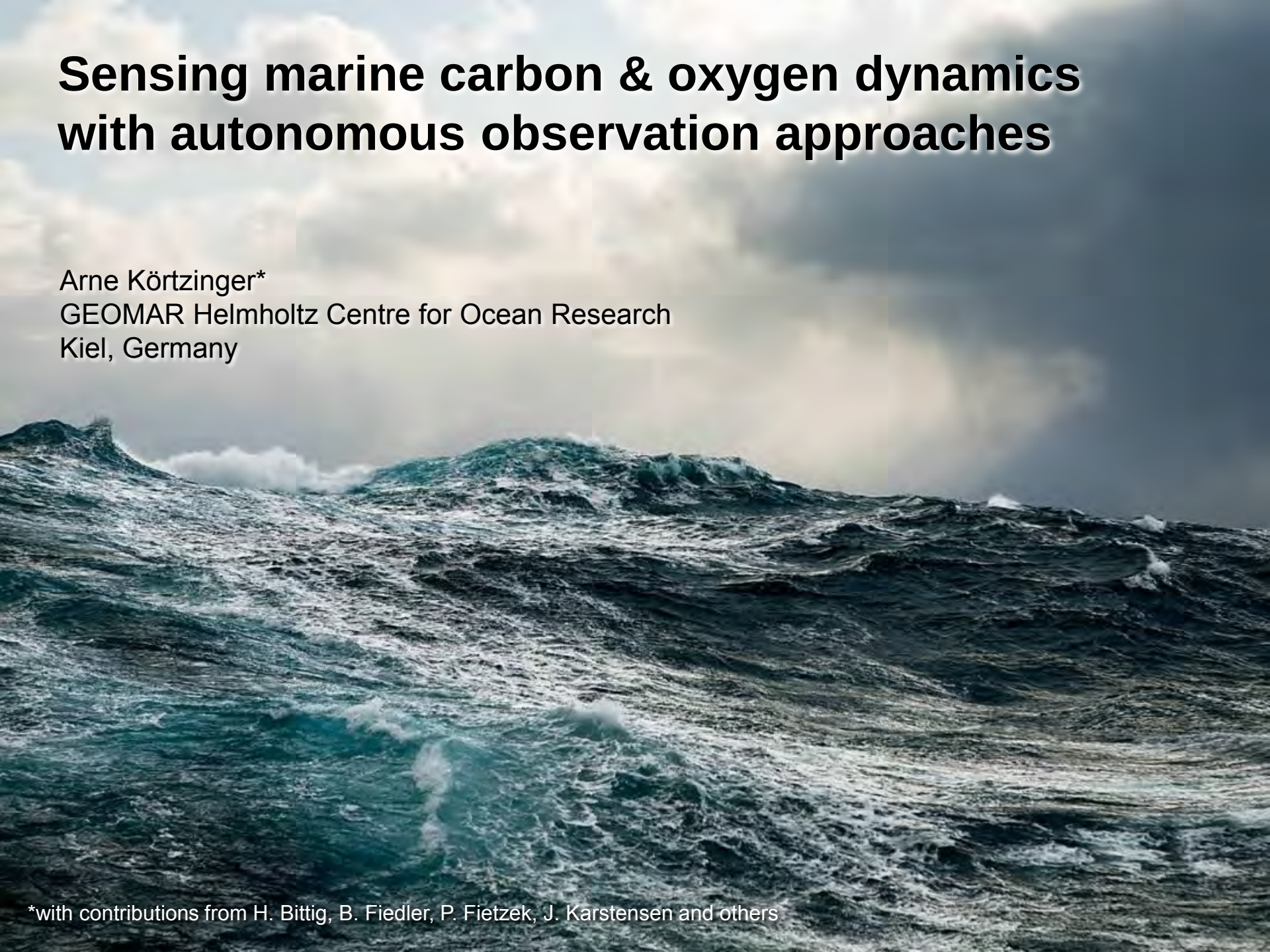
# Sensing marine carbon & oxygen dynamics with autonomous observation approaches

Arne Körtzinger*
GEOMAR Helmholtz Centre for Ocean Research
Kiel, Germany



*with contributions from H. Bittig, B. Fiedler, P. Fietzek, J. Karstensen and others

# Argo – a success story of physical oceanography

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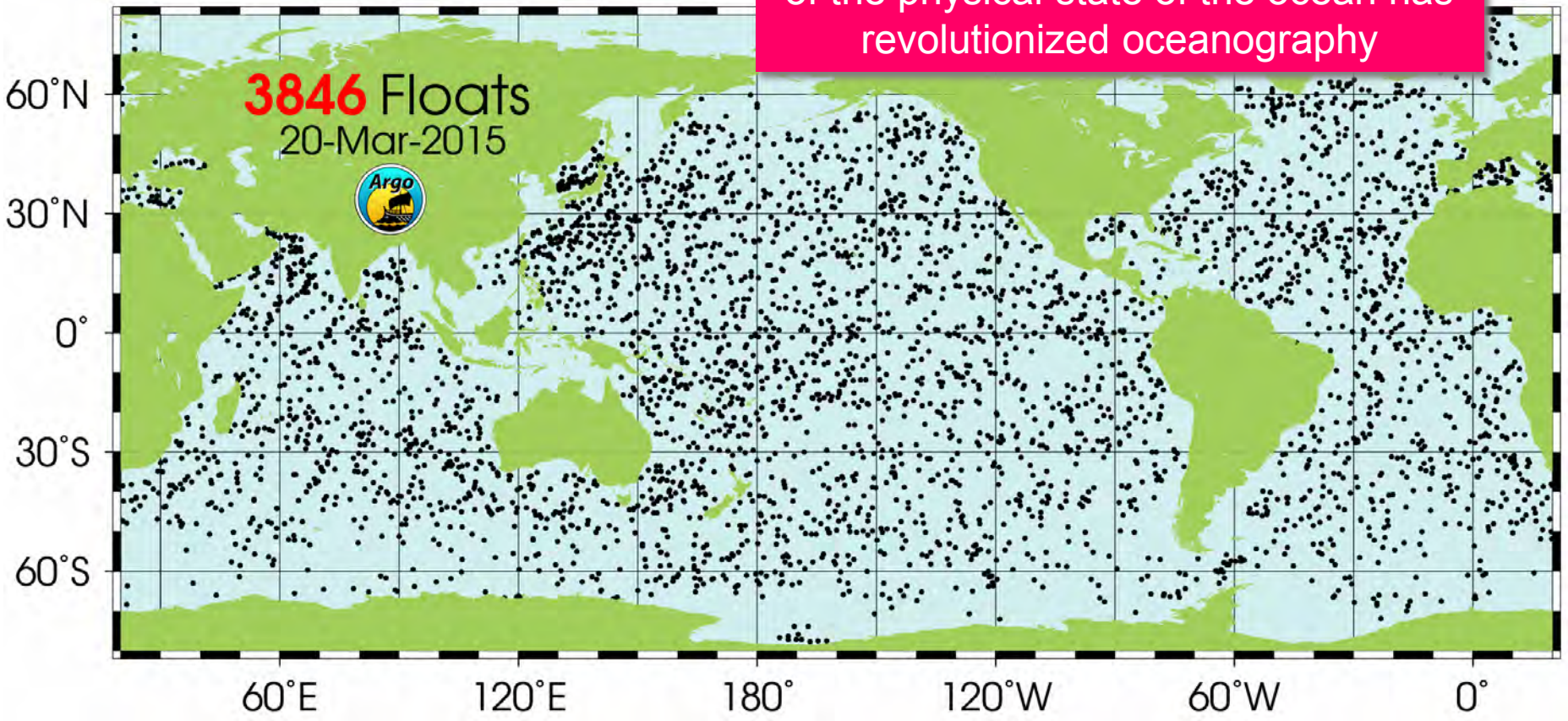
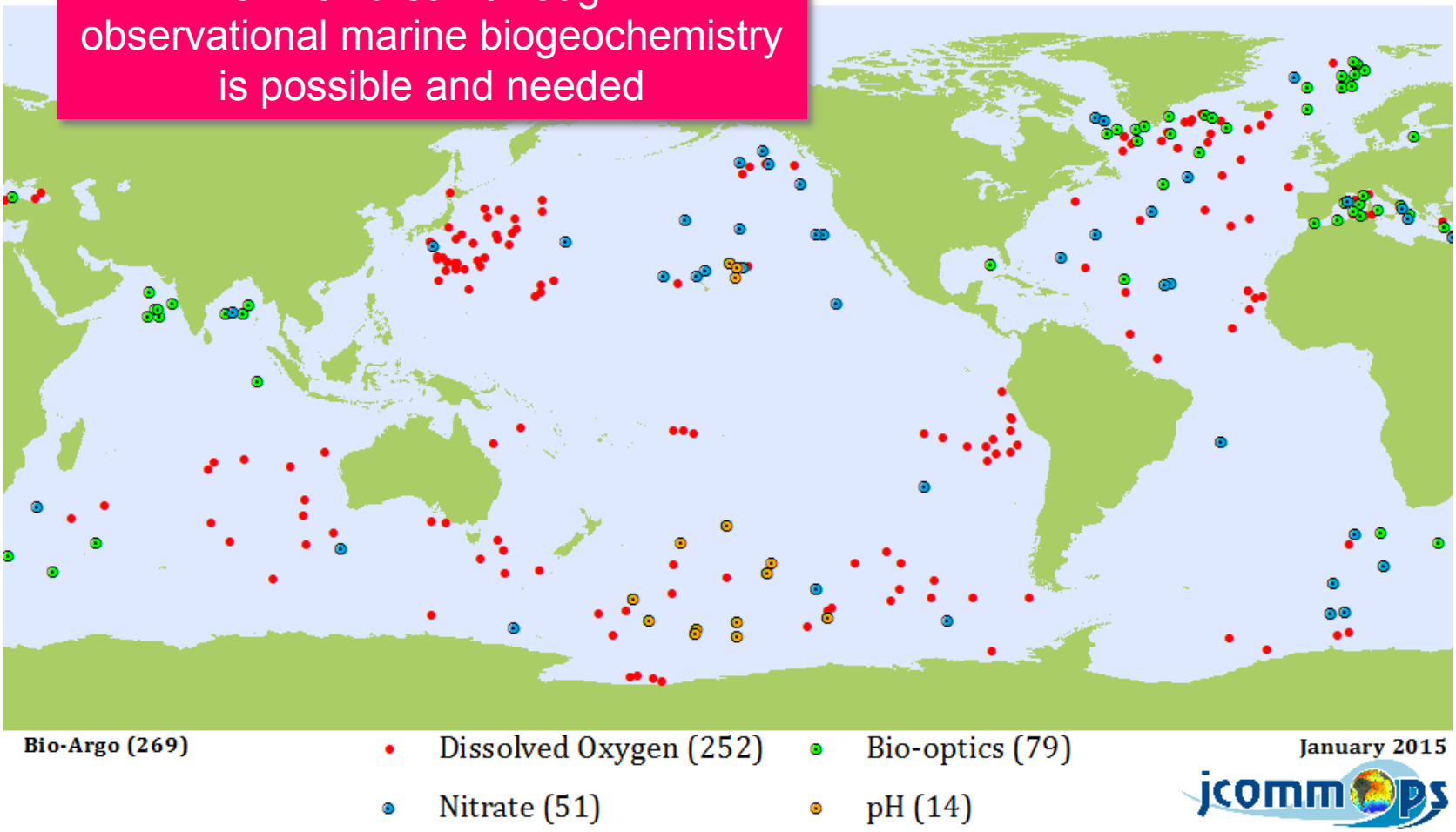
Since 2000, Argo's synoptic 3D-view of the physical state of the ocean has revolutionized oceanography



