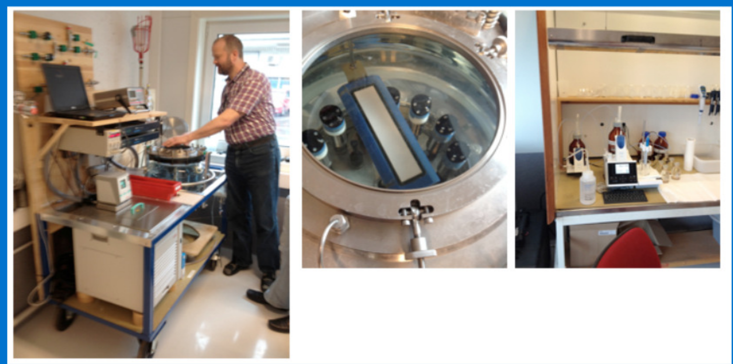
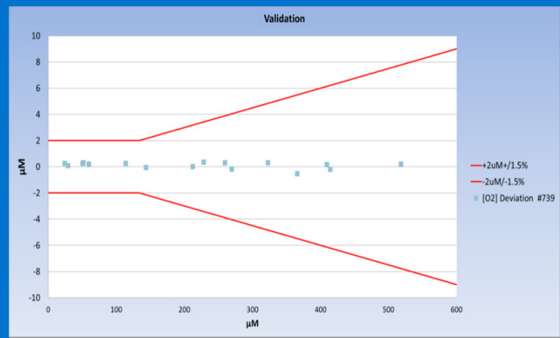
SCRIPPS, San Diego, June 12th , 2014

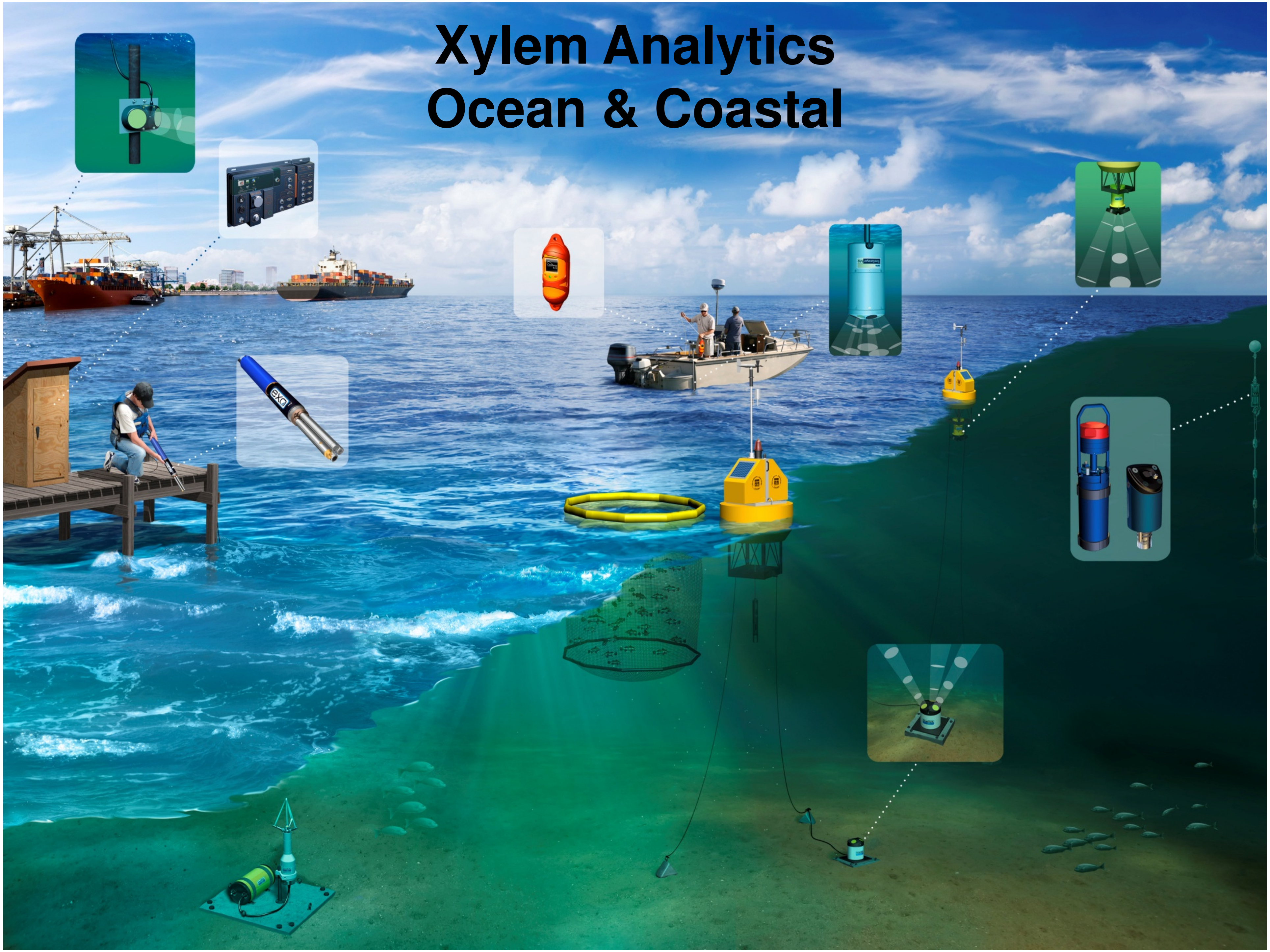
Improve your oxygen optode measurements:

user examples, practical handling and calibrations

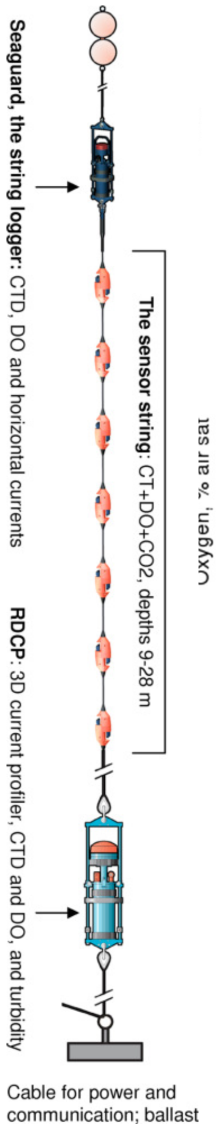


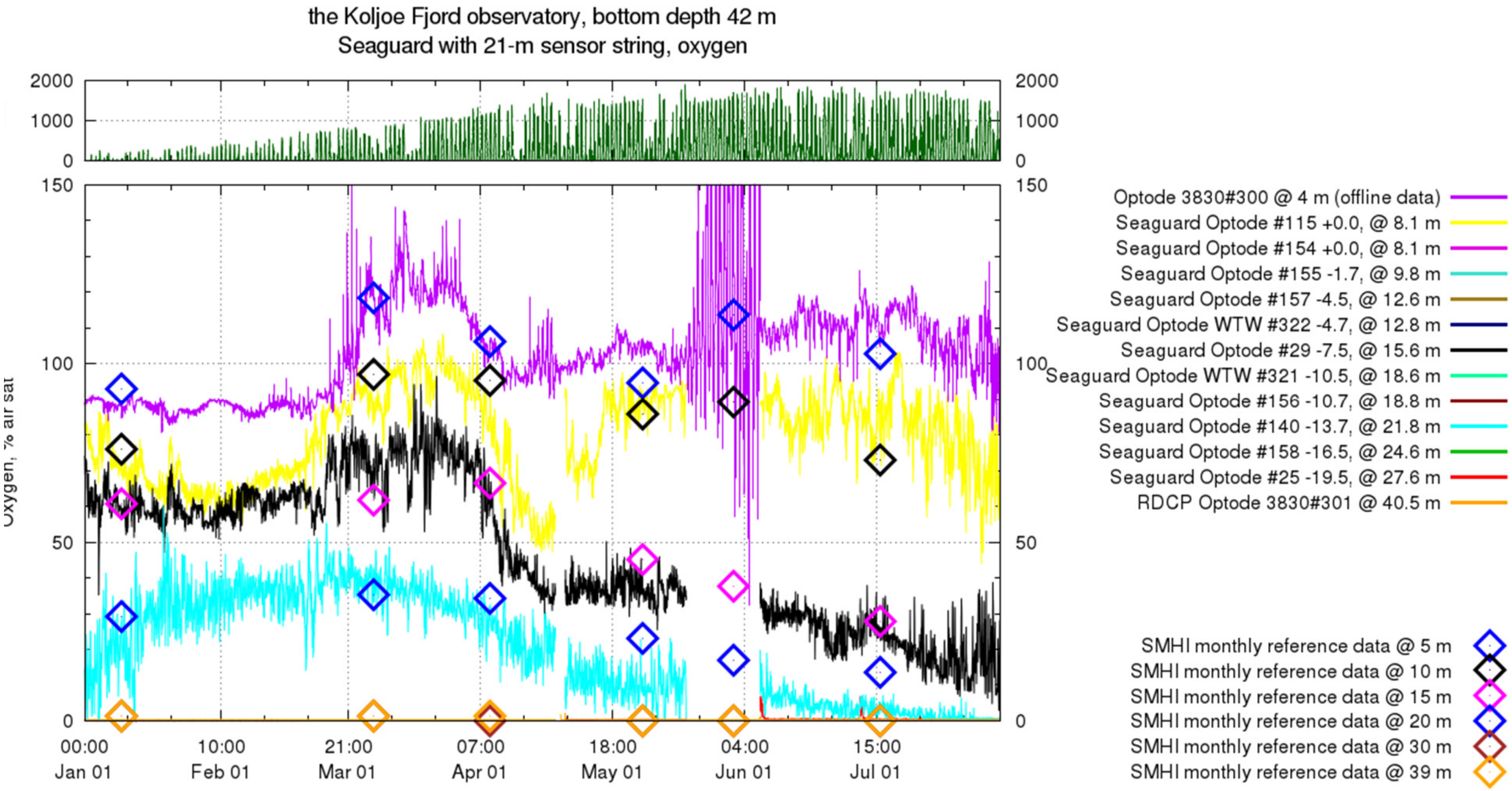


Emilie DORGEVILLE, Product Manager - emilie.dorgeville@xyleminc.com


Xylem Analytics
Ocean & Coastal

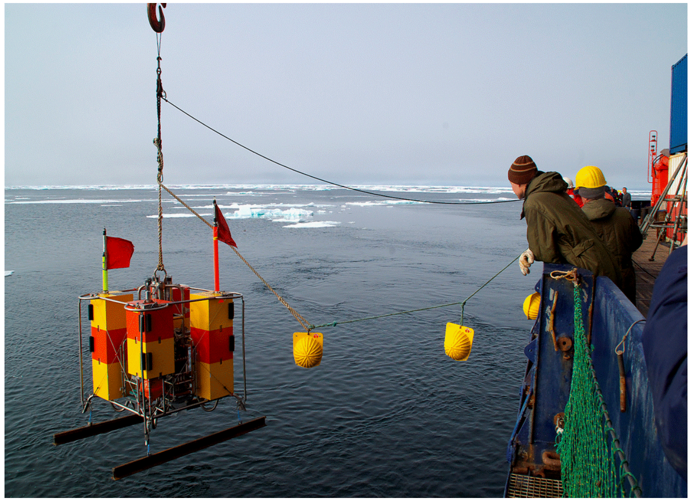
Measurement in the water column: Koljoefjord observatory: O_2 recordings, with monthly reference data from SMHI

