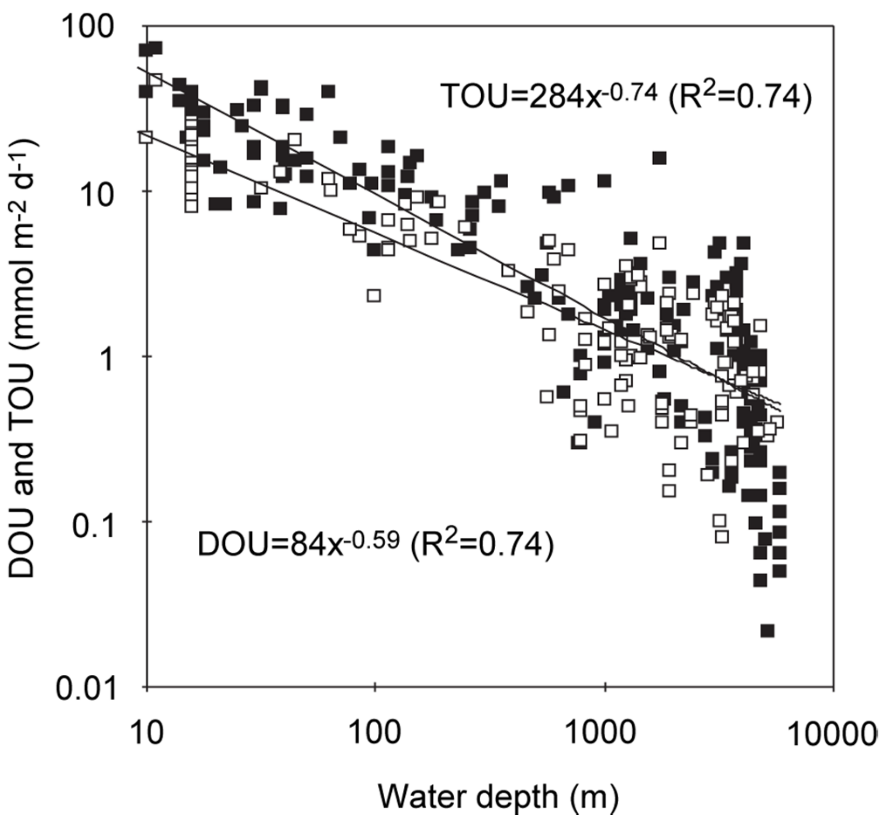


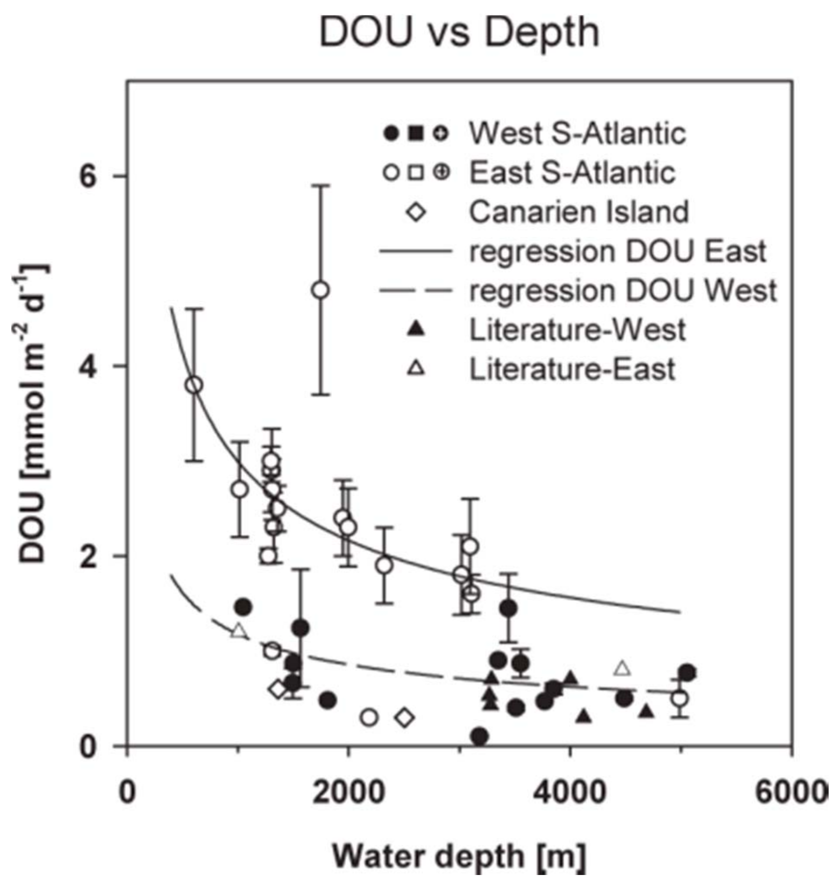
- Strengths
  > relatively fast (< 1 h per measurement)
  > non-invasive: (time series in one spot, long sensor lifetime)
  > applicable to hard & structured seafloors

- Weaknesses
  > dependent on delicate microsensors
  > close to detection limit in low-activity areas
  > data acquisition and data analysis under scientific debate
  > errors are easily introduced (sensor performance & orientation, lateral changes in bottom water oxygenation)

Oxygen fluxes of healthy environments: Fluxes indicative of good environmental status?