# Bio-Argo – future extension of Argo into bgc

A similar break-through in observational marine biogeochemistry is possible and needed



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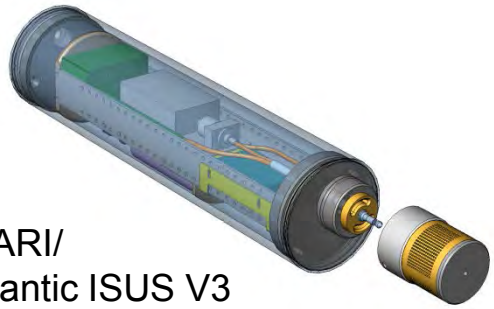
## Available Sensors

- Oxygen: mature optode technology
- Nitrogen: ISUS/SUNA nitrate sensor
- pH, $pCO_2$: promising new sensors

CONTROS HydroC™ $CO_2$

Sea-Bird Optode SBE 63


Aanderaa (AADI) Optode 4330



MBARI/ Satlantic ISUS V3

MBARI/Sea-Bird Deep-Sea DuraFET

CONTROS HydroFlash™ $O_2$


Satlantic SUNA V2

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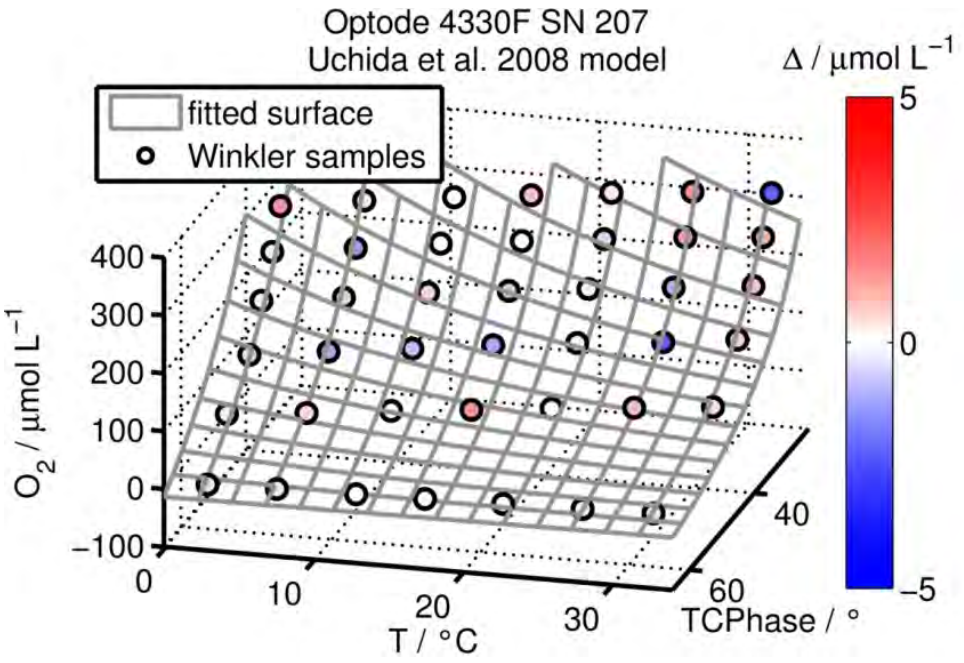
## High-accuracy multipoint calibration

- Number of setups available
- Accuracy 0.5 – 3.0 µmol/L
- Get matrix T x $O_2$ x $\Phi$
- Fit data to functional model of choice
- Similar calibration approach based on in-situ CTD cast

$$\frac{I_0}{I} = \frac{\tau_0}{\tau} = 1 + k_{SV} \cdot pO_2$$

*Stern-Volmer equation*




Bittig, Körtzinger *et al*. (2012), *Limnol. & Oceanogr.: Methods* **10**, 921-933.



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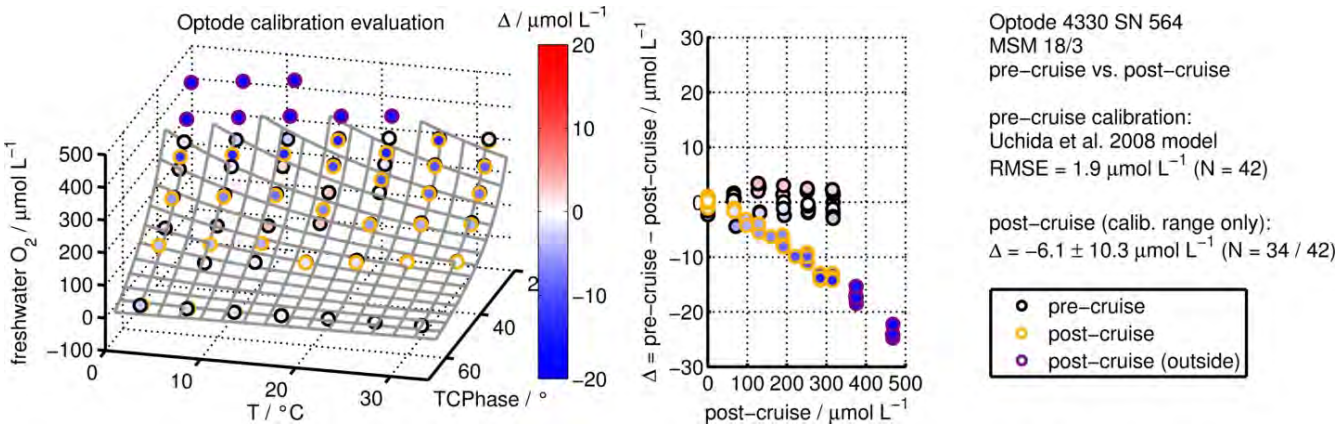
# Oxygen optodes – the most mature bgc sensor

Sensors show drift during storage & transport...

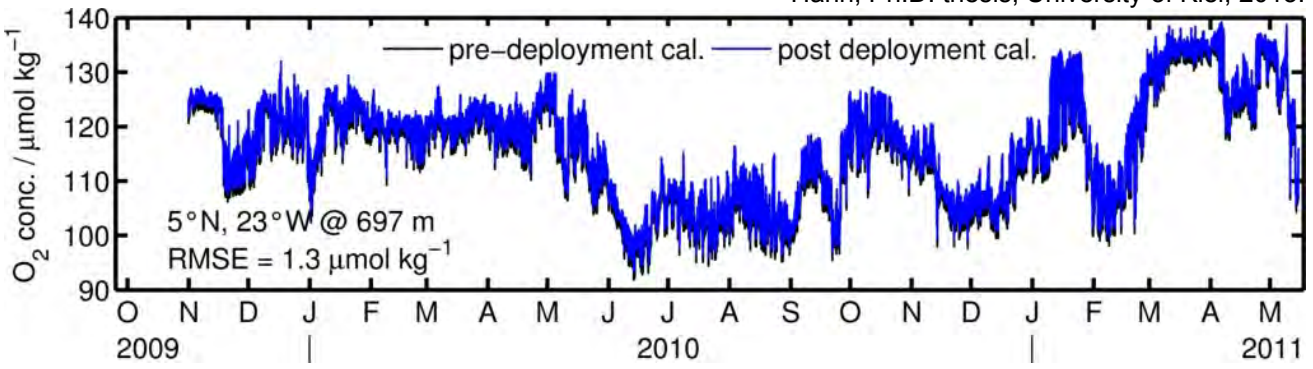
## Sensor drift




Bittig, Körtzinger *et al*. (2012), *Limnol. & Oceanogr.: Methods* **10**, 921-933.

...but not during deployments!?

Hahn, Ph.D. thesis, University of Kiel, 2013.



# Oxygen optodes – the most mature bgc sensor

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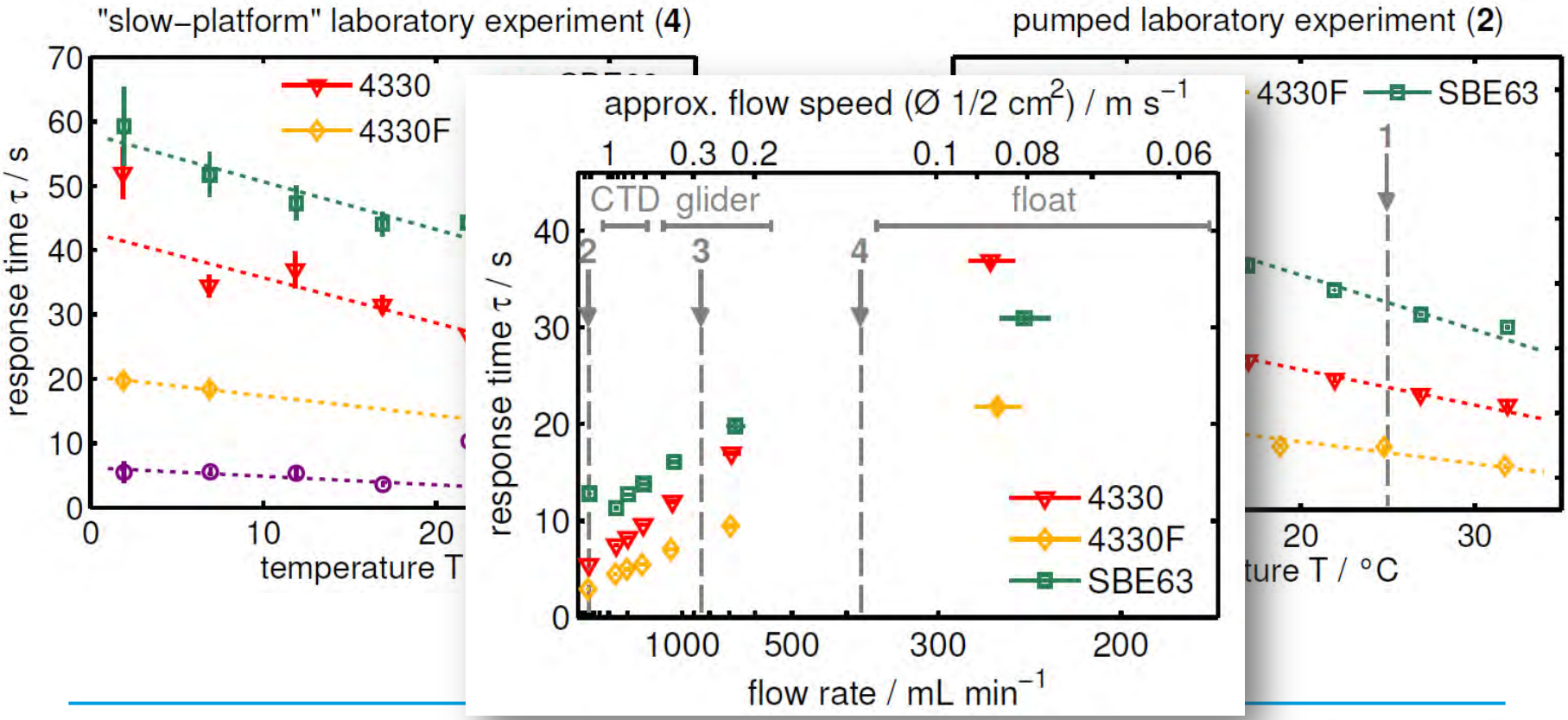
## Time response of oxygen optodes on profiling platforms and its dependence on flow speed and temperature