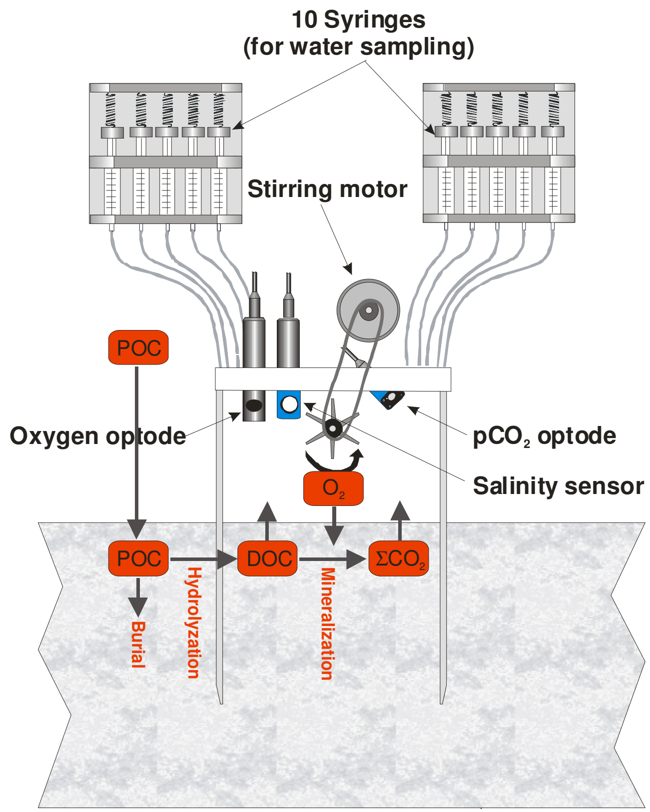


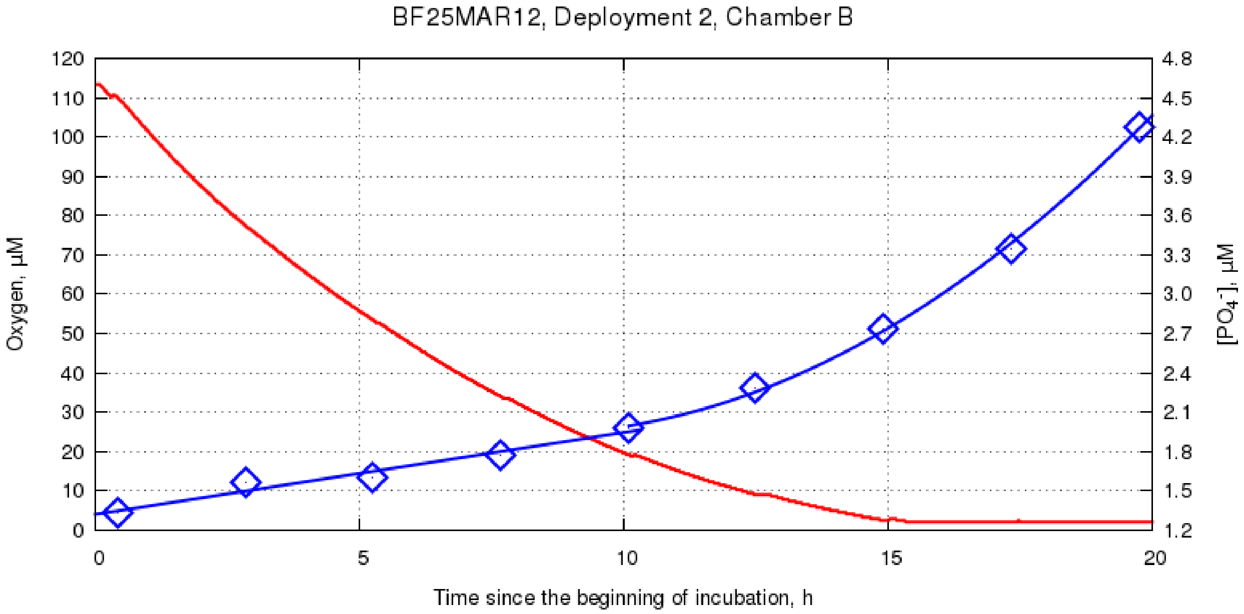


- Monthly sampling not enough
- Reference data needed for high quality sensor data
- Are plastic (PVC) bottles suitable for sampling at low O2?

Bottom measurement: Gothenburg Autonomous Bottom Landers for Sediment-Water Incubations. Deployed ~300 times from 5-5600 m water depth

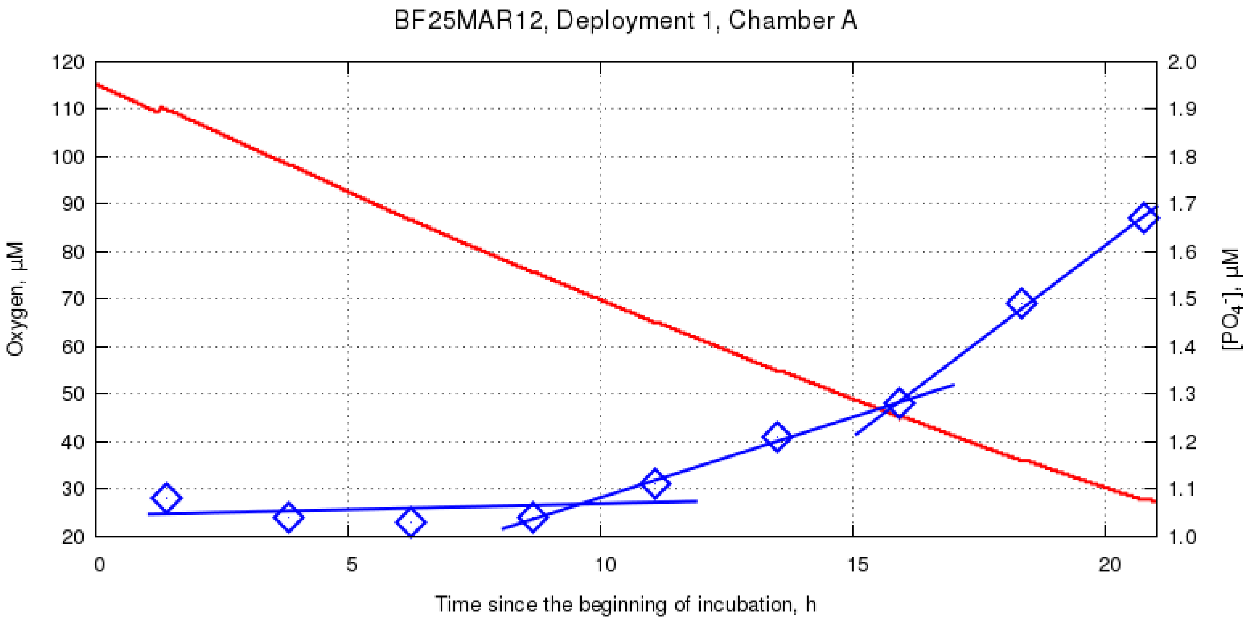




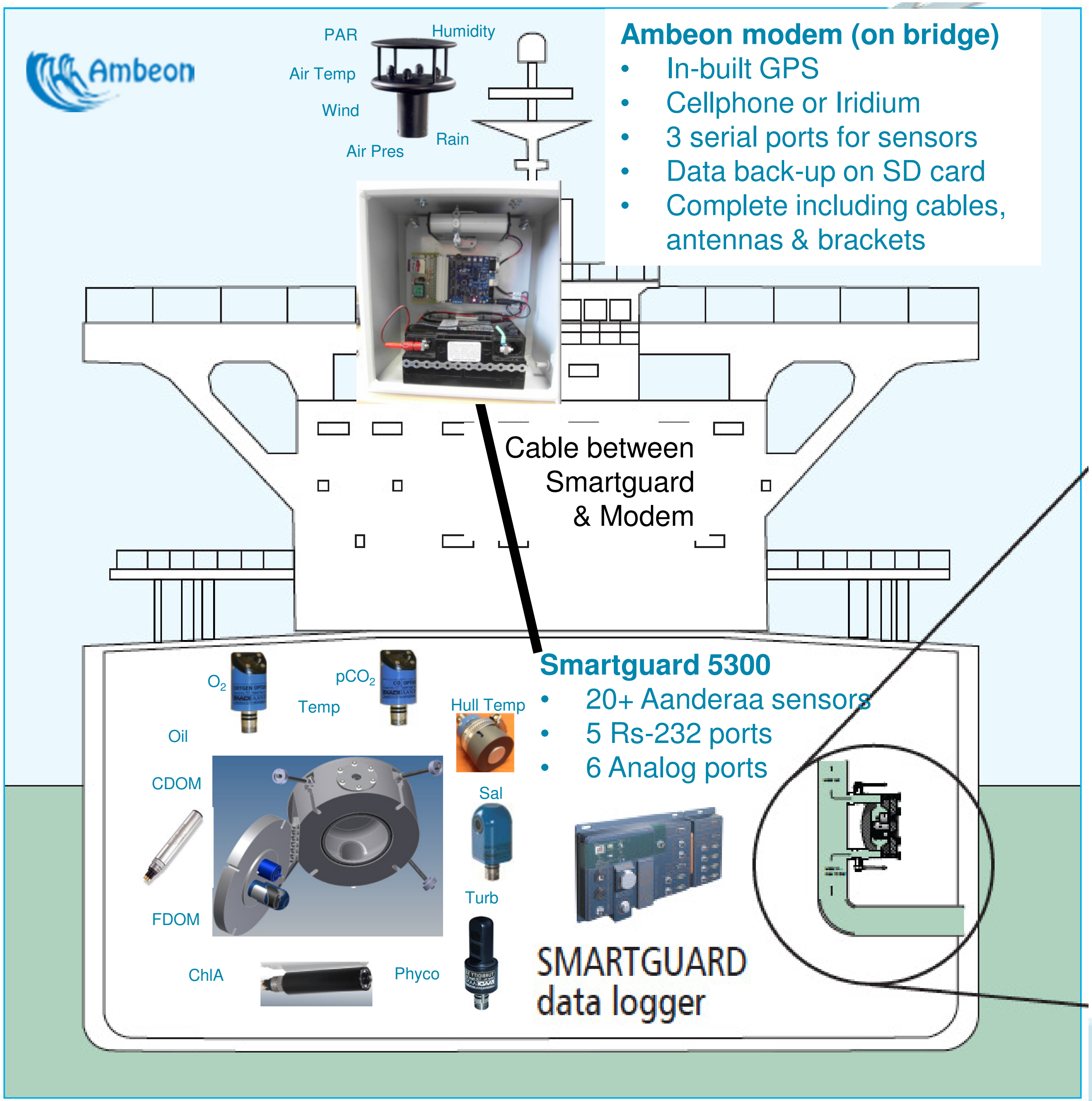


Red: Oxygen conc.
Blue: PO4 conc.
in benthic chambers

•Phosphate: Eutrophication contributor. Phosphate released from sediment when oxygen reaches values under 20-30µM