- Absolute fluxes are site specific – the most prominent pattern is depth
- Some of the variability can be explained by surface productivity



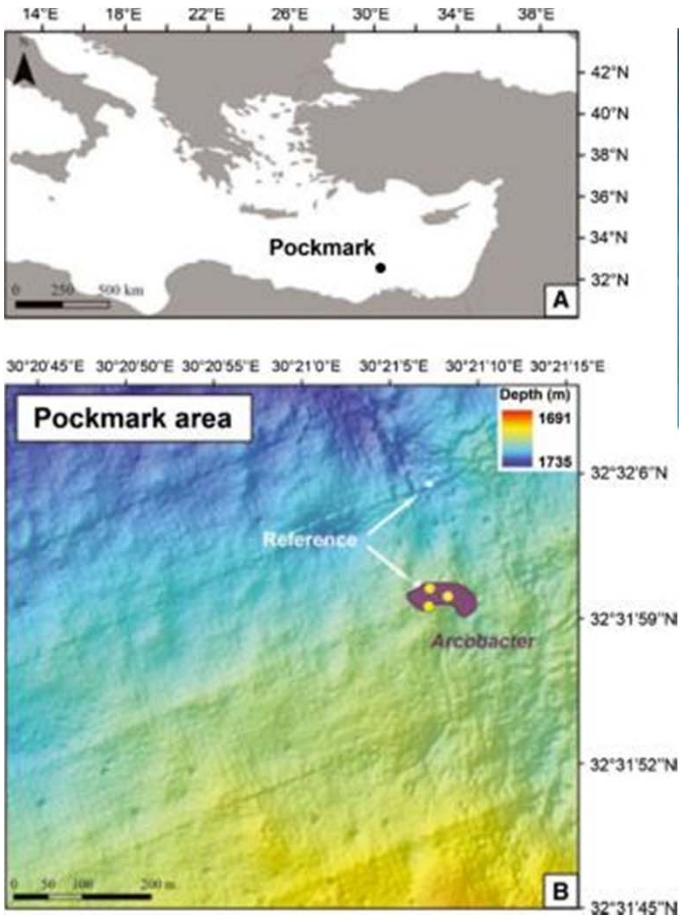


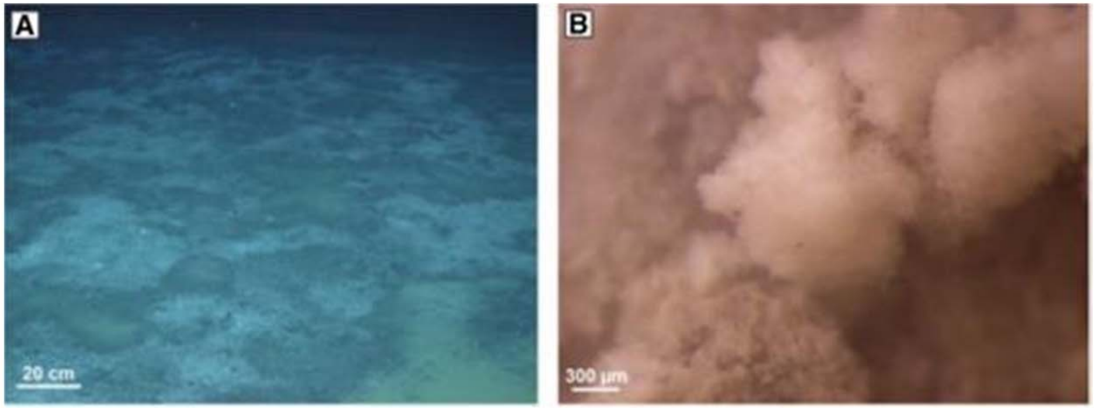
Glud, 2008

Wenzhöfer & Glud 2002

Environmental gradients as a analogue of impact-related effects (1): sulfide efflux at cold seeps

- Chambers and micro profilers are used to compare oxygen demand at seep sites with nearby reference areas in pockmark areas in the deep sea Nile fan