*Henry C. Bittig*, Björn Fiedler, Roland Scholz, Gerd Krahmann, and Arne Körtzinger*
Helmholtz Centre for Ocean Research Kiel (GEOMAR), Kiel/Germany

*Limnol. Oceanogr.: Methods* 12, 2014, 617–636

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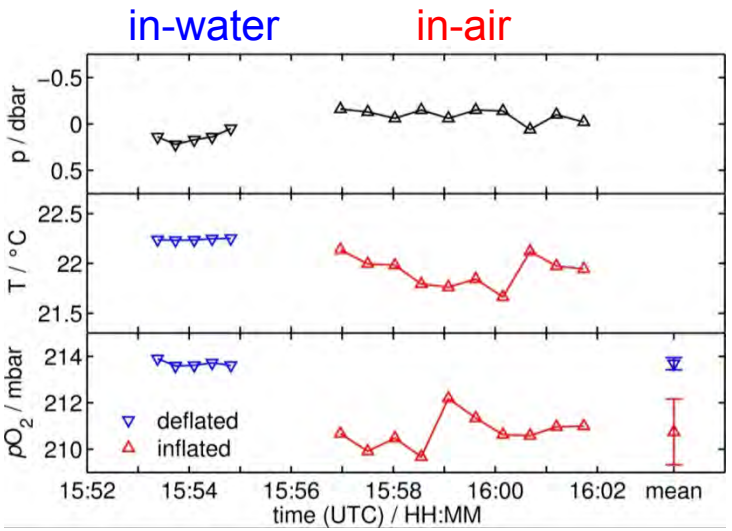
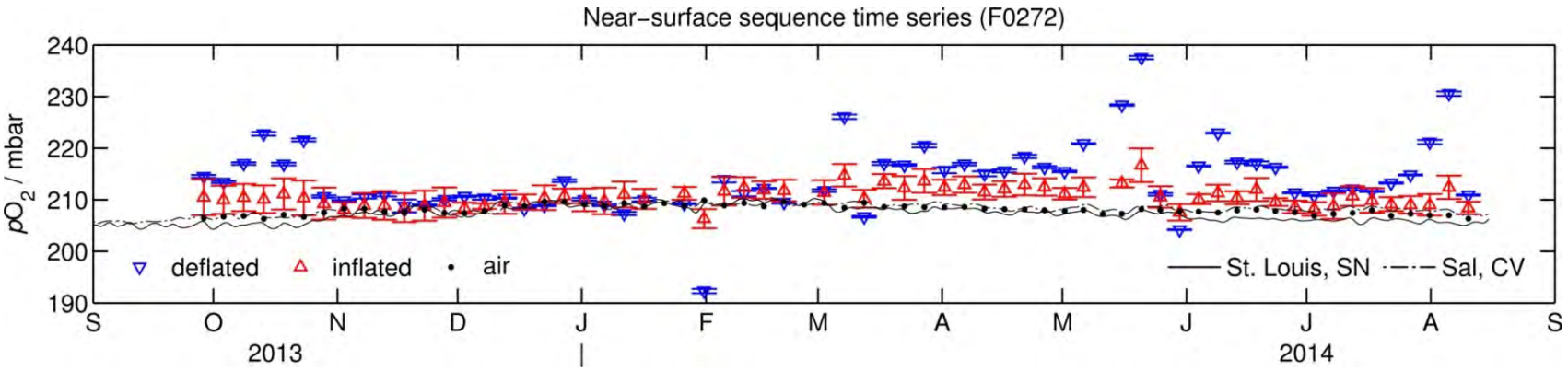
# Oxygen optodes – the most mature bgc sensor

## In-situ in-air measurements as drift check

- Carry-over effect that follows clear trend: Can be corrected for.
- Accurate in-situ reference (at saturation level)
- Available for entire float lifetime

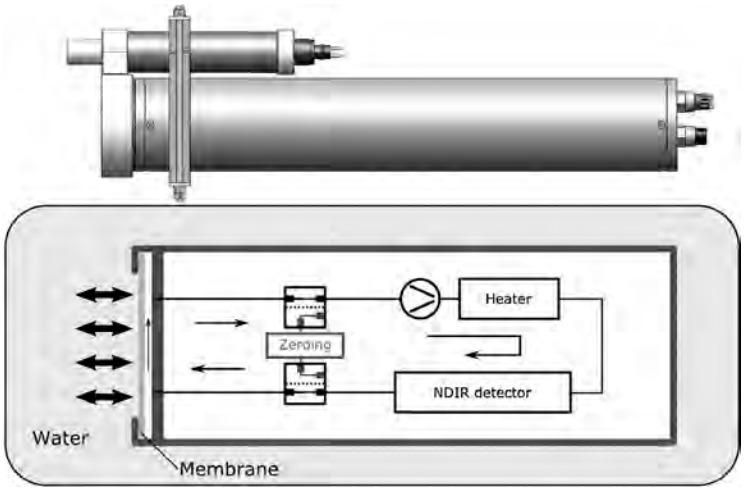


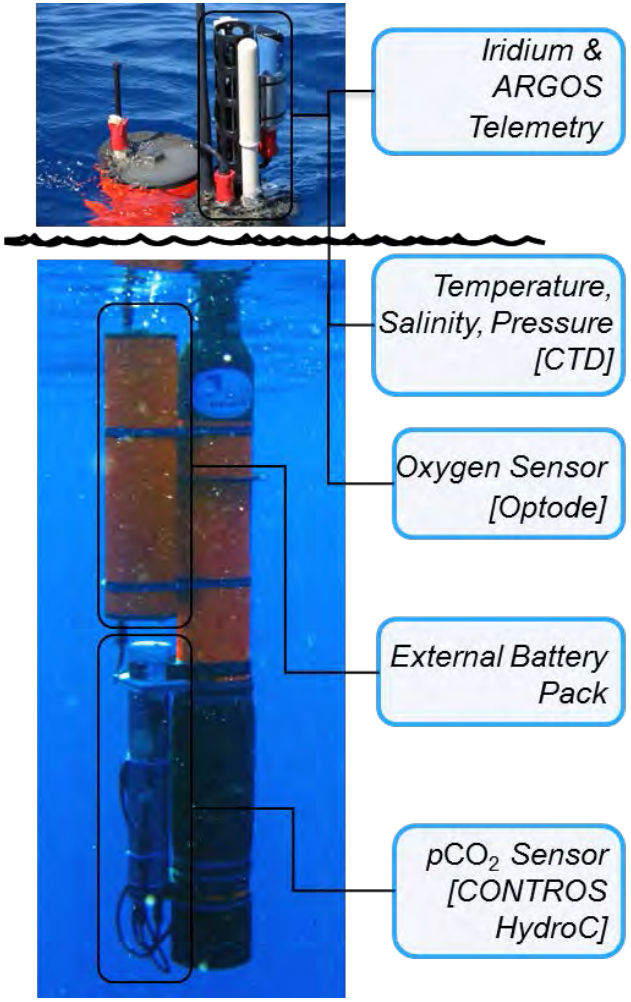

Bittig and Körtzinger (2015), *J. Atmos. Ocean Techn.*, in press.

# $pCO_2$ sensors – work in progress…

## $pCO_2$ sensor with membrane equilibration and NDIR-detection




| Sensor | Mean (μatm) | σ (μatm) | RMSE (μatm) | n |
|---|---|---|---|---|
| HC1 | −3.1 | 2.9 | 4.2 | 24 791 |
| HC2 | 1.8 | 3.4 | 3.9 | 24 163 |
| HC3 | −0.7 | 2.8 | 2.8 | 12 770 |
| Overall mean | −0.6 | 3.0 | 3.7 | |

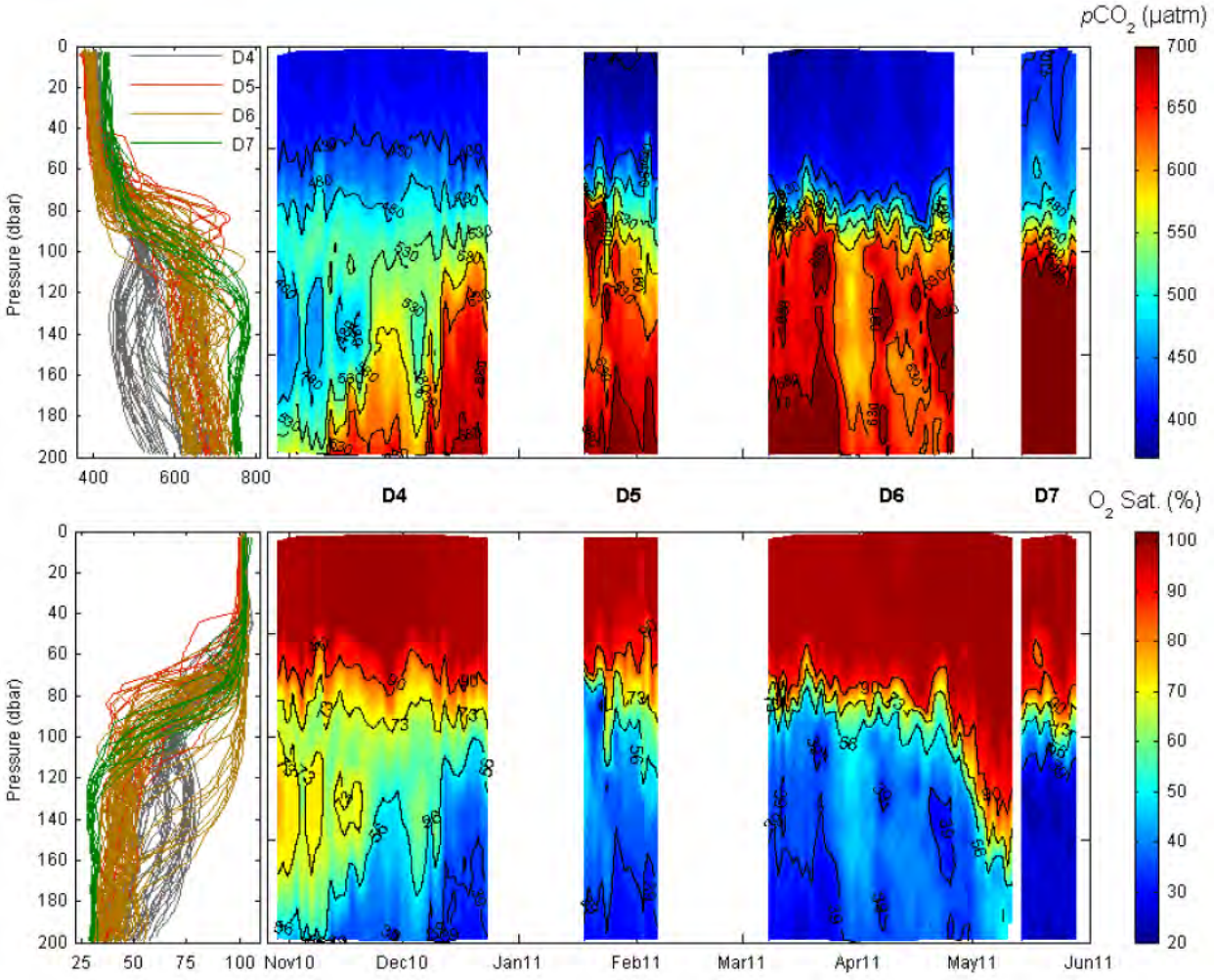




Fiedler, Körtzinger *et al*. (2013). *J. Atm. Ocean. Techn*. **30**, 112-126
Fietzek, Körtzinger *et al*. (2014), *J. Atmos. Ocean Techn.* **31**, 181-196.