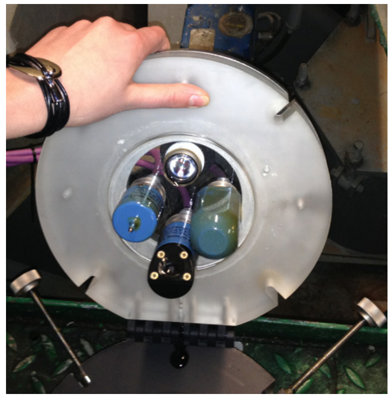


Surface measurement



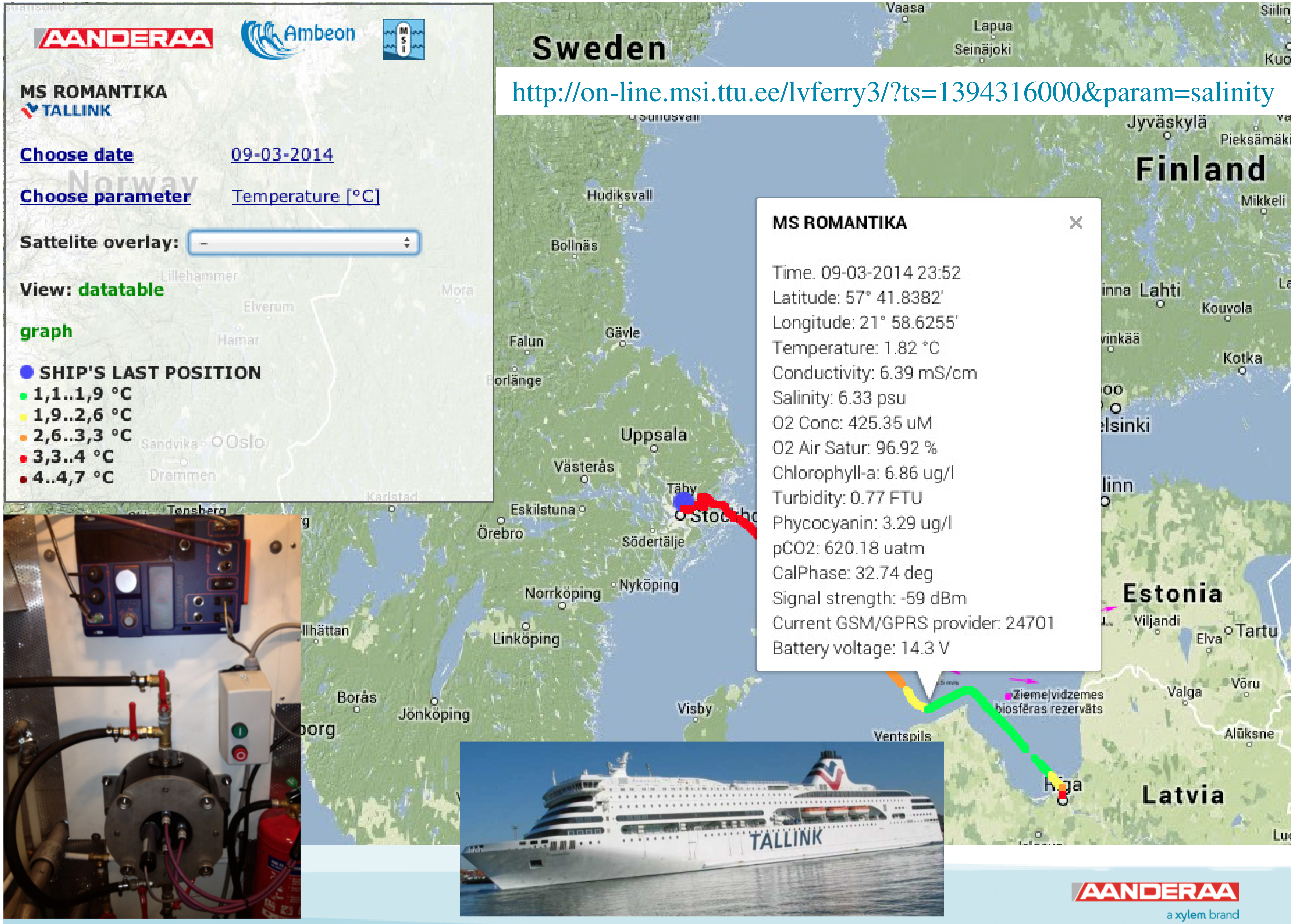
SOOGuard Chamber

- Compact 30*30*20 cm
- Easy to install, brackets included
- Add extra chamber & sensors for more parameters
- 10 bar rated
- Easy to service, takes less than 10 s to open



AANDERAA a xylem brand

http://on-line.msi.ttu.ee/lvferry3/?ts=1394316000&param=salinity



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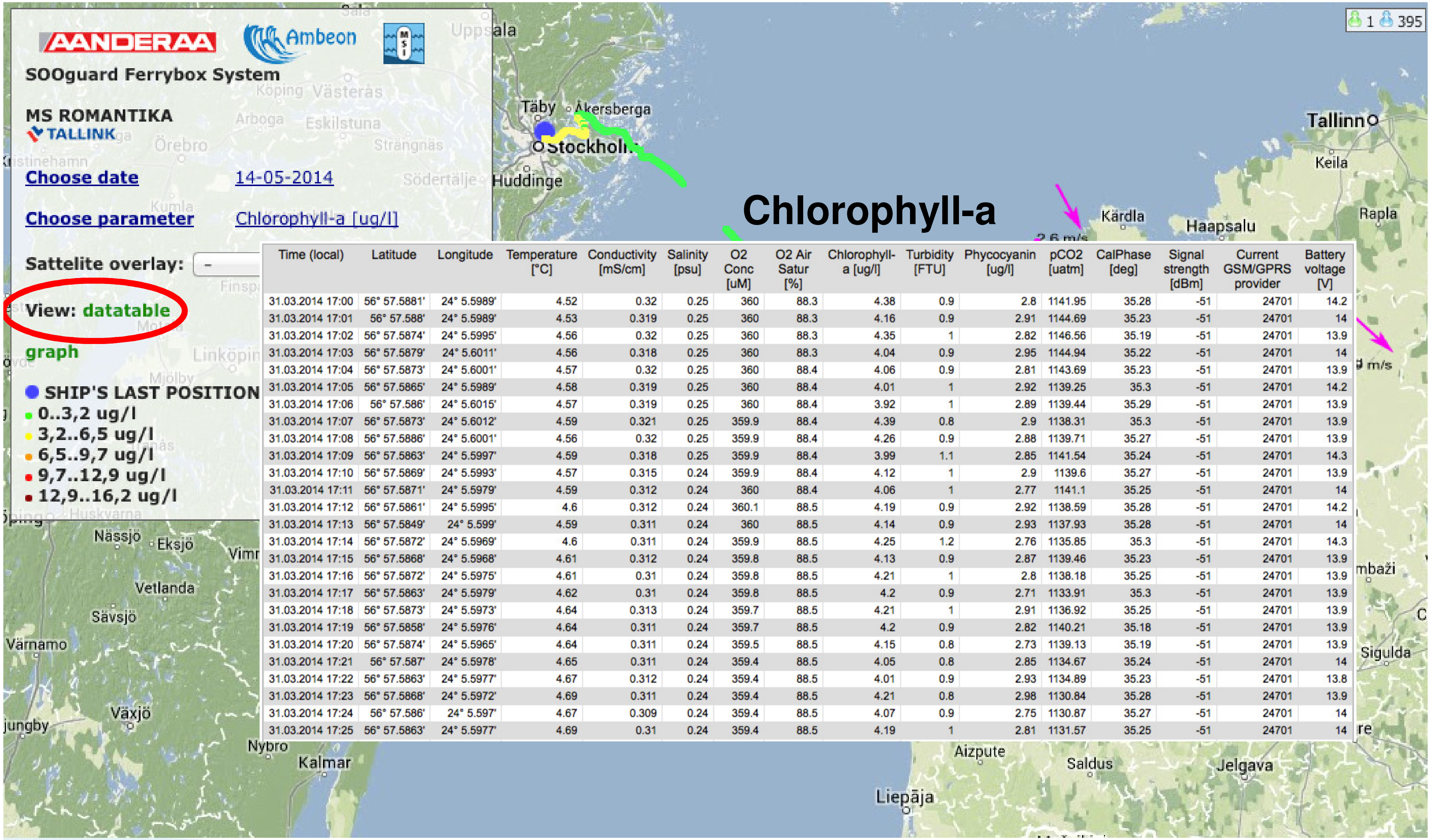
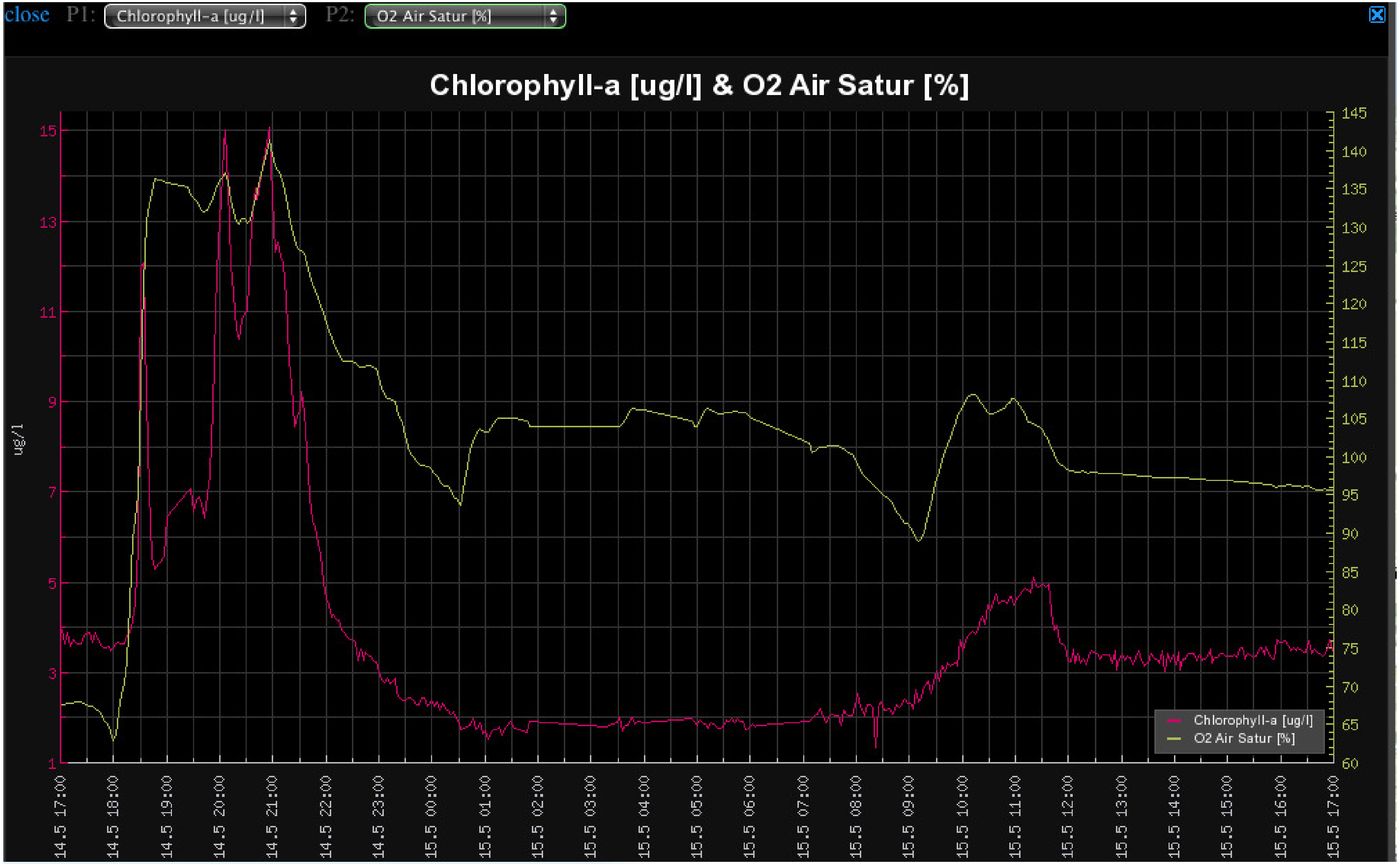
a xylem brand