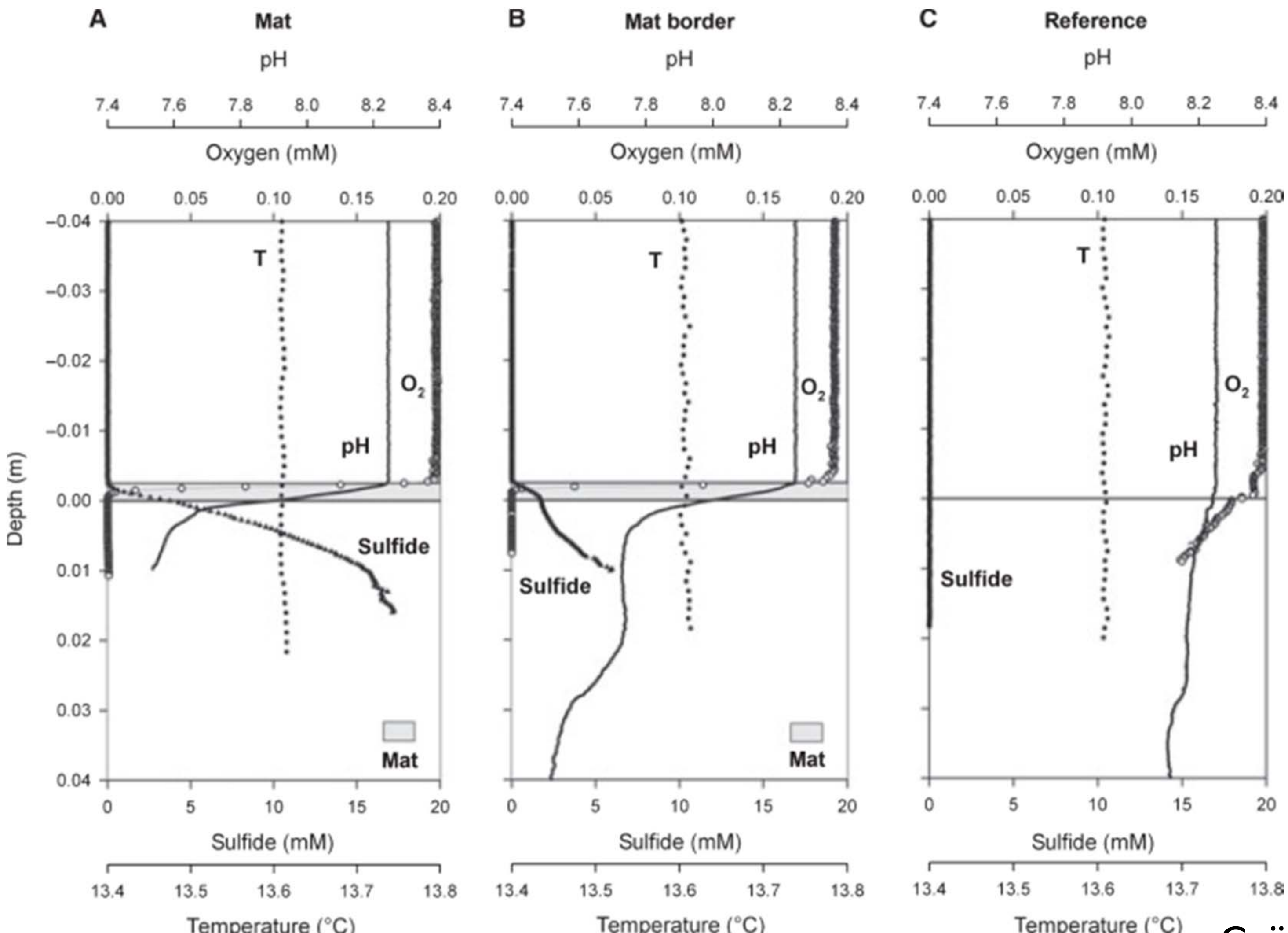




Grünke et al. 2011

Environmental gradients as a analogue of impact-related effects (1): sulfide efflux at cold seeps