# $pCO_2$ sensors – work in progress…

**First combined float-based $O_2$ and $CO_2$ measurements**




Fiedler, Körtzinger *et al*. (2013). *J. Atm. Ocean. Techn*. **30**, 112-126

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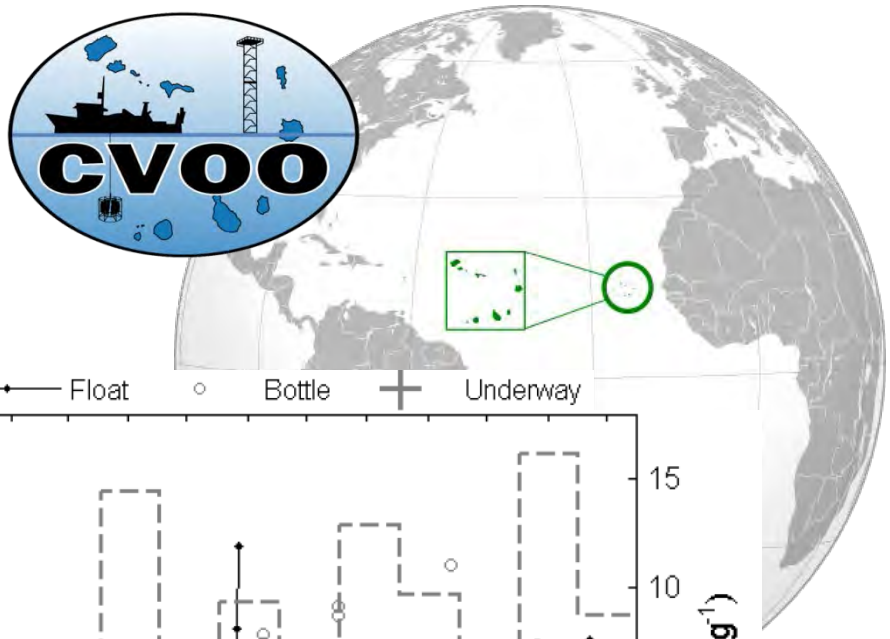
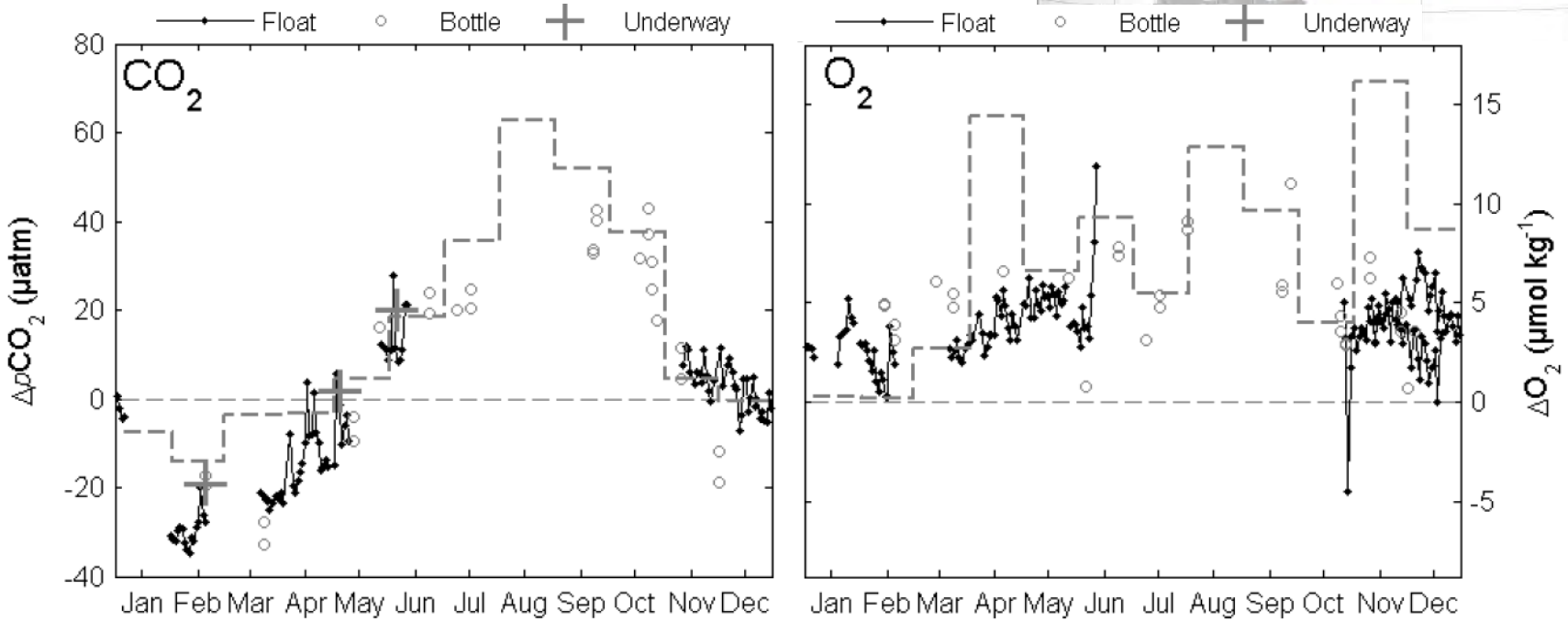
## Seasonal cycle of $O_2$ and $CO_2$ at Cape Verde Ocean Observatory




Fiedler (2013). Ph.D. thesis, Kiel University.
Fiedler, Körtzinger *et al.*, in prep.



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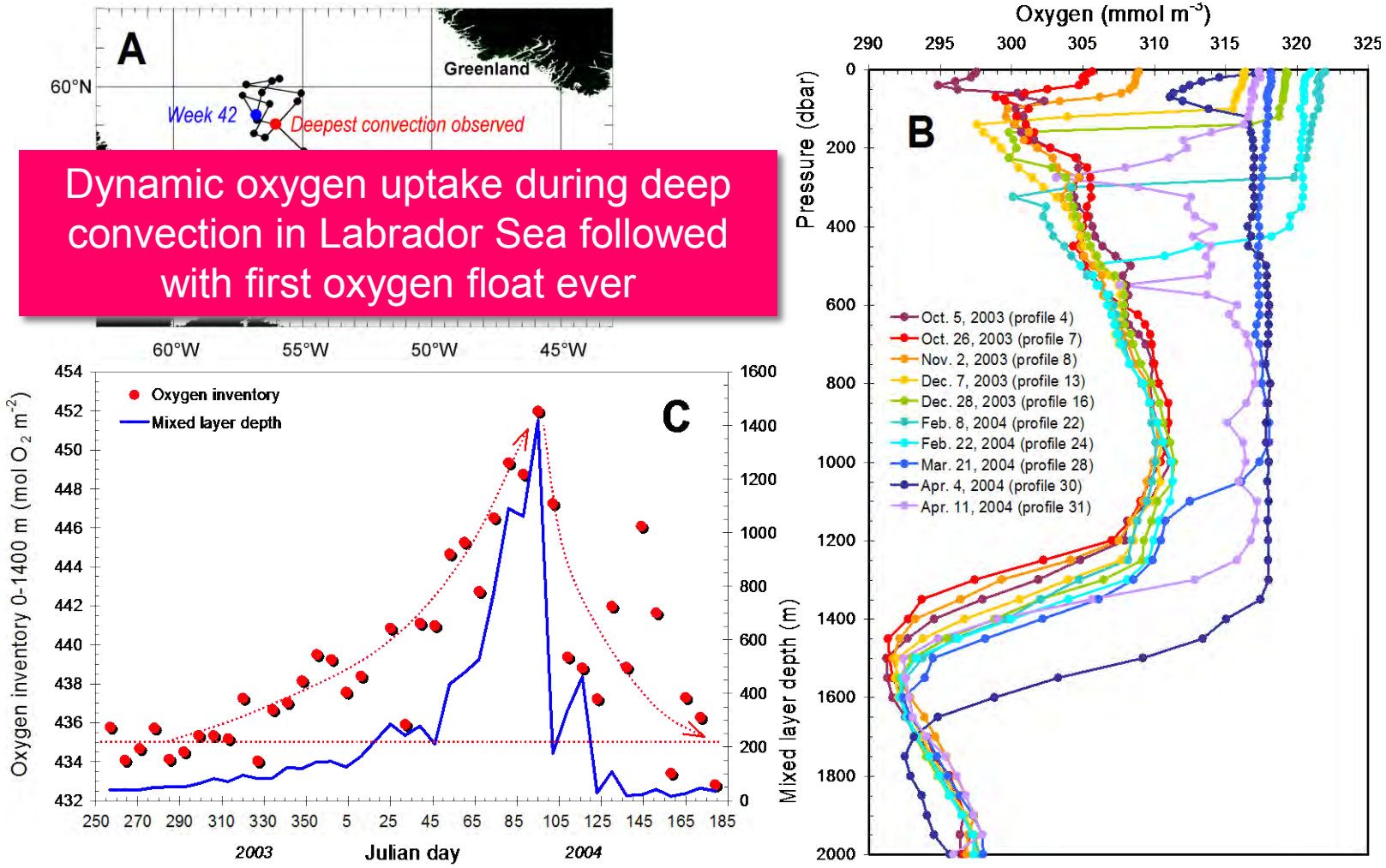
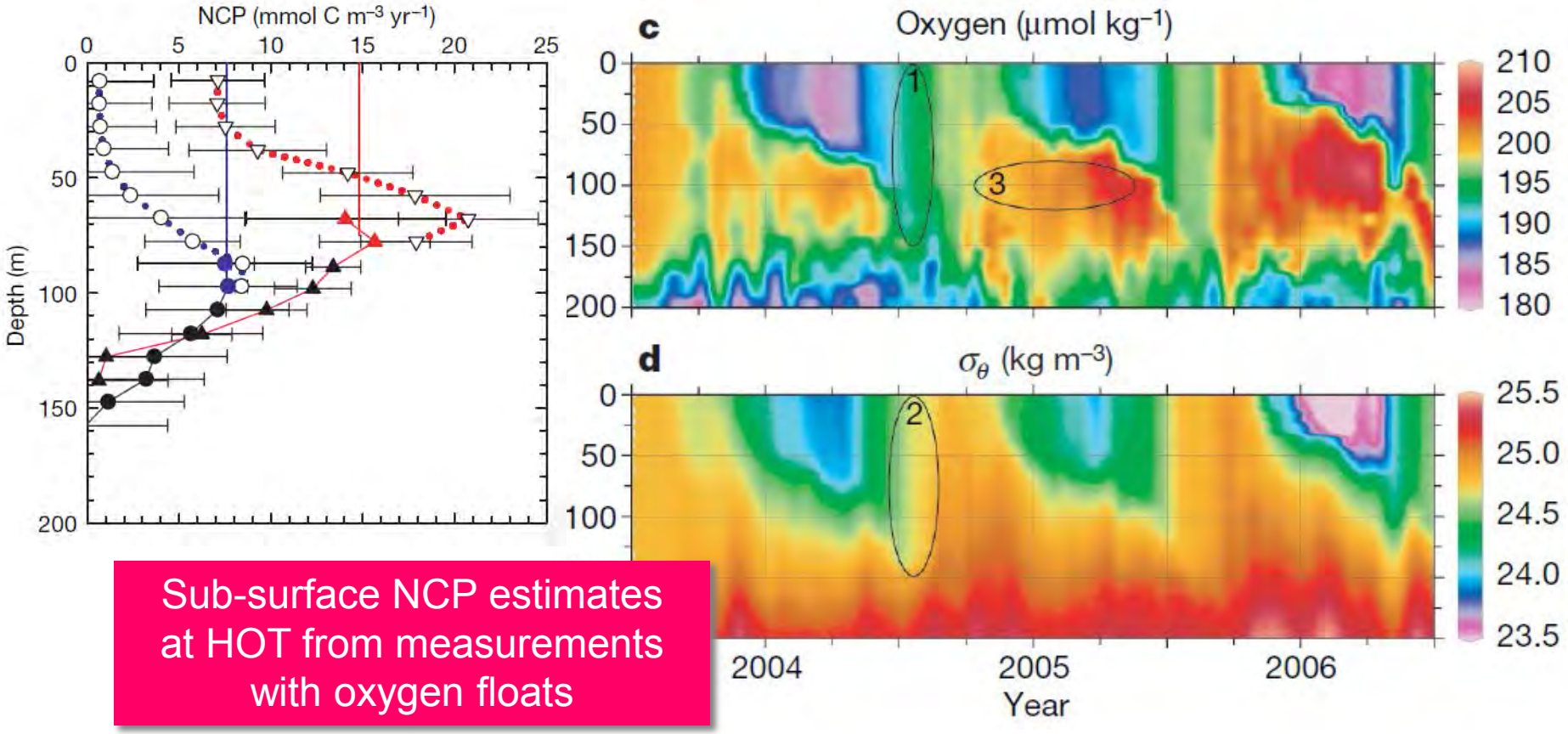
# Field studies: prominent examples