On-line data visualization tool: single property transect and datatable



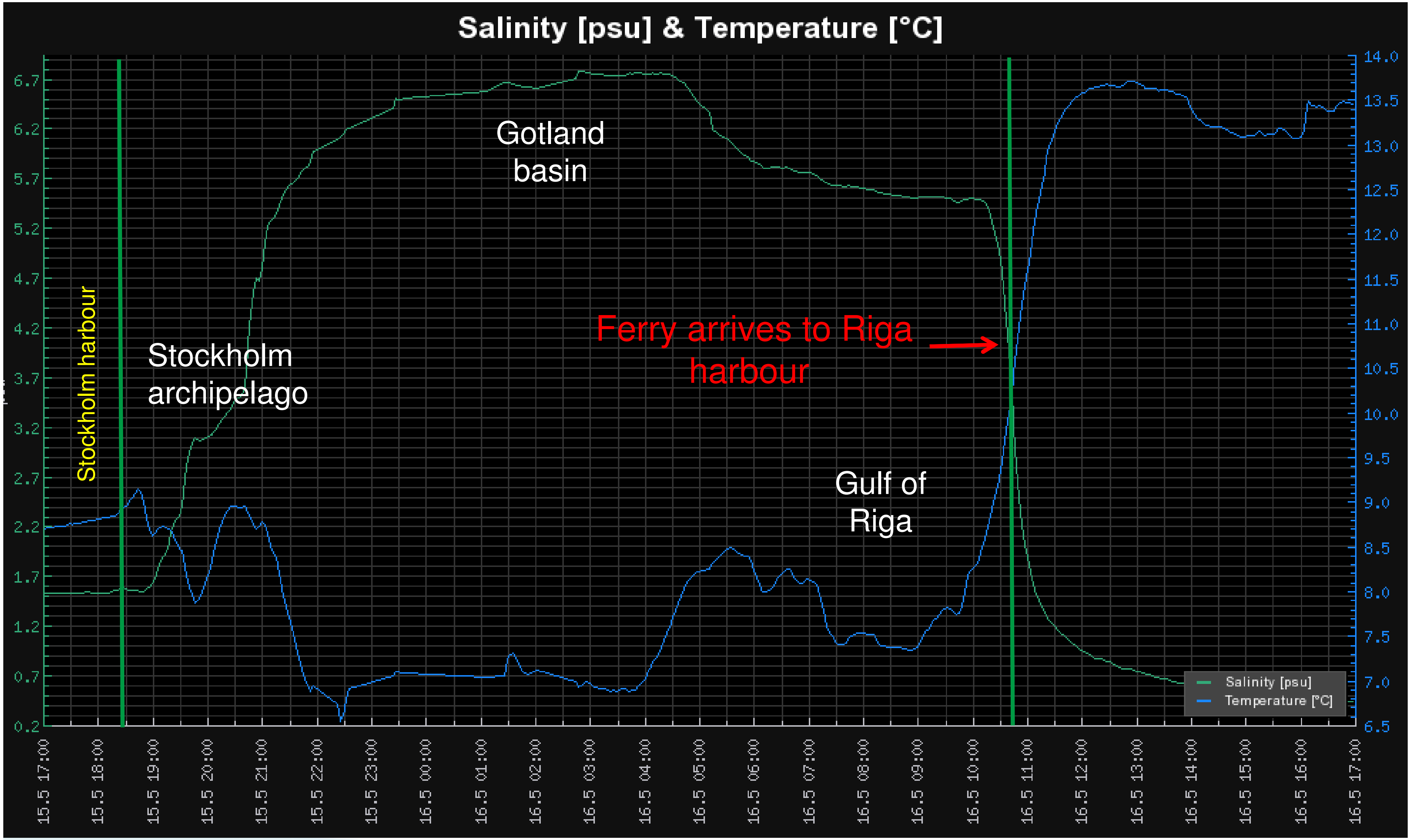
Time (local)	Latitude	Longitude	Temperature [°C]	Conductivity [mS/cm]	Salinity [psu]	O2 Conc [uM]	O2 Air Satur [%]	Chlorophyll-a [ug/l]	Turbidity [FTU]	Phycocyanin [ug/l]	pCO2 [uatm]	CalPhase [deg]	Signal strength [dBm]	Current GSM/GPRS provider	Battery voltage [V]
31.03.2014 17:00	56° 57.5881'	24° 5.5989'	4.52	0.32	0.25	360	88.3	4.38	0.9	2.8	1141.95	35.28	-51	24701	14.2
31.03.2014 17:01	56° 57.588'	24° 5.5989'	4.53	0.319	0.25	360	88.3	4.16	0.9	2.91	1144.69	35.23	-51	24701	14
31.03.2014 17:02	56° 57.5874'	24° 5.5995'	4.56	0.32	0.25	360	88.3	4.35	1	2.82	1146.56	35.19	-51	24701	13.9
31.03.2014 17:03	56° 57.5879'	24° 5.6011'	4.56	0.318	0.25	360	88.3	4.04	0.9	2.95	1144.94	35.22	-51	24701	14
31.03.2014 17:04	56° 57.5873'	24° 5.6001'	4.57	0.32	0.25	360	88.4	4.06	0.9	2.81	1143.69	35.23	-51	24701	13.9
31.03.2014 17:05	56° 57.5865'	24° 5.5989'	4.58	0.319	0.25	360	88.4	4.01	1	2.92	1139.25	35.3	-51	24701	14.2
31.03.2014 17:06	56° 57.586'	24° 5.6015'	4.57	0.319	0.25	360	88.4	3.92	1	2.89	1139.44	35.29	-51	24701	13.9
31.03.2014 17:07	56° 57.5873'	24° 5.6012'	4.59	0.321	0.25	359.9	88.4	4.39	0.8	2.9	1138.31	35.3	-51	24701	13.9
31.03.2014 17:08	56° 57.5886'	24° 5.6001'	4.56	0.32	0.25	359.9	88.4	4.26	0.9	2.88	1139.71	35.27	-51	24701	13.9
31.03.2014 17:09	56° 57.5863'	24° 5.5997'	4.59	0.318	0.25	359.9	88.4	3.99	1.1	2.85	1141.54	35.24	-51	24701	14.3
31.03.2014 17:10	56° 57.5869'	24° 5.5993'	4.57	0.315	0.24	359.9	88.4	4.12	1	2.9	1139.6	35.27	-51	24701	13.9
31.03.2014 17:11	56° 57.5871'	24° 5.5979'	4.59	0.312	0.24	360	88.4	4.06	1	2.77	1141.1	35.25	-51	24701	14
31.03.2014 17:12	56° 57.5861'	24° 5.5995'	4.6	0.312	0.24	360.1	88.5	4.19	0.9	2.92	1138.59	35.28	-51	24701	14.2
31.03.2014 17:13	56° 57.5849'	24° 5.599'	4.59	0.311	0.24	360	88.5	4.14	0.9	2.93	1137.93	35.28	-51	24701	14
31.03.2014 17:14	56° 57.5872'	24° 5.5969'	4.6	0.311	0.24	359.9	88.5	4.25	1.2	2.76	1135.85	35.3	-51	24701	14.3
31.03.2014 17:15	56° 57.5868'	24° 5.5968'	4.61	0.312	0.24	359.8	88.5	4.13	0.9	2.87	1139.46	35.23	-51	24701	13.9
31.03.2014 17:16	56° 57.5872'	24° 5.5975'	4.61	0.31	0.24	359.8	88.5	4.21	1	2.8	1138.18	35.25	-51	24701	13.9
31.03.2014 17:17	56° 57.5863'	24° 5.5979'	4.62	0.31	0.24	359.8	88.5	4.2	0.9	2.71	1133.91	35.3	-51	24701	13.9
31.03.2014 17:18	56° 57.5873'	24° 5.5973'	4.64	0.313	0.24	359.7	88.5	4.21	1	2.91	1136.92	35.25	-51	24701	13.9
31.03.2014 17:19	56° 57.5858'	24° 5.5976'	4.64	0.311	0.24	359.7	88.5	4.2	0.9	2.82	1140.21	35.18	-51	24701	13.9
31.03.2014 17:20	56° 57.5874'	24° 5.5965'	4.64	0.311	0.24	359.5	88.5	4.15	0.8	2.73	1139.13	35.19	-51	24701	13.9
31.03.2014 17:21	56° 57.587'	24° 5.5978'	4.65	0.311	0.24	359.4	88.5	4.05	0.8	2.85	1134.67	35.24	-51	24701	14
31.03.2014 17:22	56° 57.5863'	24° 5.5977'	4.67	0.312	0.24	359.4	88.5	4.01	0.9	2.93	1134.89	35.23	-51	24701	13.8
31.03.2014 17:23	56° 57.5868'	24° 5.5972'	4.69	0.311	0.24	359.4	88.5	4.21	0.8	2.98	1130.84	35.28	-51	24701	13.9
31.03.2014 17:24	56° 57.586'	24° 5.597'	4.67	0.309	0.24	359.4	88.5	4.07	0.9	2.75	1130.87	35.27	-51	24701	14
31.03.2014 17:25	56° 57.5863'	24° 5.5977'	4.69	0.31	0.24	359.4	88.5	4.19	1	2.81	1131.57	35.25	-51	24701	14