- Micro sensor profiles and fluxes



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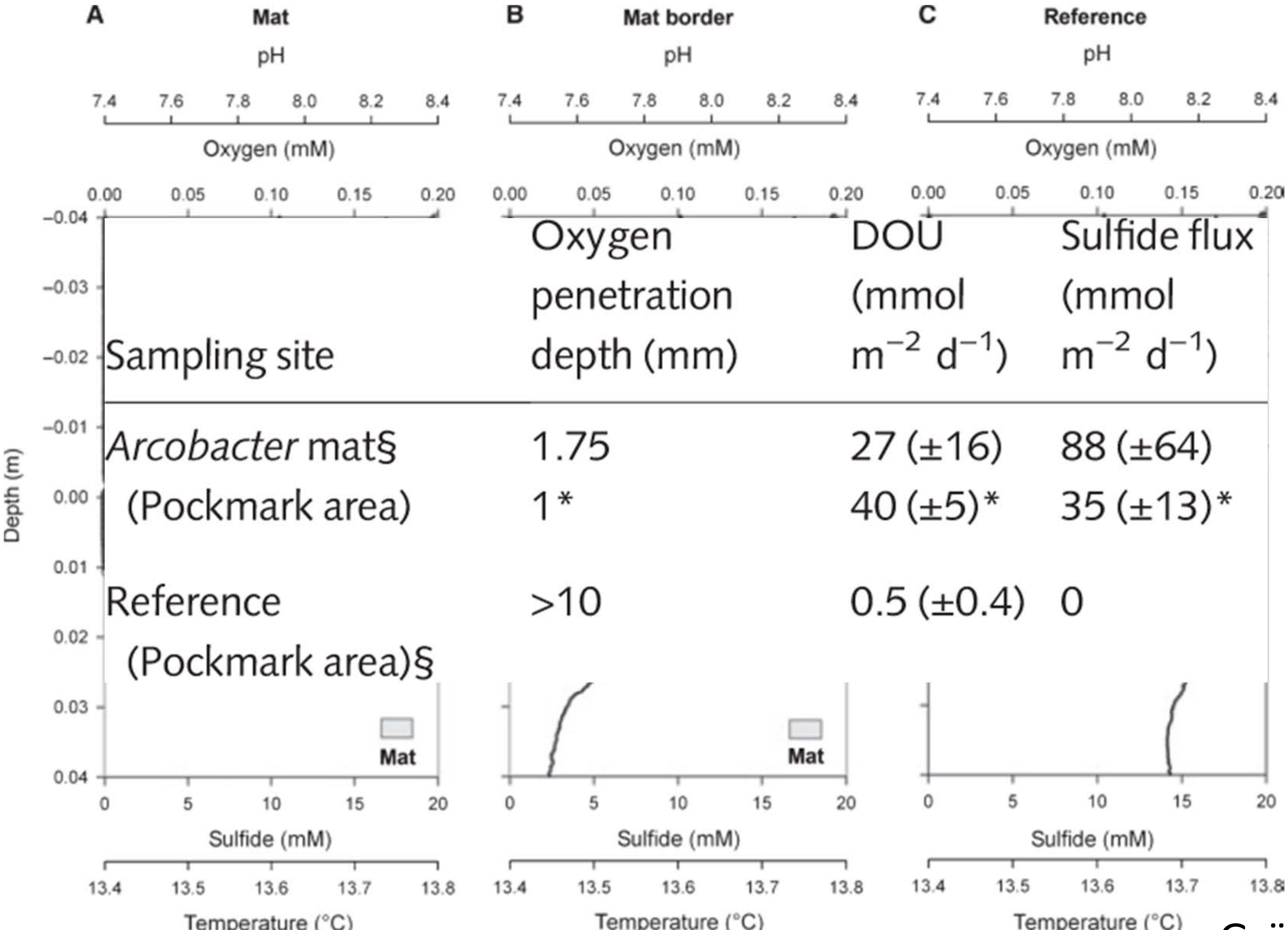
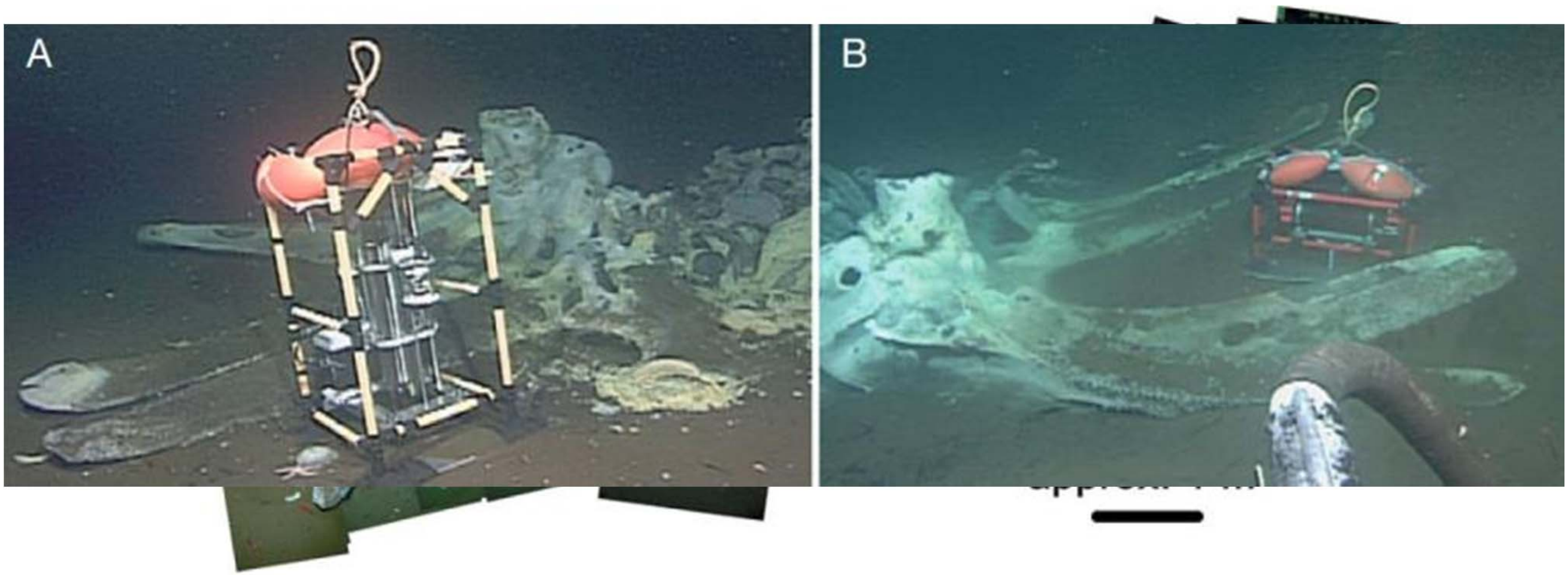