Körtzinger *et al*. (2004). *Science* **306**, 1337.

# Field studies: prominent examples

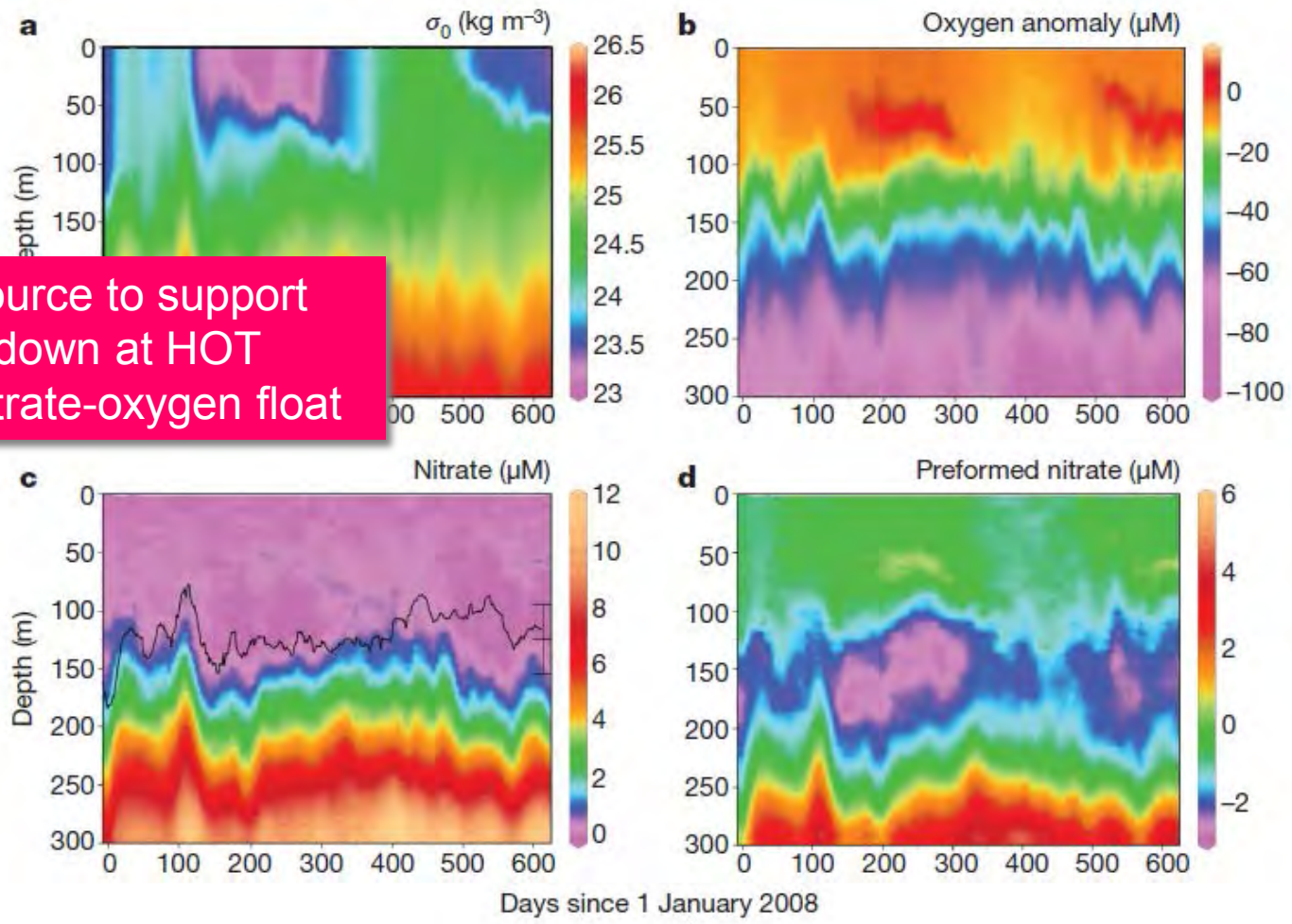



Sub-surface NCP estimates at HOT from measurements with oxygen floats

Riser and Johnson (2008). *Nature* **451**, 323-325.

# Field studies: prominent examples

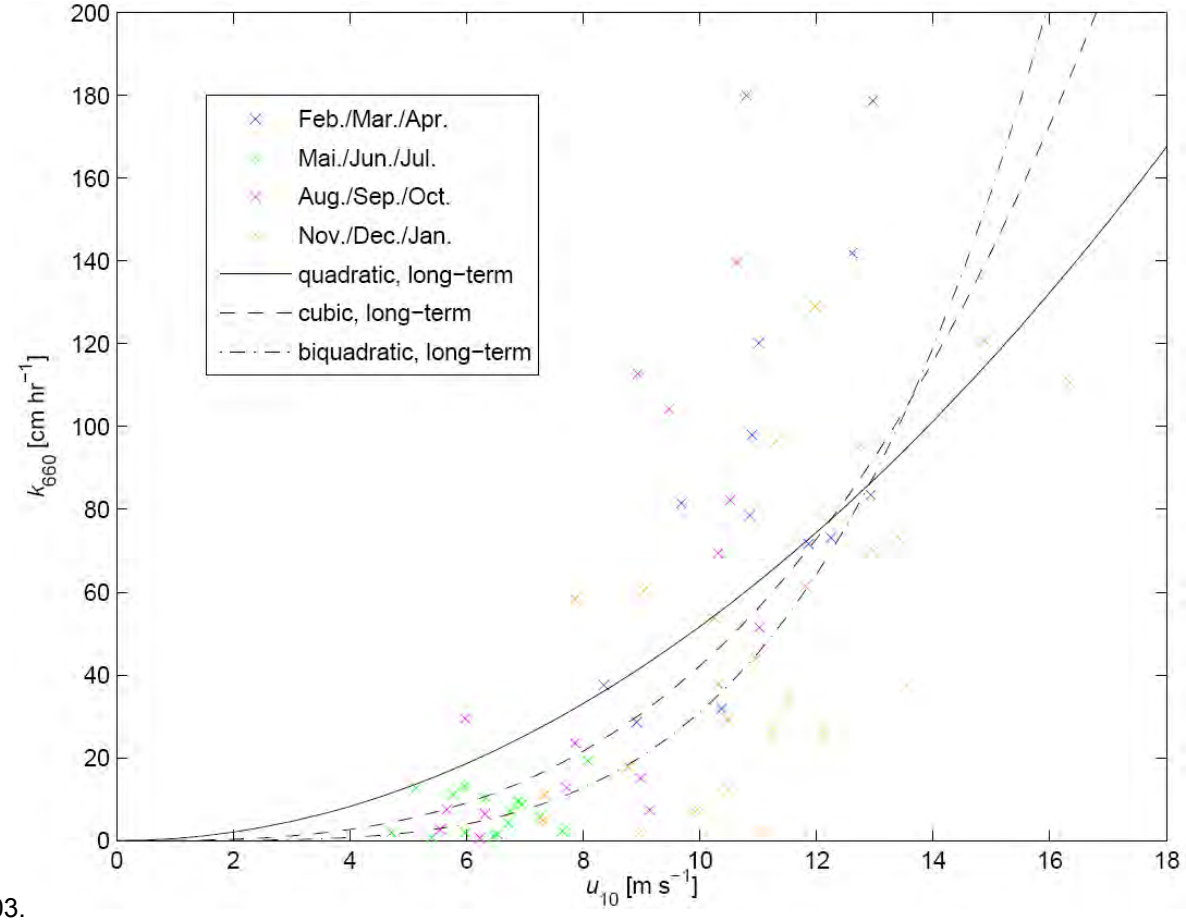
Deep nitrate source to support carbon drawdown at HOT observed with nitrate-oxygen float




Johnson et al. (2010). *Nature* **465**, 1062-1065.