On-line data visualization tool: property vs. property



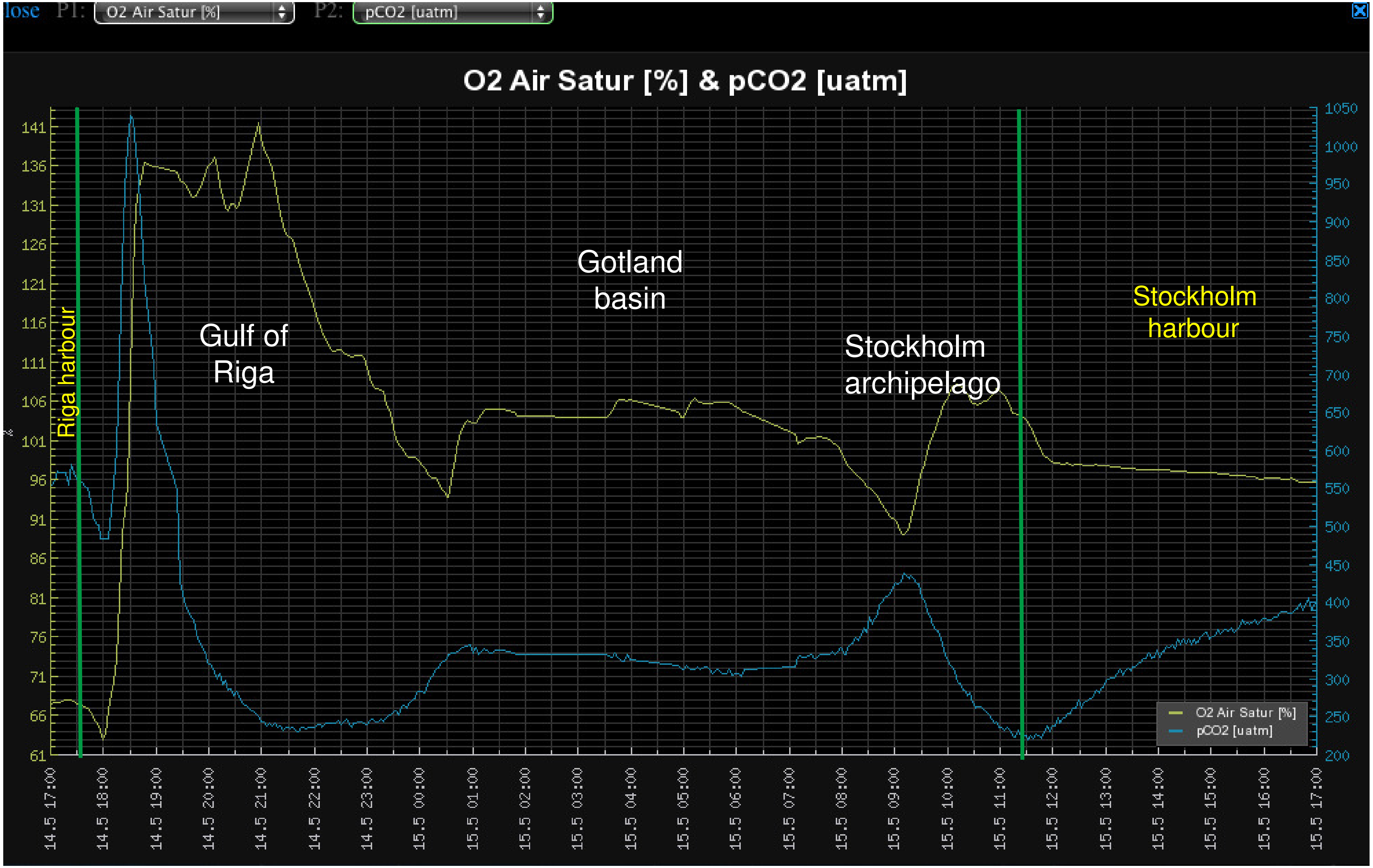
AANDERAA
a xylem brand

Delay in the response to in situ conditions



AANDERAA
a xylem brand

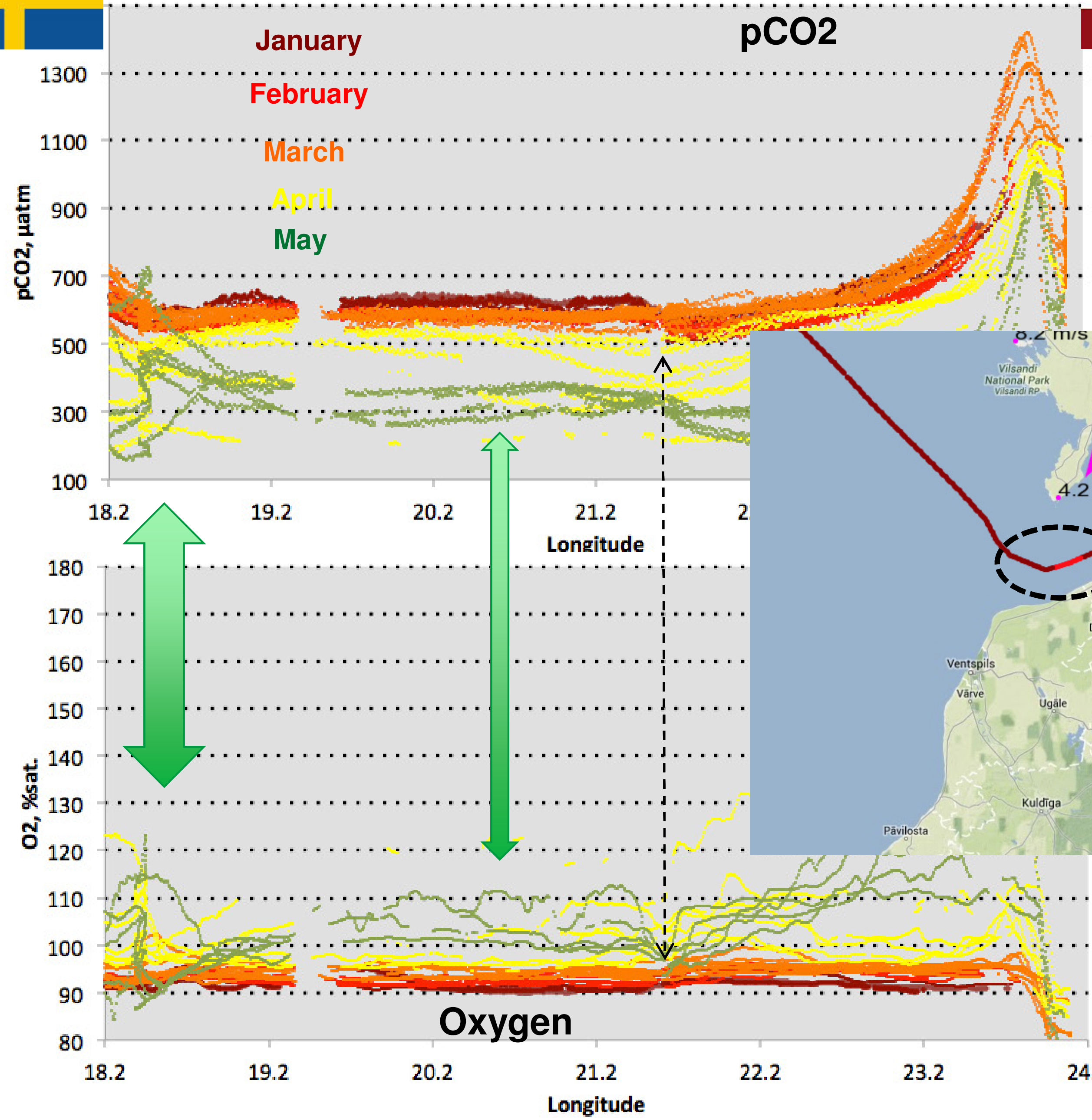
Route Riga-Stockholm

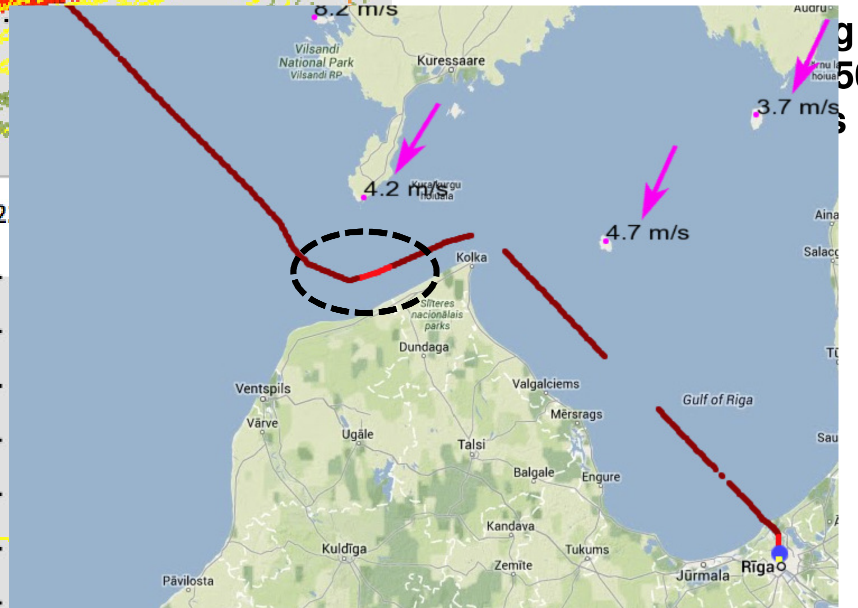


Observational period Jan-May 2014

- one-directional transect every second day

g
50
s per



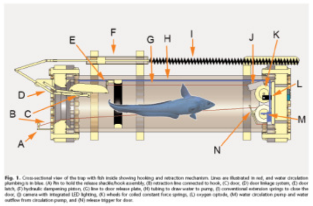


Oxygen Optodes

Examples of Scientific Papers

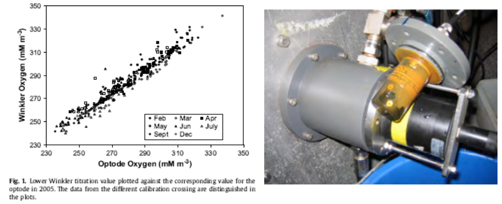
Tengberg et al (2006)

Incubators



Drazen et al (2005), Almroth et al (2012), Wikner et al (2013)

Ferry boxes



Hydes et al (2009)

Gas Exchange Chamber

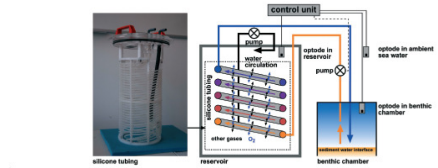
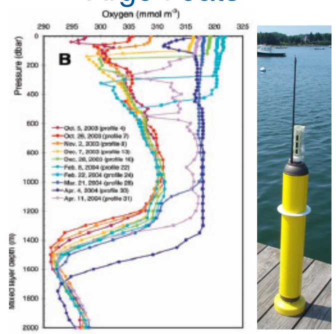


Figure 1. Schematic drawing of the gas exchange system. For explanation, see text.

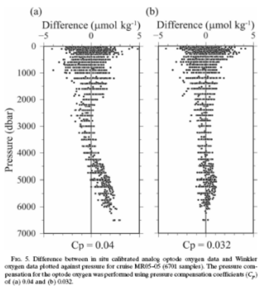
Sommer et al (2008)

Argo floats



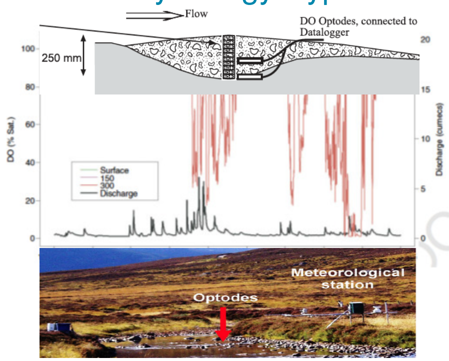
Körtzinger et al (2004, Nature)
Johnson et al (2010, Nature)
Fiedler et al (2013)
Takeshita et al (2013)

Cabled CTD



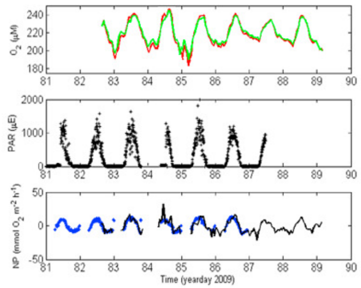
Uchida et al (2008)

Rivers/Hydrology/Hyporheic



Birkel et al (2013), Malcolm et al (2006, 2008, 2010), Soulsby et al (2008)

Gradients

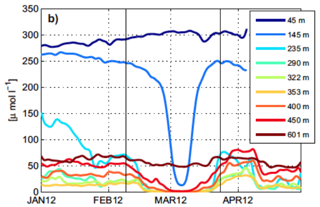


McGillis et al (2011), Champenois and Borges (2012)

Buoys

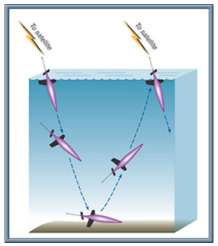
Jannash et al (2008), Bushinsky & Emerson (2013)

Moorings



Stramma et al (2014), Viktorsson et al (2012)

Gliders

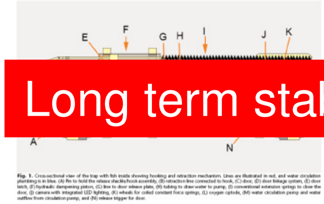


Nicholson et al (2008)

Oxygen Optodes

Examples of Scientific Papers

Incubators



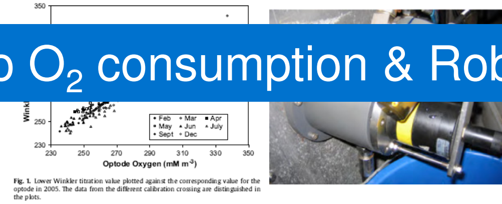
Long term stable

Drazen et al (2005), Almroth et al (2012), Wikner et al (2013

Not freezing sensitive

...berg et al (2006)

Ferry boxes



No O_2 consumption & Robust

Hydes et al (2009)

Gas Exchange Chamber

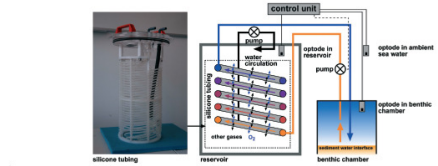
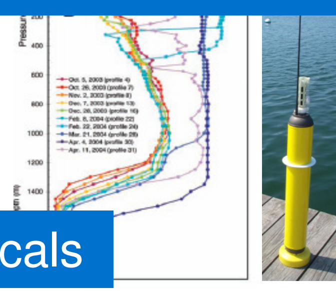


Figure 1. Schematic drawing of the gas exchange system. For explanation, see text.