Sampling site	Oxygen penetration depth (mm)	DOU (mmol m^{-2} d^{-1})	Sulfide flux (mmol m^{-2} d^{-1})
Arcobacter mat§	1.75	27 (±16)	88 (±64)
(Pockmark area)	1*	40 (±5)*	35 (±13)*
Reference	>10	0.5 (±0.4)	0
(Pockmark area)§			

Grünke et al. 2011

Environmental gradients as a analogue of impact-related effects (2): OM gradients at an artificial whale fall (California margin, 1700 m)

- Chambers and micro profilers are used to compare sediment oxygen demand at different distance to the largely decomposed whale carcass



Treude et al. 2009

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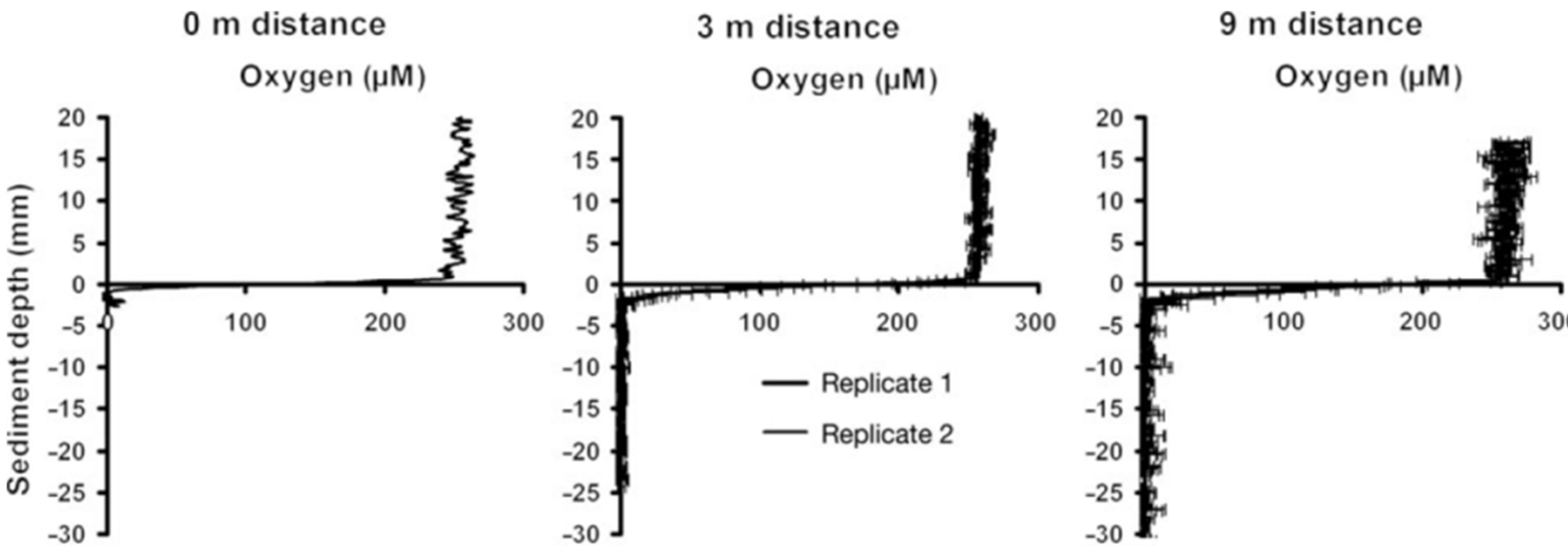