# Field studies: less prominent examples

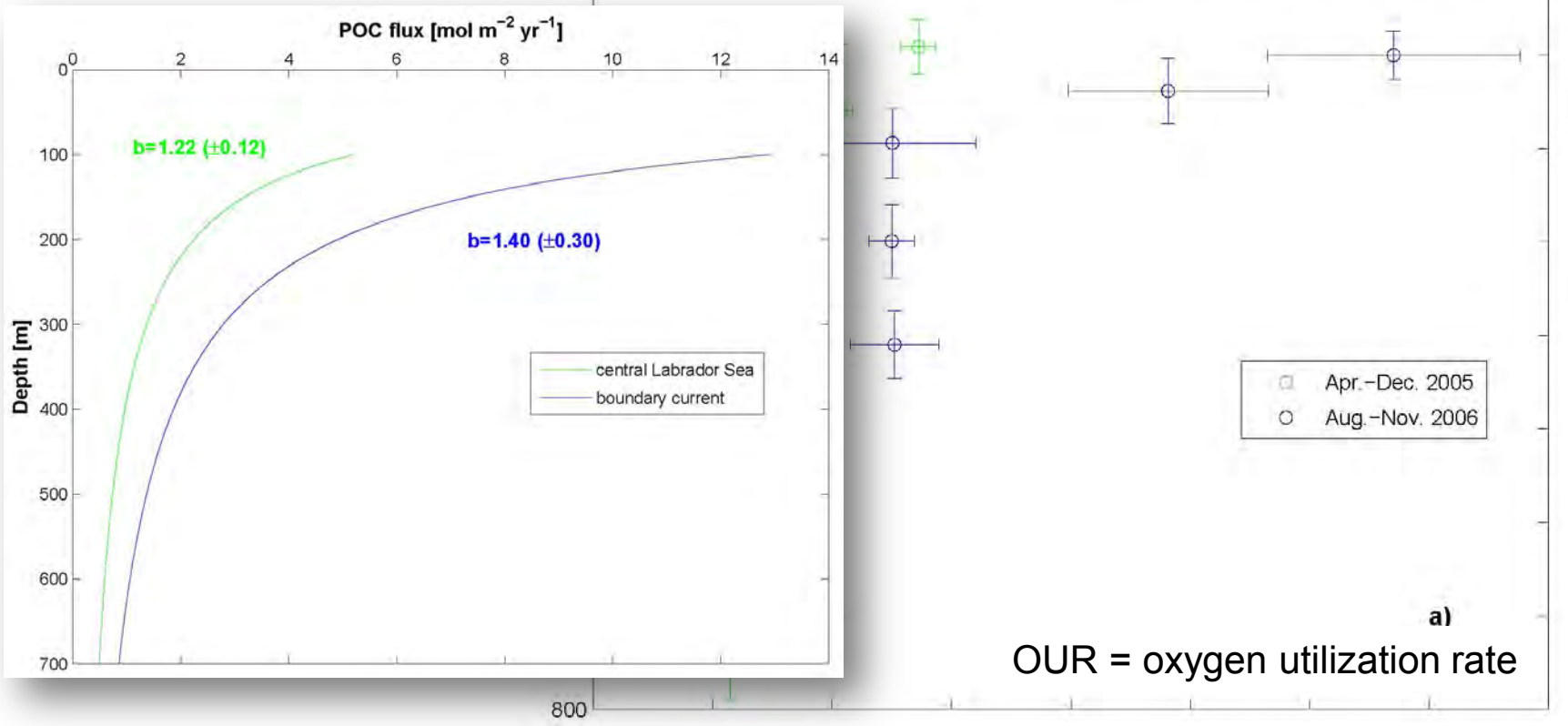
## Estimation of gas transfer coefficient for oxygen (central Labrador Sea)




Kiihm and Körtzinger (2010). *JGR* **115**, C12003.

# Field studies: less prominent examples

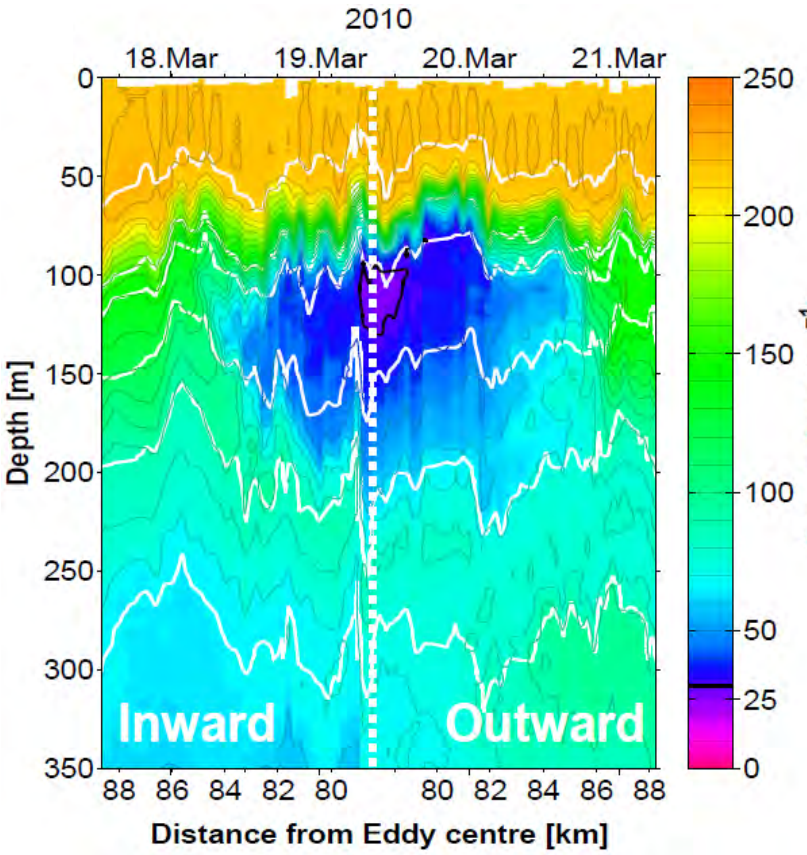
## Estimation of oxygen utilization rates (central Labrador Sea)



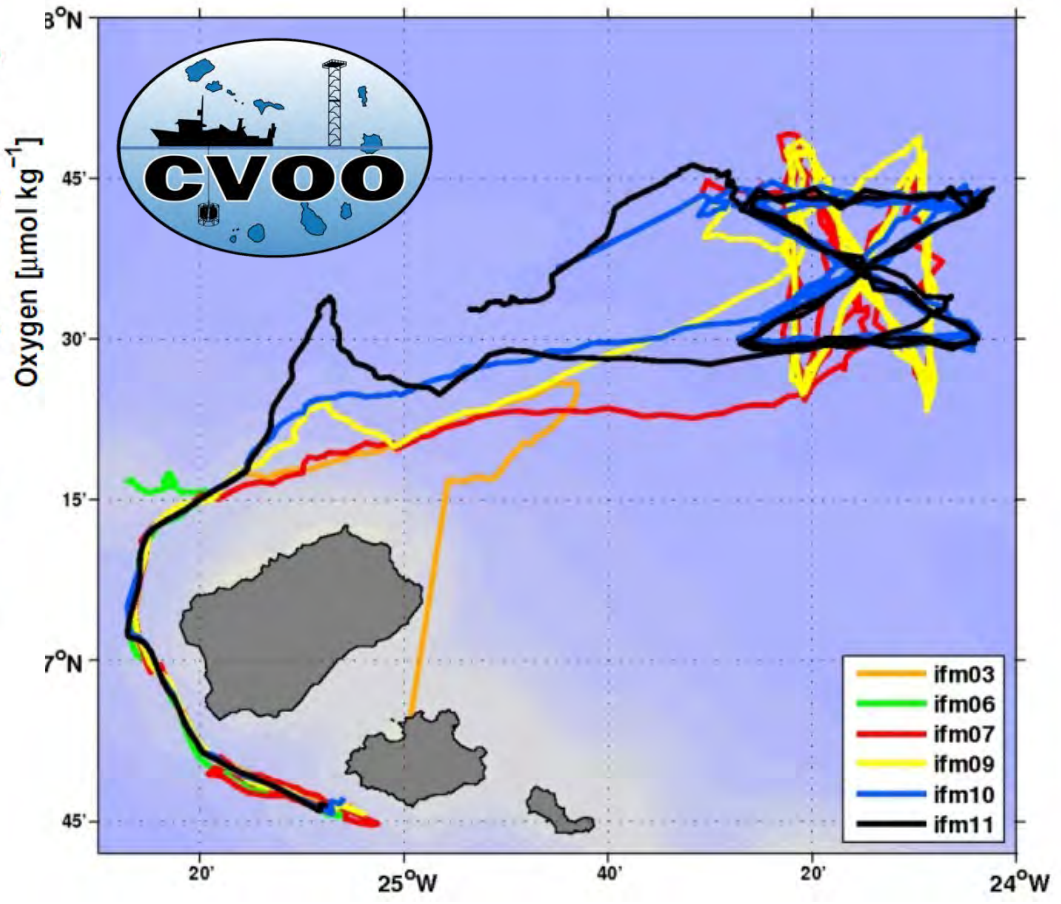

OUR = oxygen utilization rate

Kihm,C., Ph.D. thesis, University of Kiel, 2010.