Sommer et al (2008)

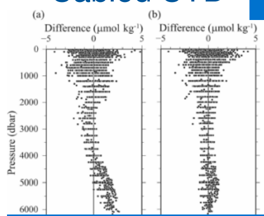
Good for hot water monitoring



...zinger et al (2004, Nature)
Johnson et al (2010, Nature)
Fiedler et al (2013)
Takeshita et al (2013)

Not sensitive to H_2S and most other chemicals

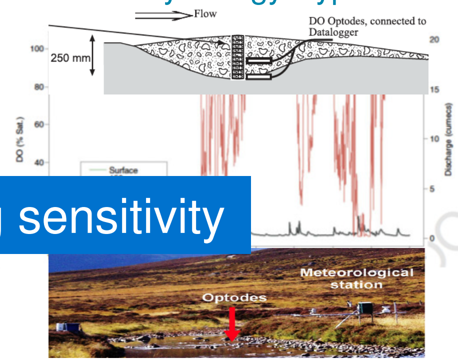
Cabled CTD



High accuracy & low noise

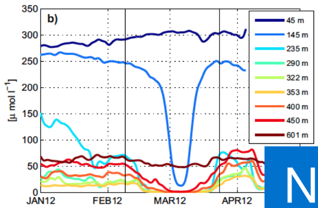
Uchida et al (2008)

Rivers/Hydrology/Hyporheic



Birkel et al (2013), Malcolm et al (2006, 2008, 2010), Soulsby et al (2008)

Moorings



Stramma et al (2014), Viktorsson et al (2012)

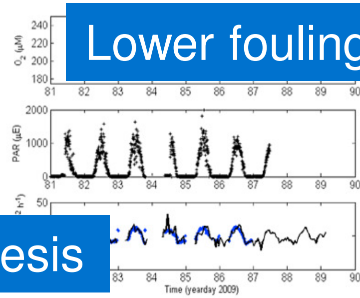
Buoys

No pressure hysteresis

Jannasch et al (2008), Bushinsky & Emerson (2013)

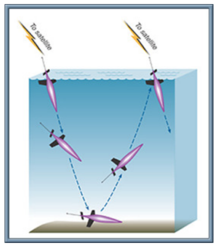
Gradients

Lower fouling sensitivity



McGillis et al (2011), Champenois and Borges (2012)

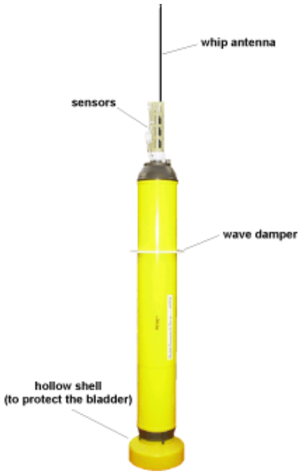
Gliders



Nicholson et al (2008)

Long term data from 69 Optodes on Argo floats

Yuichiro Takeshita et al., Poster presented at AGU fall meeting, San Francisco, Dec 2010.
Now published in: Takeshita et al. (2013) A climatology-based quality control procedure for profiling float oxygen data. J . Geophysical Res, Vol. 118, 1–11.



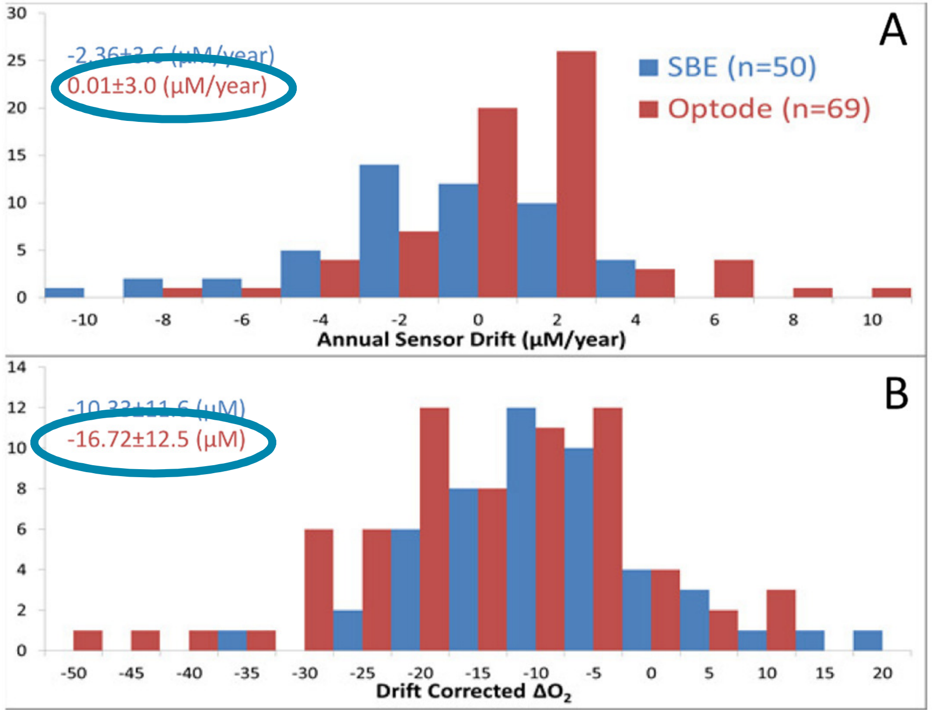
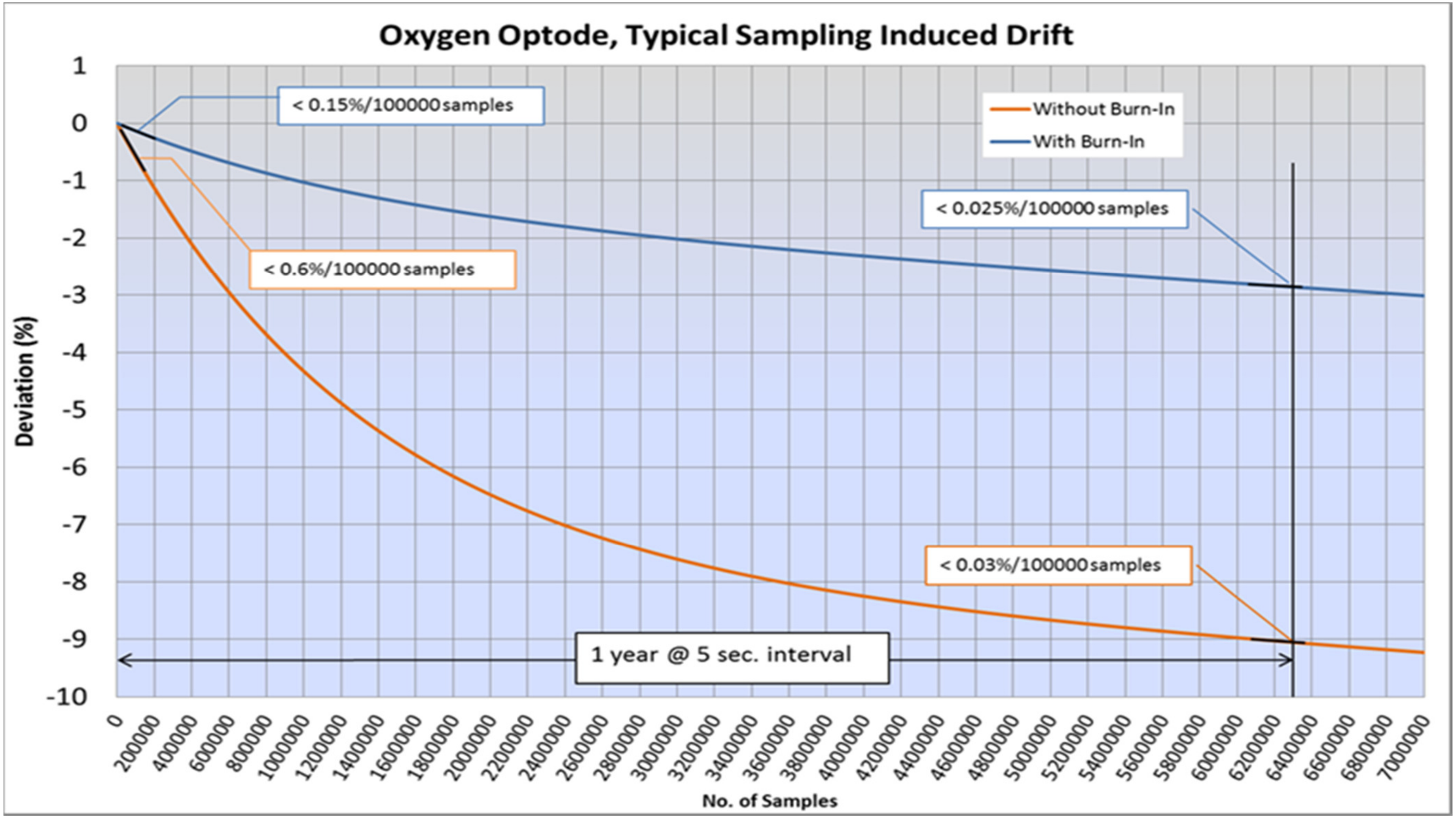


Figure 2. Histogram of sensor drift (A) and the Drift Corrected Average Deep ΔO_2 (B) for the two different types of oxygen sensors. The mean±std. dev. is labeled on the plot with its corresponding color.

- Conclusion: Optodes stable but gave lower values
- Reason: Foils bleach in ambient light (especially fluorescent) and if sampling is done at high frequency

When storing sensors use black protection cap!

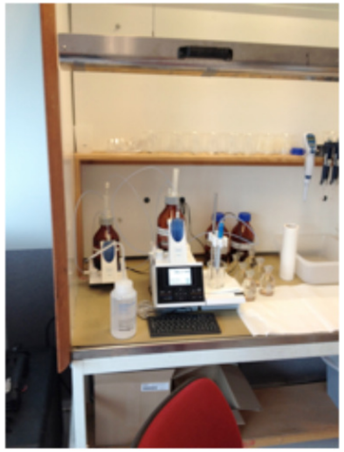
Optode drift in relation to number of measurements and pre-treatment (with burn-in) or not



All Multipoint calibrated Foils are Pre-matured ► Better Accuracy
► Better Stability Drift < 0.15 µM/100,000 samples
If not mechanically damaged foils get better over time

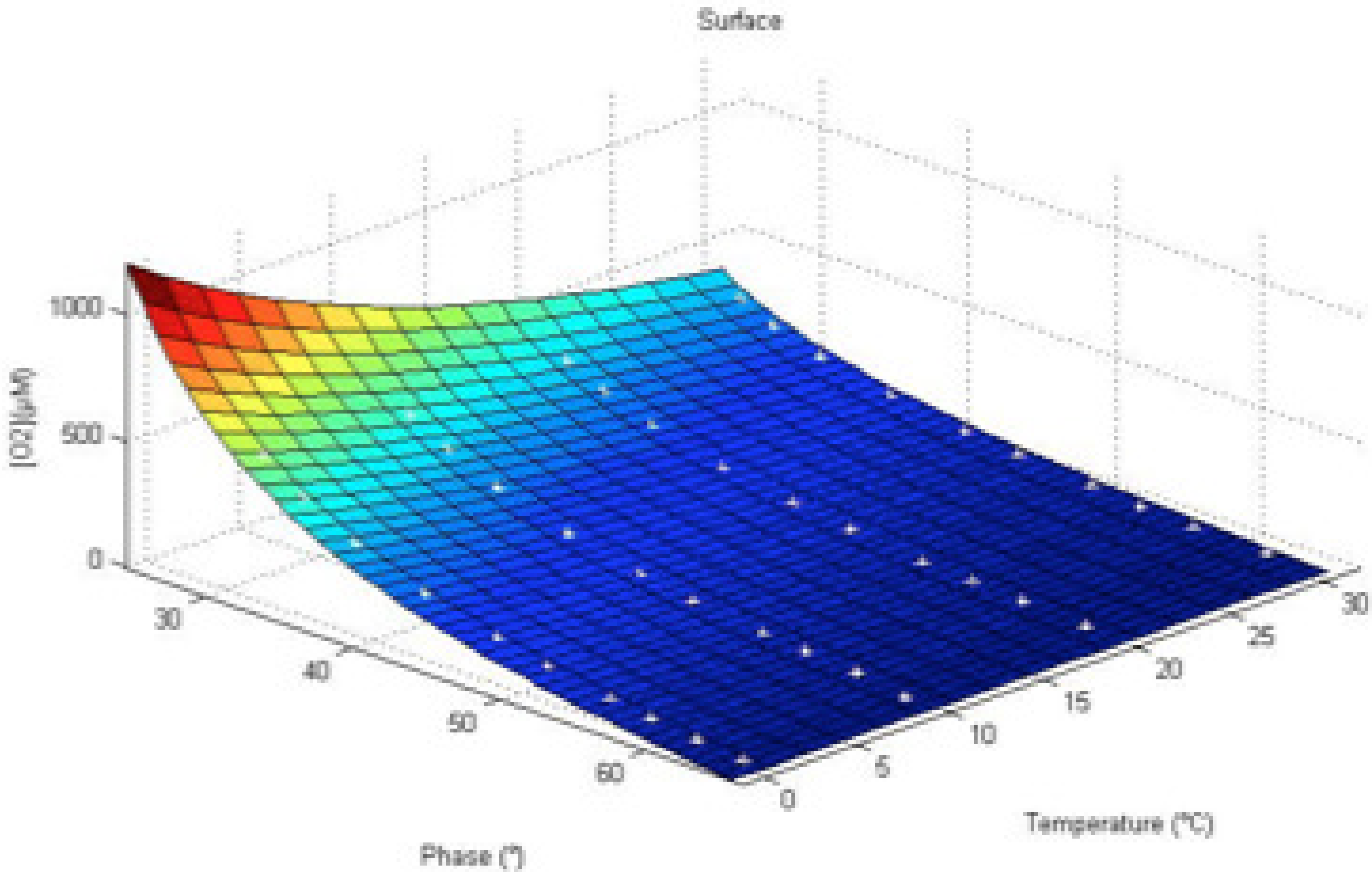
Multipoint Calibration System

- Gas injection by use of mass flow controllers
- Automatic System 40 point calibration & 20 point subsequent verification
- Operational since August 2012
- 3 parallel reference optodes in system
- Automatic Winkler system from SI Analytics for frequent verification
- Absolute accuracy better than 1.5%/±2.5 µM