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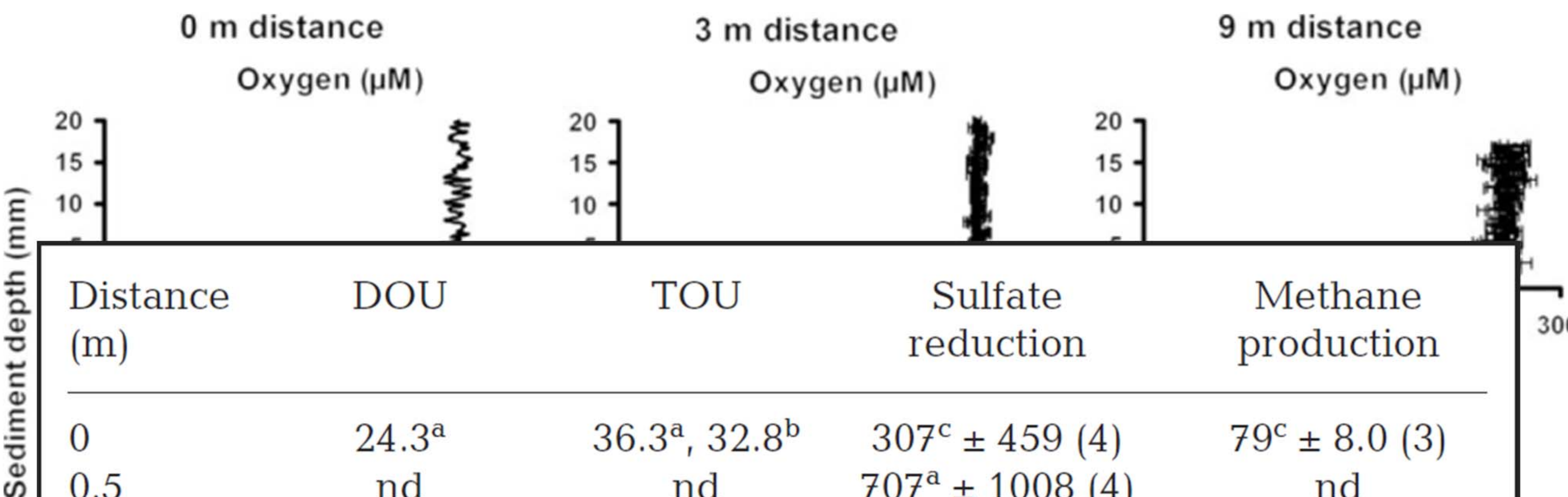


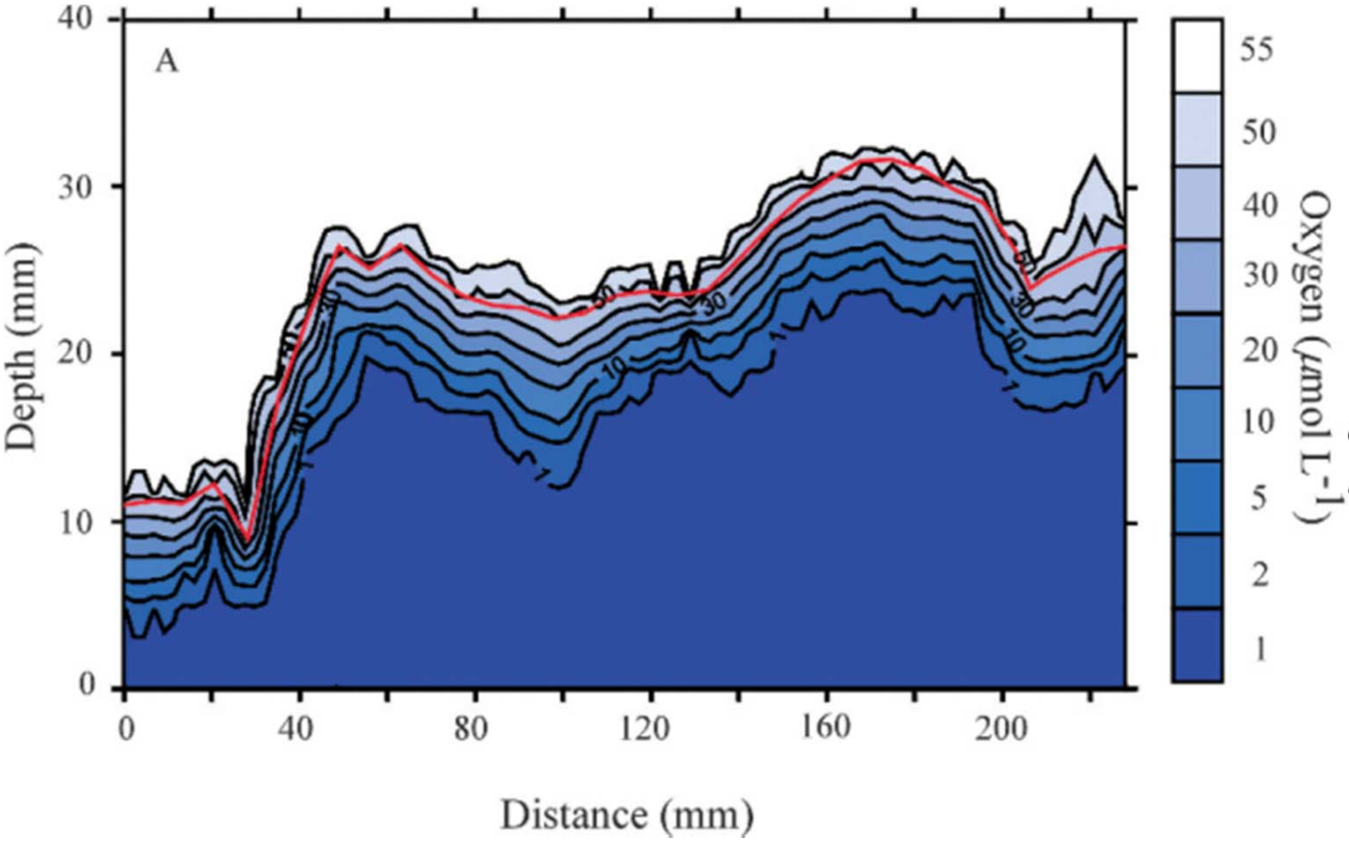
Distance (m)	DOU	TOU	Sulfate reduction	Methane production
0	24.3[a]	36.3[a], 32.8[b]	307[c] ± 459 (4)	79[c] ± 8.0 (3)
0.5	nd	nd	707[a] ± 1008 (4)	nd
1	nd	nd	0.39 ± 0.38 (3)	1.1 ± 0.07 (3)
3	18.7 ± 0.62 (4)	nd	0.05 ± 0.08 (3)	0.29 ± 0.03 (3)
9	14.8 ± 0.84 (3)	22.3	0.18 ± 0.04 (2)	nd