# Field studies: dead zone eddies at Cape Verde




## Glider swarm experiment at Cape Verde Ocean Observatory



# Field studies: dead zone eddies at Cape Verde

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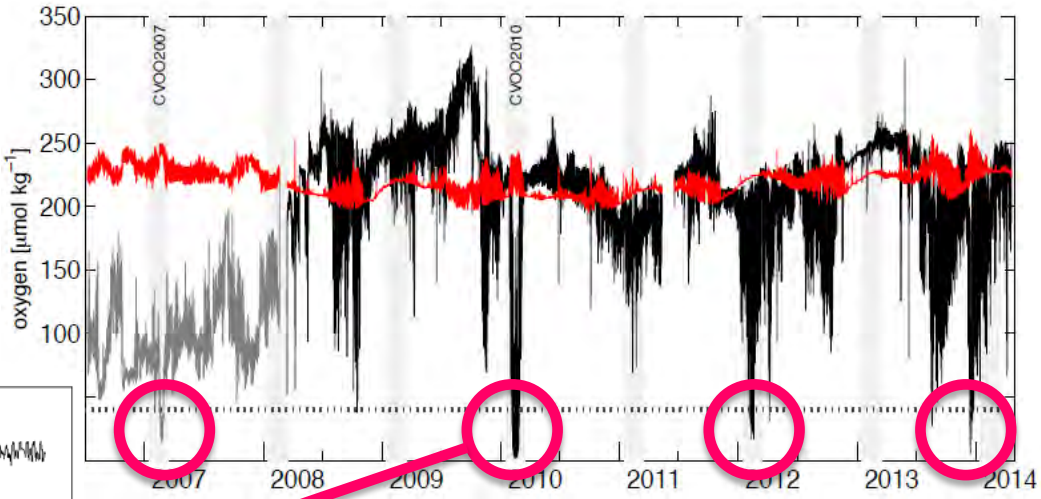
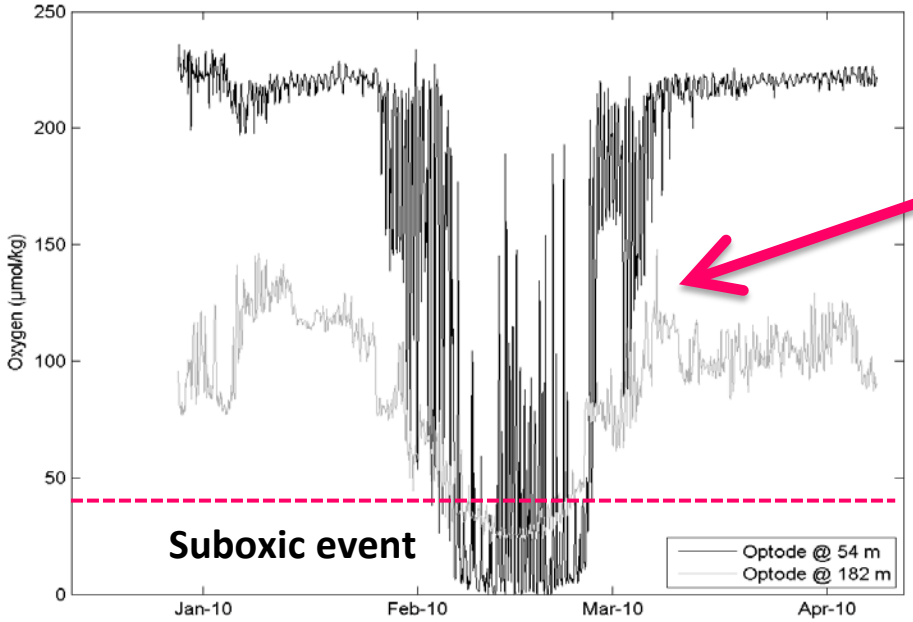
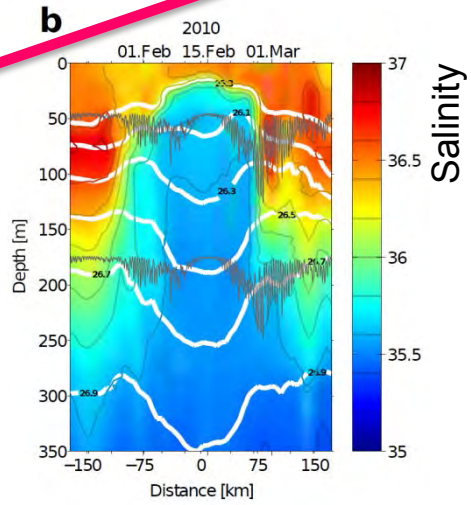
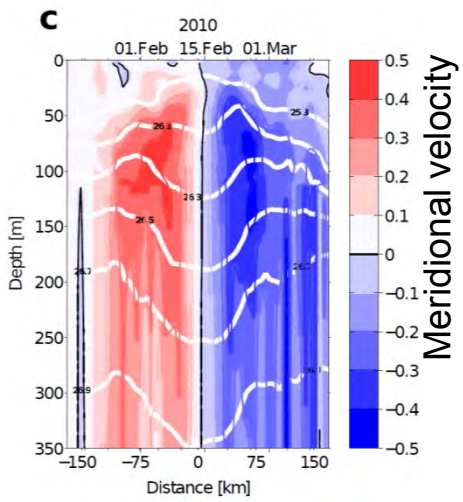
## Long-term mooring at Cape Verde Ocean Observatory

Karstensen, Körtzinger *et al*. (2014). *Biogeosci. Disc.* **11**, 17391–1741.



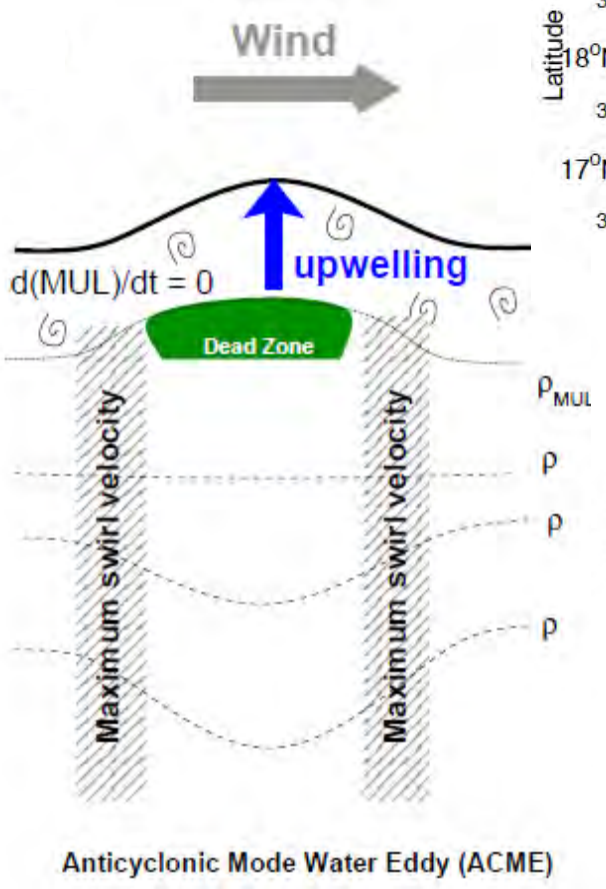



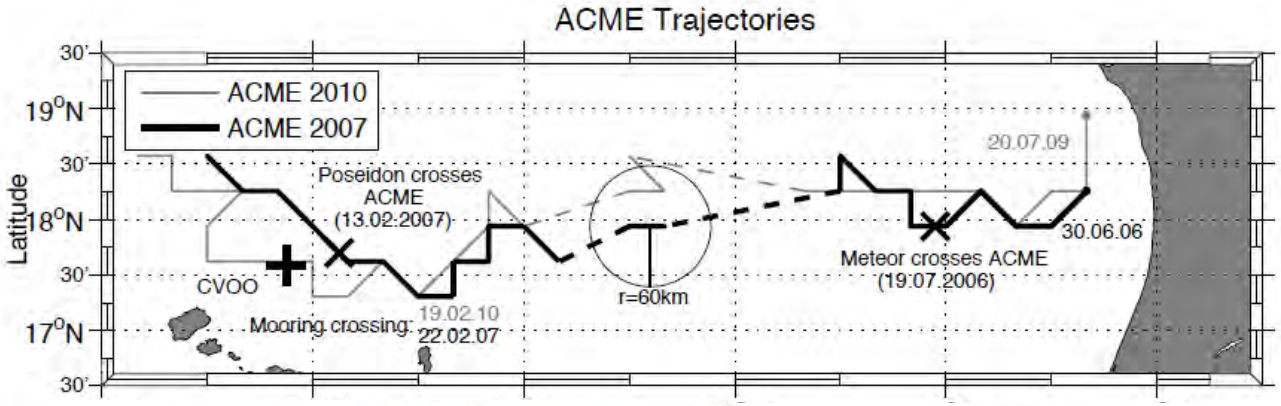



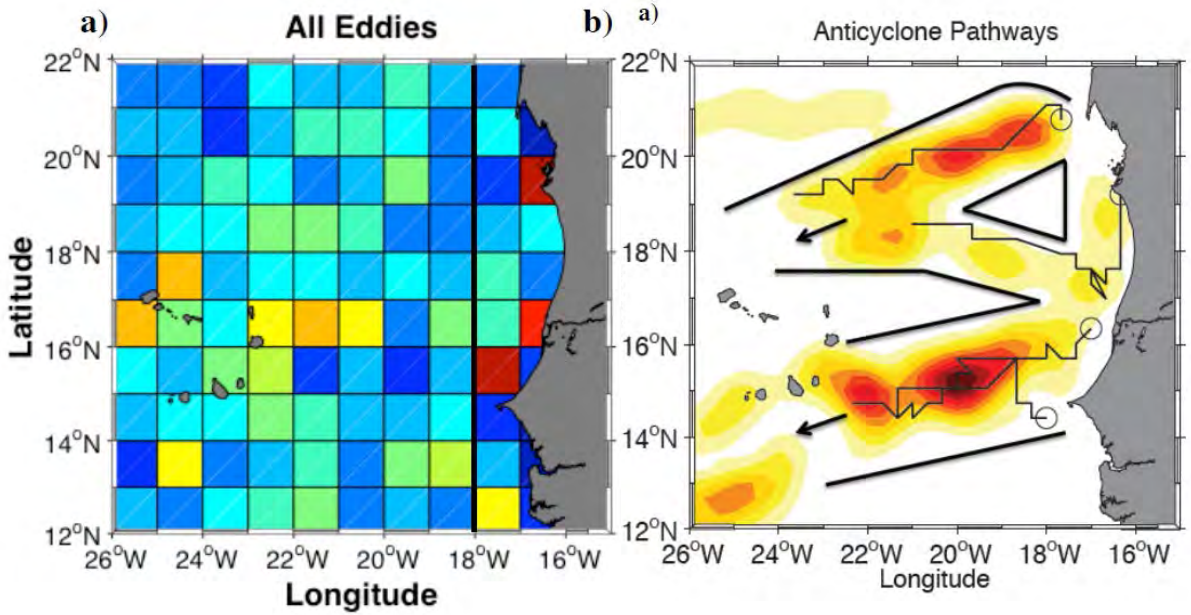



# Field studies: dead zone eddies at Cape Verde

## ACME – Anticyclonic Mode Water Eddies




Schütte, F., M.Sc. Thesis, Kiel University, 2013.