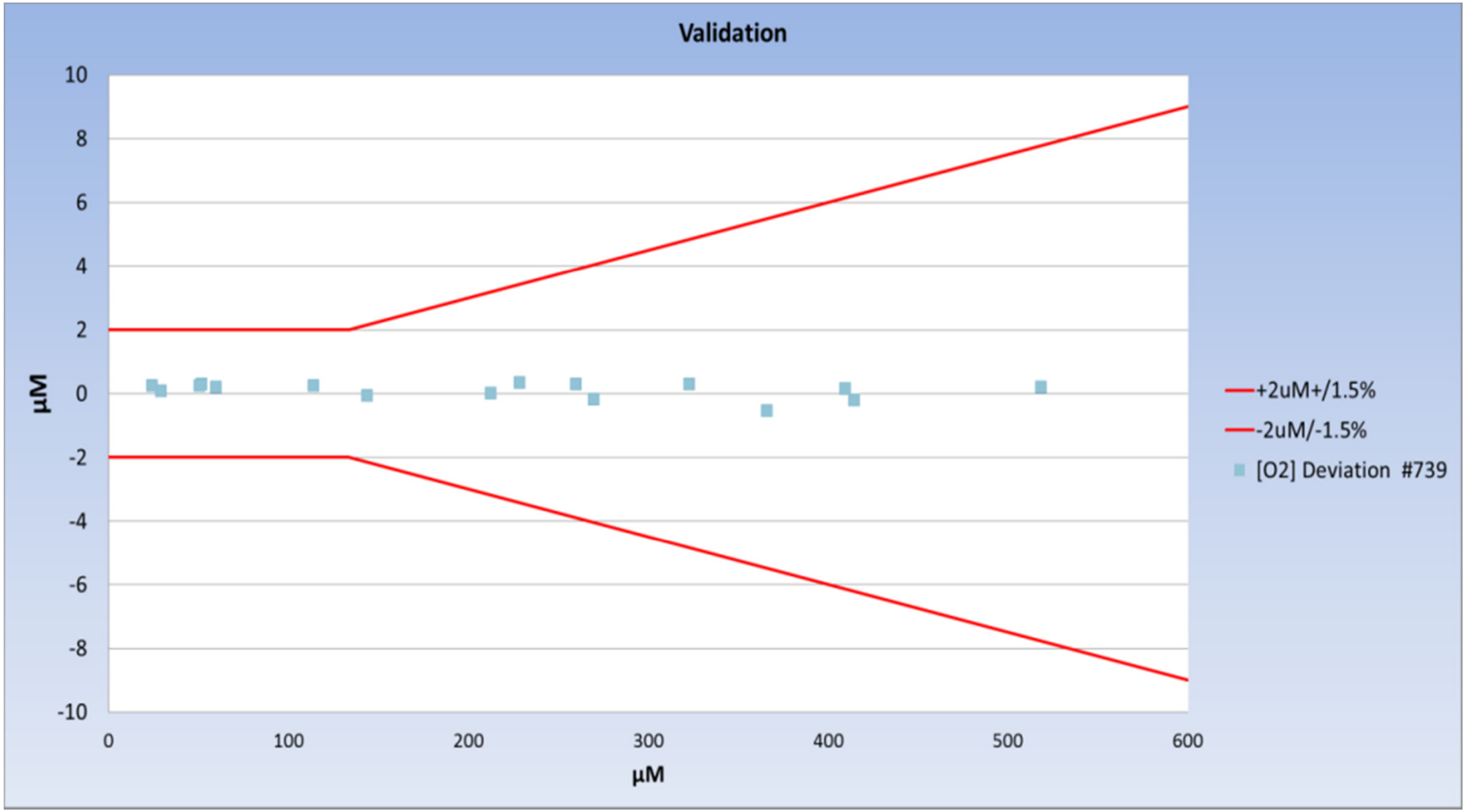


Multipoint calibration only for MkII: 4330 & 4831

Calibration plot



Validation



Accuracy over entire range of O_2 and Temp: ±2 µM or ±1.5%. Field resolution: ±0.2µM

Multipoint Calibration + red LED referencing gives the highest accuracy

Sensor Development

MKI (2002)
Main models:
3830 & 3835

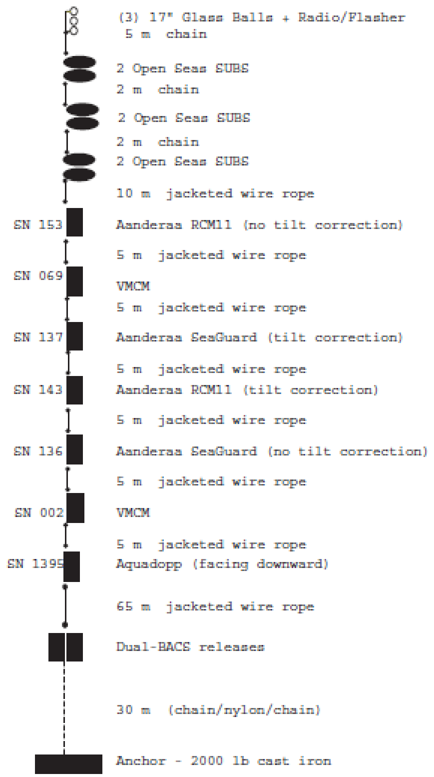
- Better electronics
- Better optics (faster foils)
- Red reference LED
- Better temperature compensation
- Better formulas to calculate absolute oxygen (Uchida 2008)
- Multipoint calibrations with pre-treated foils

MKII (2012)
Main models:
4330, 4831 & 4835

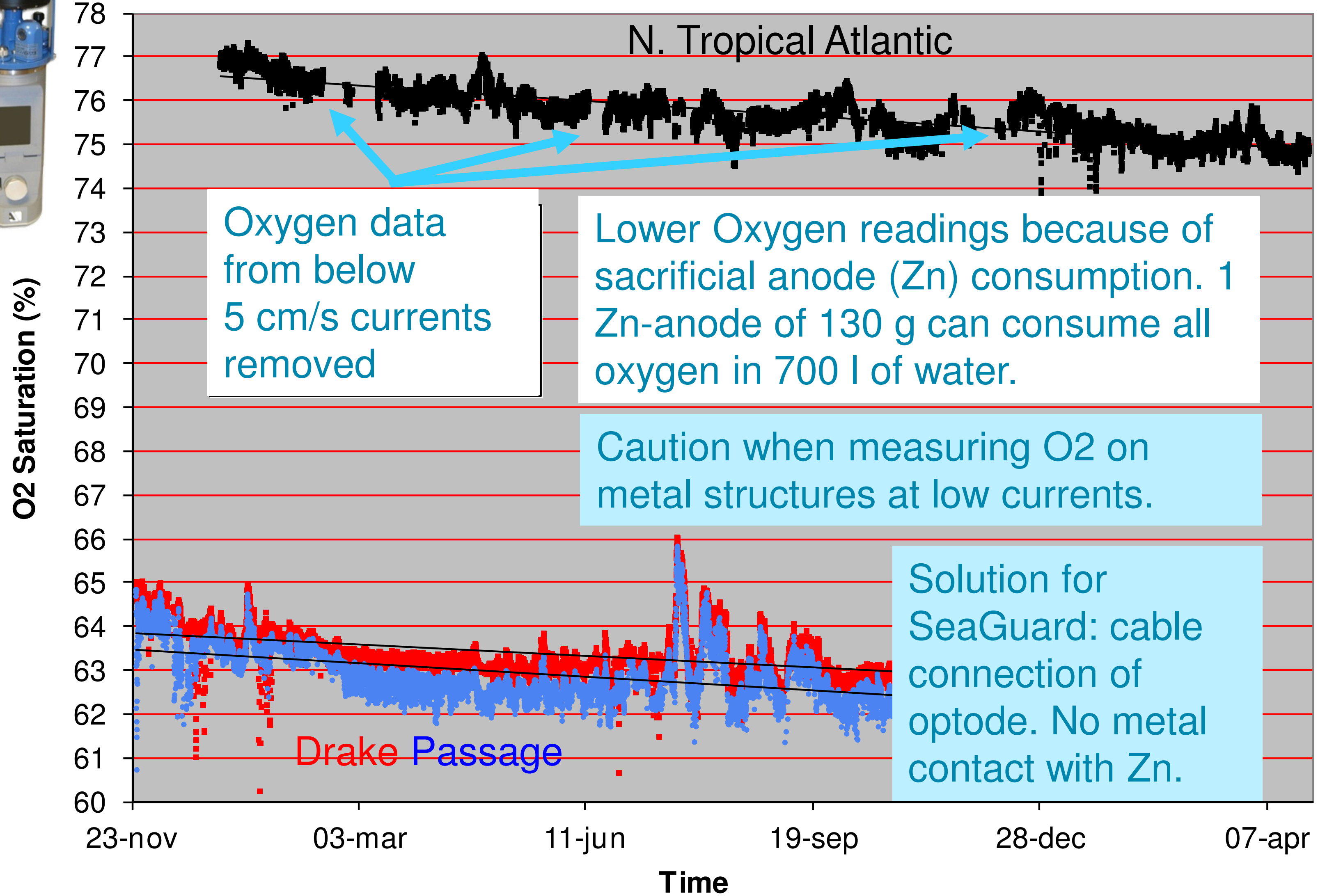
Affordable, High quality, 100 m rated
Aquaoptode 4531 introduced in 2013