[a]Black patch, [b]between jaw bones, [c]bacterial mat

Treude et al. 2009

Natural variability in benthic oxygen fluxes on small spatial scales: Micro profiler transects (Sagami Bay, Japan, 1450m)

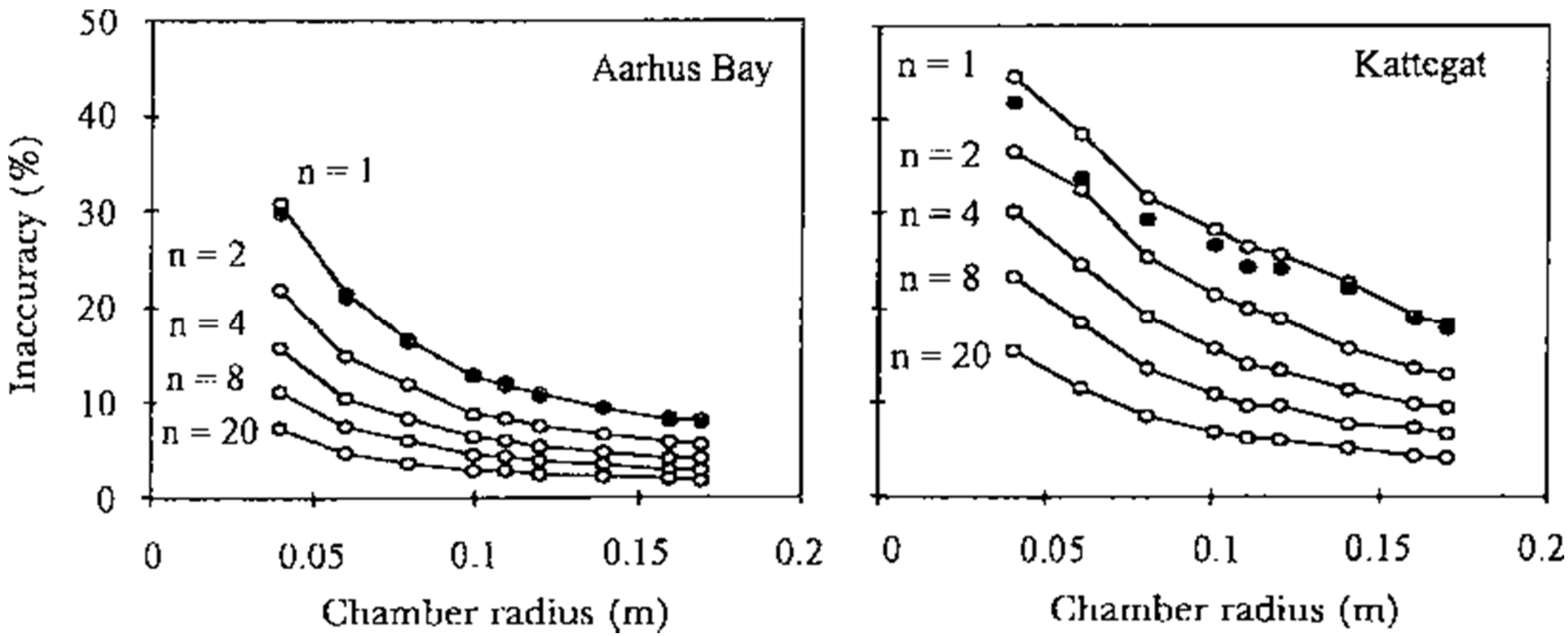
- The deep sea floor is heterogeneous and oxygen conditions and fluxes vary on any spatial scale