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# Field studies: dead zone eddies at Cape Verde

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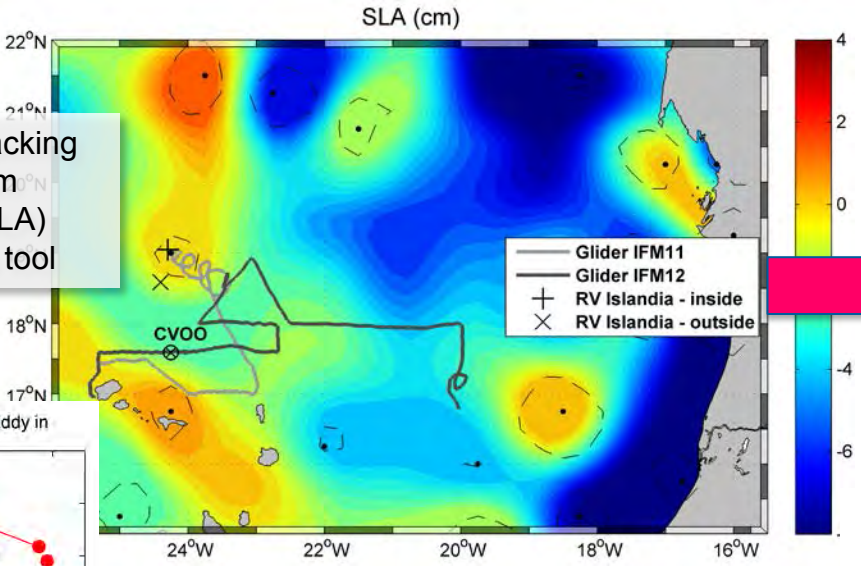
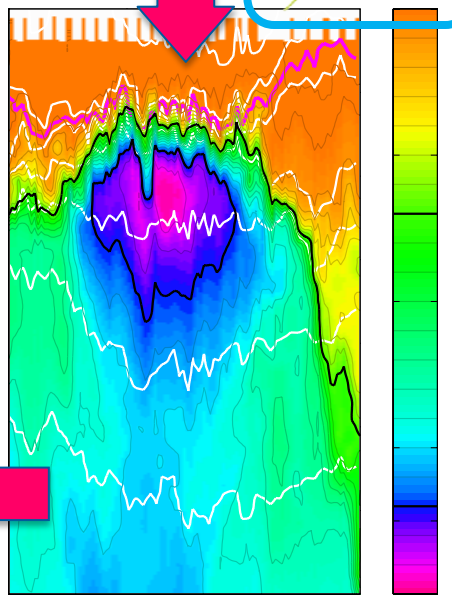
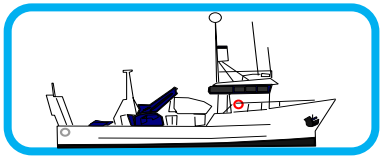
## Eddy Hunt Project

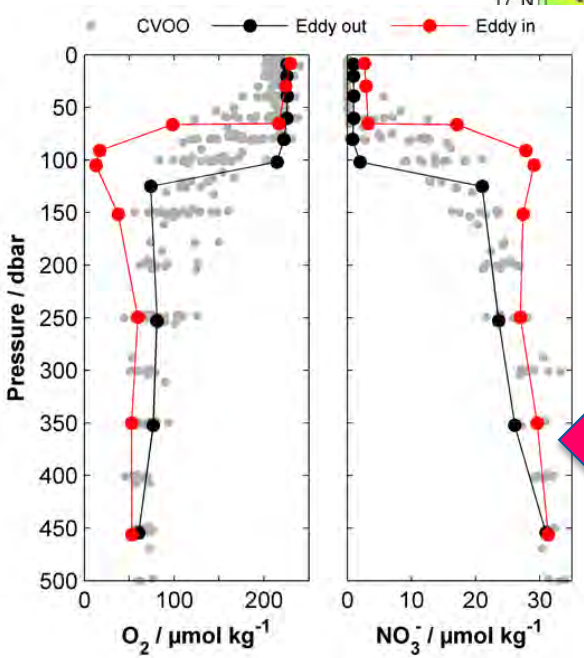
(1) Identification and tracking of candidate eddies from remote satellite data (SLA) with dedicated analysis tool




(2) Pre-survey of promising eddy with two gliders → confirmation of low $O_2$





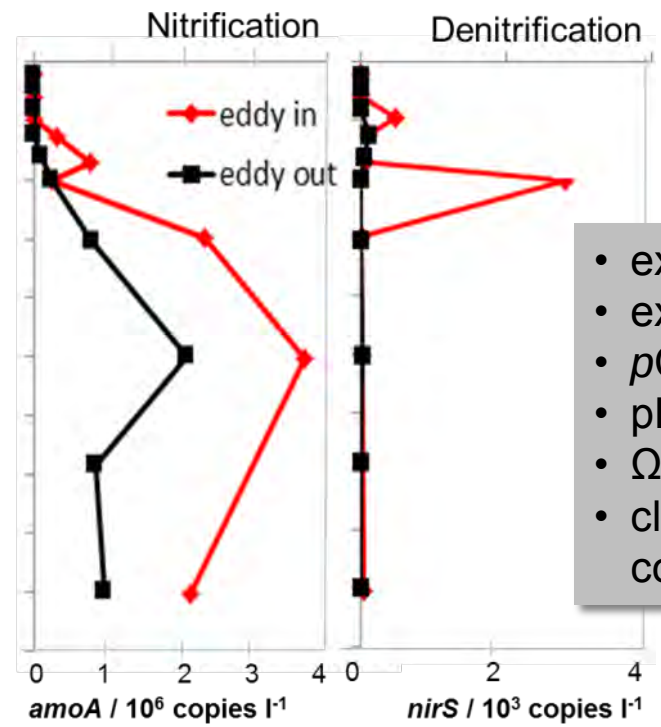

(3) Initial sampling of low $O_2$ eddy during 2.5 day cruise with R/V *Islandia*

Fiedler, Karstensen, Krahmann, Körtzinger, Schütte *et al.*, div. manuscripts, in prep.

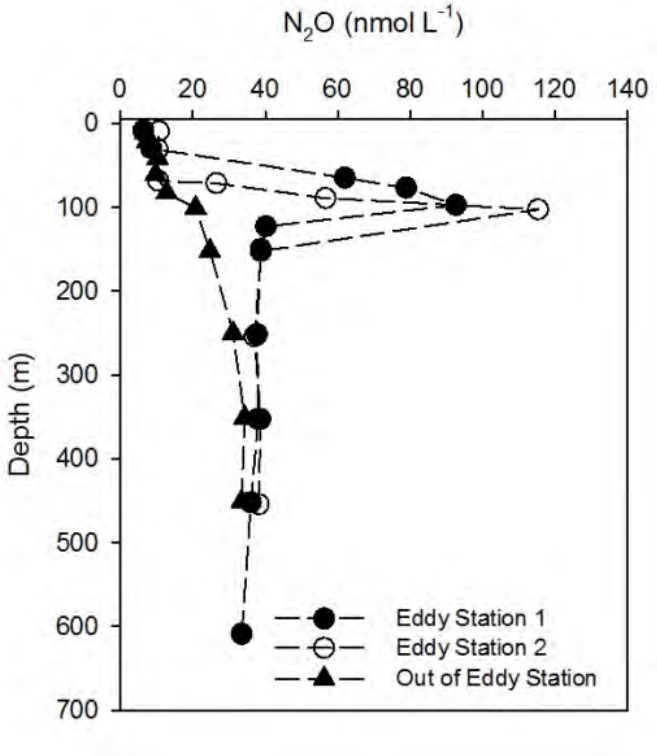
# Field studies: dead zone eddies at Cape Verde

(4) Enhanced & repeated sampling of low $O_2$ eddy during R/V *Meteor* Cruise M105 → spatial mapping of eddy physics, zooplankton distribution as function of $O_2$, etc., particle max. at $O_2$ min.

## Eddy Hunt Project




- extremely low $O_2$
- extremely high $N_2O$
- $pCO_2$ > 1000 µatm
- pH < 7.7
- $\Omega_{Ar}$ ~1 @ 100 m
- clear indication of water column denitrification




Fiedler, Grundle, Löscher, Philippi, Körtzinger *et al.*, div. manuscripts, in prep.

# Perspectives of Bio-Argo

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With $pH/pCO_2$, nitrate, bio-optics we could much more

**$O_2$**

- Detect changes in ocean biogeochemistry
- Determine net community production
- Determine net remineralization rates as a proxy for export production
- Help interpretation of variations in water mass ventilation rates
- Help interpretation of sparse data from repeat hydrographic surveys
- Provide data (initial conditions, evaluation) for ocean bgc models
- Improve atmospheric $O_2/N_2$ constraint on ocean/land partitioning of anthropogenic $CO_2$

# Perspectives of Bio-Argo

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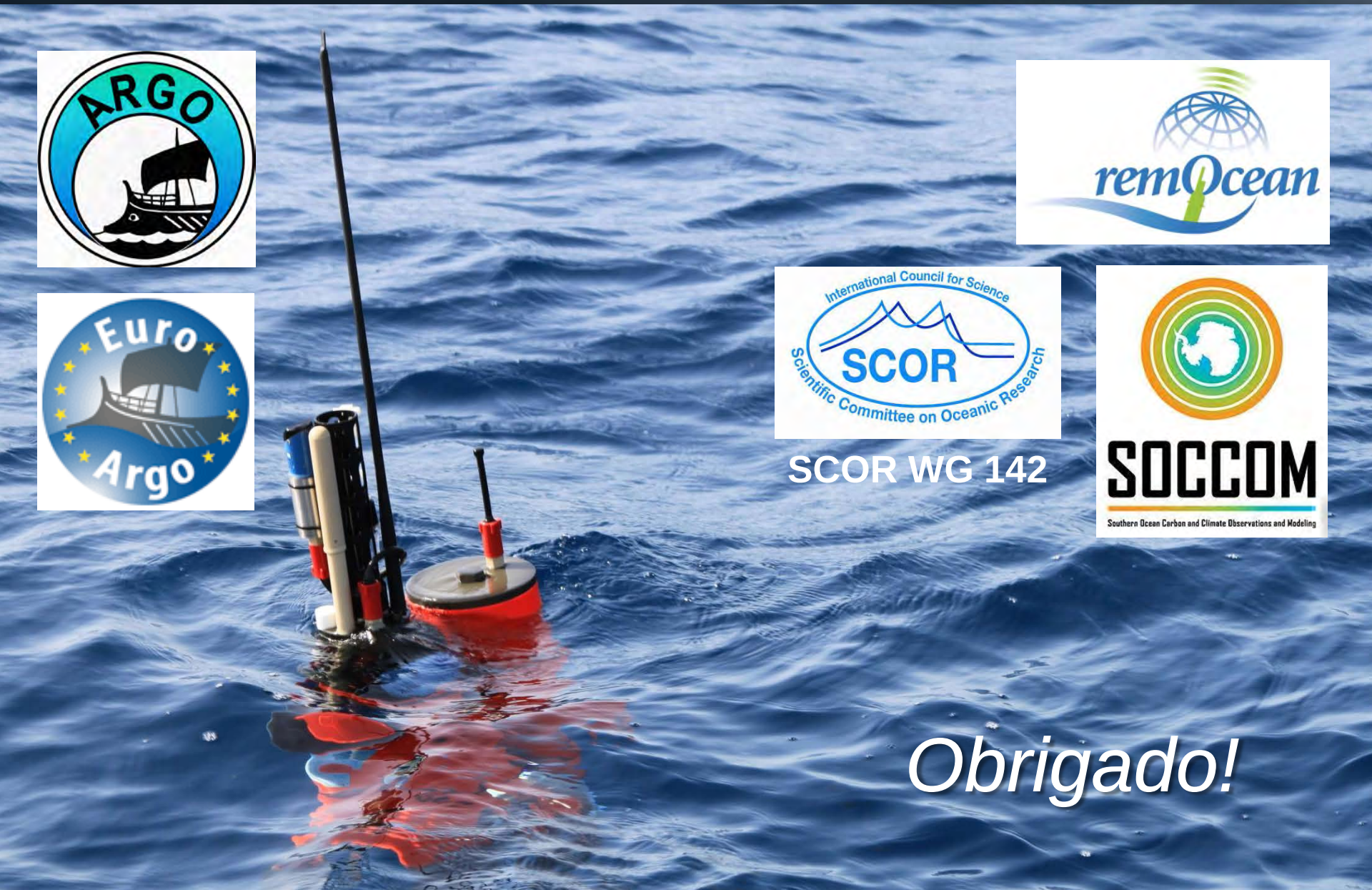


*Obrigado!*