Glud et al. 2009

How to address spatial variability: a modeling approach

- Chamber size / replication needed to ‘remove’ fauna induced variability

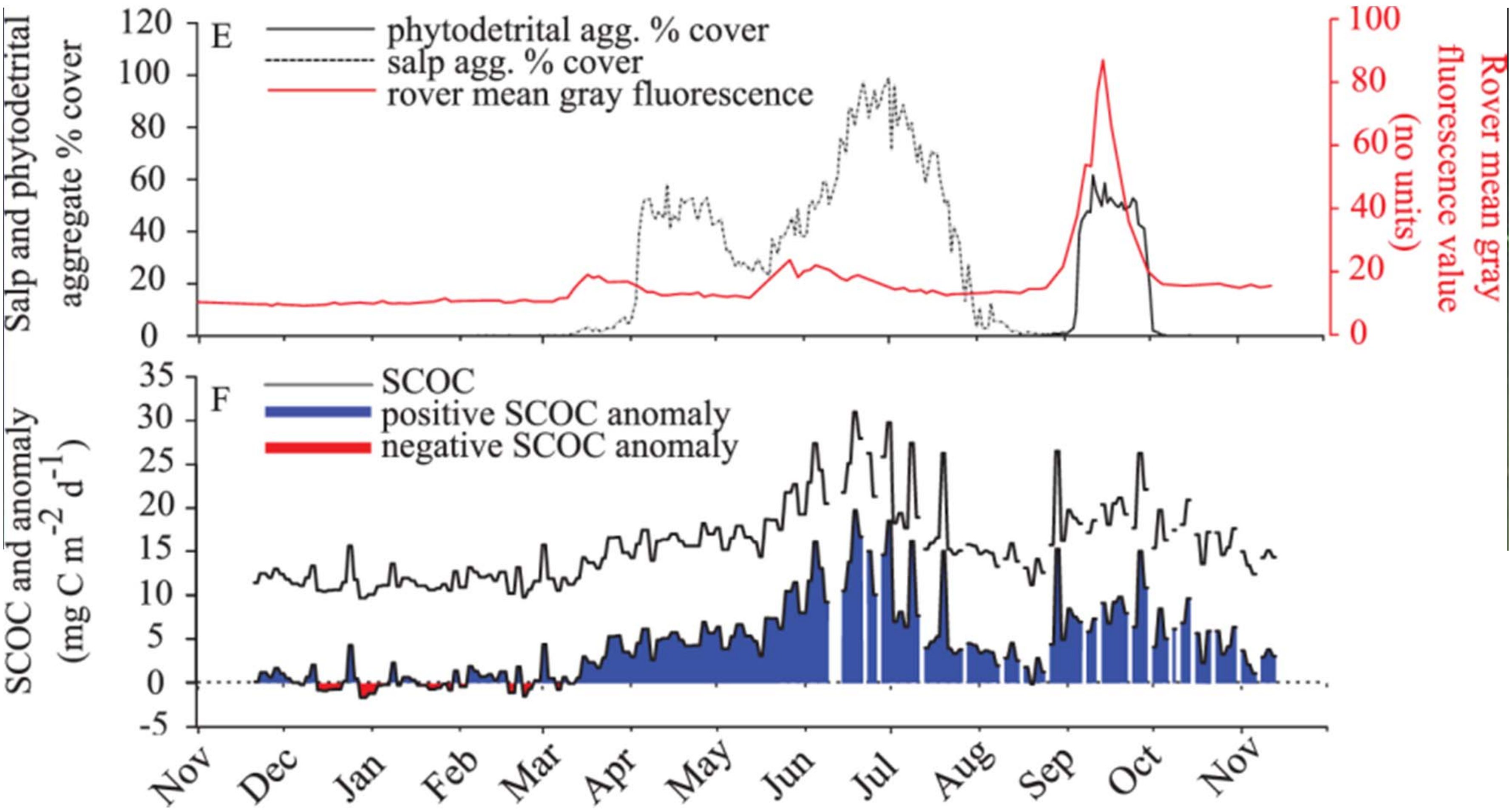


Small bivalve dominated *Large ophiuroid dominated*

Glud & Blackburn 2002

Temporal variability in deep sea oxygen fluxes: Time series chamber incubations (MBARI's 'Benthic Rover', Stat. M)

- Seasonal variations in water column primary and secondary productivity are transferred to the deep sea floor and reflected in O_2-flux (NE Pacific, 4000 m)



Smith et al. 2014

Conclusions

- Methods for oxygen flux measurements are well established
- Oxygen flux measurements can resolve natural spatiotemporal patterns (e.g., in geochemical conditions, OM availability)
- To identify subtle changes, well established baseline studies are needed, taking seasonal variability into account, i.e. time series
- Depending how remote the ecosystem is this may require autonomous mobile platforms that are beginning to emerge
- Eddy correlation has a high potential for time series but needs improvement