Intercomparison deployment

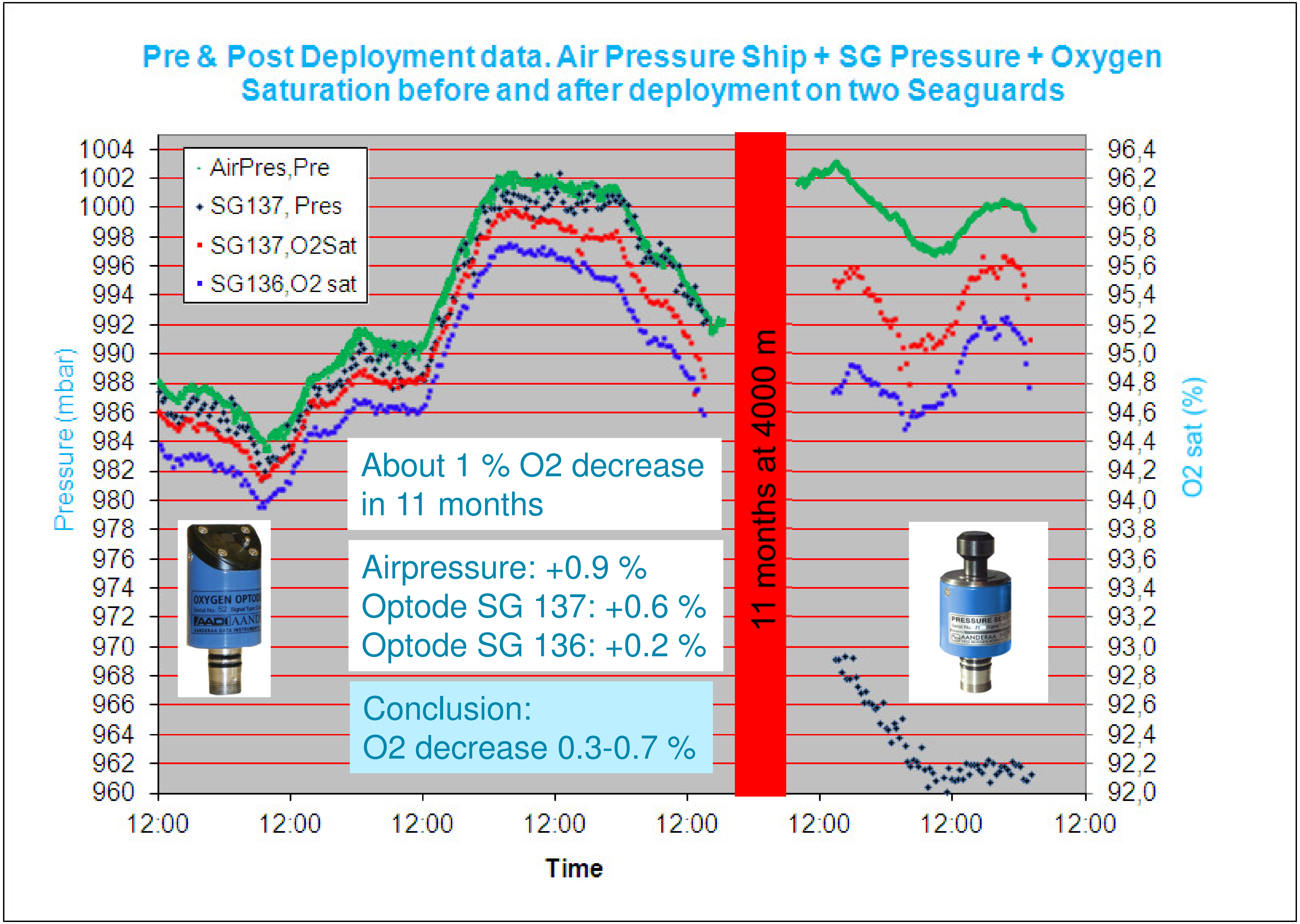
Year	Tester	Instruments	Duration/ Sampling	Conditions	Availability
2008	Bedford Inst, Canada	Seaguard (2), RCM8, RDI-DVS, RDI-ADCP (300)	1 month, 10 min	155 m, Nova Scotian Shelf, max speed 40 cm/s	Publication: "An intercomparison of acoustic current meter measurements in low to moderate flow regions", Drozdowski and al.
2008-2009	Bedford Inst, Canada	Seaguard (2), RCM11, RDI-ADCP (300)	12 months, 60 min	1600 m, Scotian Slope, max speed 26 cm/s	Results in paper & report, see references Upcoming peer reviewed paper
2008-2009	NOAA-PMEL, USA	Seaguard, Sontek Argonaut	9 months, 20 min	10 m, Pirata buoy, Atlantic, wave zone, max speed 60 cm/s	Results in paper, see references
2009	WSA, Germany	Seaguard (2), Nortek Aquadopp (2)	1 month, 5 min	5-10 m, Ems and Elbe rivers, max speed 120 cm/s, high tilt	Results in paper, see references
2009-2010	Univ of Rhode Island, USA	Seaguard (2), RCM11 (2), VMCM (2), Nortek Aquadopp	11 months, 30 min, low backscatter conditions	4000 m, Drake Passage, max speed 65 cm/s, downdrag	Publication: "Four Current Meter models compared in strong currents in Drake Passage", Watts and al.
2010-2011	Univ of Miami, USA	Seaguard, RDI-DVS, Nortek Aquadopp	18 months, 20 min, low backscatter conditions	4000 m, Trop Atlantic, max speed 54 cm/s, long mooring, downdrag & tilt	Will not be published



Oxygen at 4000 m

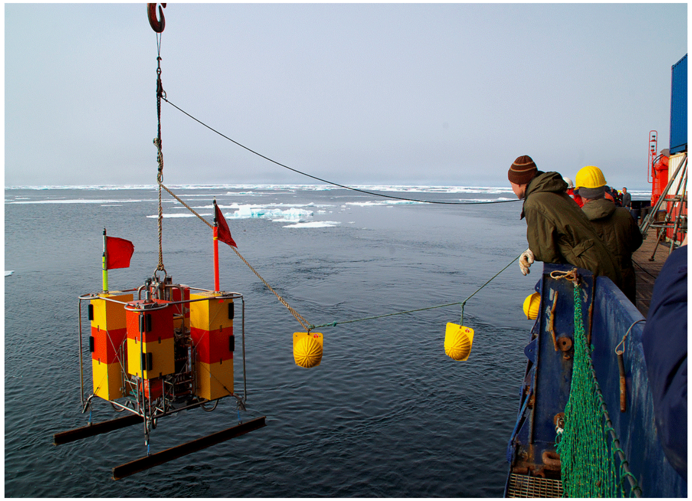


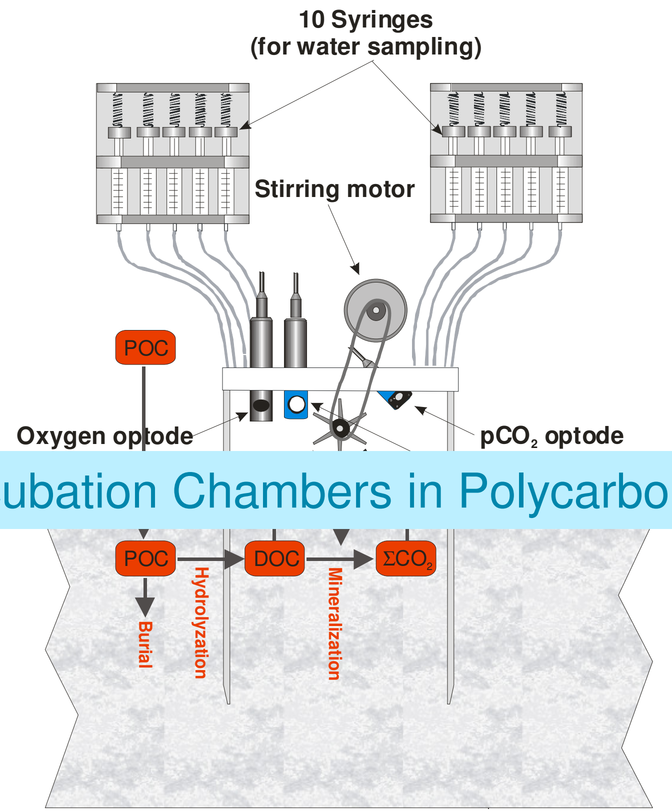
Lo Bue N. et al. (2011) Anomalies of oxygen measurements performed with Aanderaa optodes. J of Operational Oceanography. Volume 4 No. 118, 1–11.


Pre & Post Deployment data. Air Pressure Ship + SG Pressure + Oxygen Saturation before and after deployment on two Seaguards
AirPres,Pre
SG137, Pres
SG137,O2Sat
SG136,O2 sat
Pressure (mbar)
O2 sat (%)
1004
1002
1000
998
996
994
992
990
988
986
984
982
980
978
976
974
972
970
968
966
964
962
960
96,4
96,2
96,0
95,8
95,6
95,4
95,2
95,0
94,8
94,6
94,4
94,2
94,0
93,8
93,6
93,4
93,2
93,0
92,8
92,6
92,4
92,2
92,0
12:00
Time
11 months at 4000 m
About 1 % O2 decrease in 11 months
Airpressure: +0.9 %
Optode SG 137: +0.6 %
Optode SG 136: +0.2 %
Conclusion:
O2 decrease 0.3-0.7 %
OXYGEN OPTODE
AANDERAA
PRESSURE SE
AANDERAA

Gothenburg Autonomous Bottom Landers for Sediment-Water Incubations. Deployed ~300 times from 5-5600 m water depth

RCM Blue
in action measuring
above sediment
incubation system

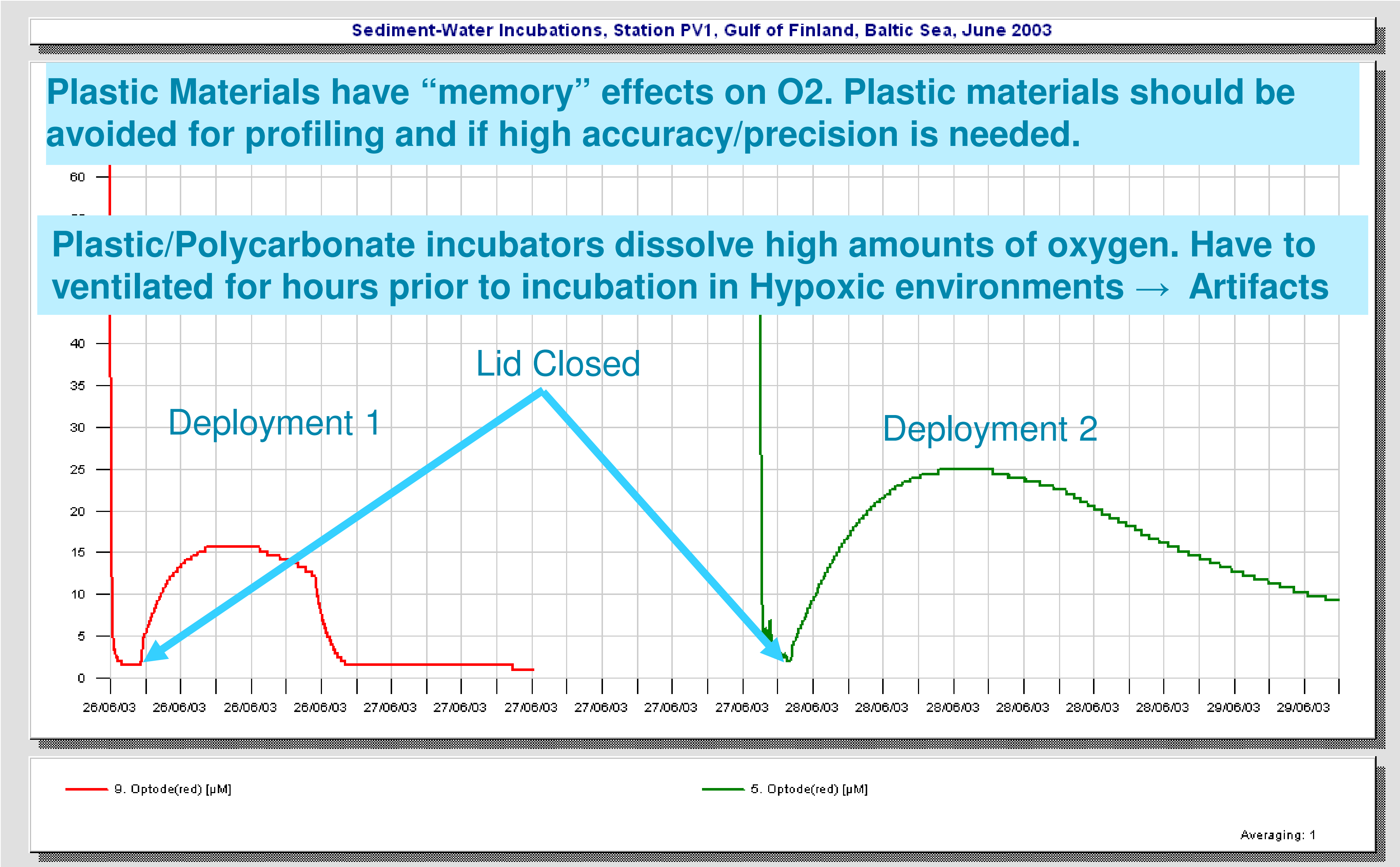




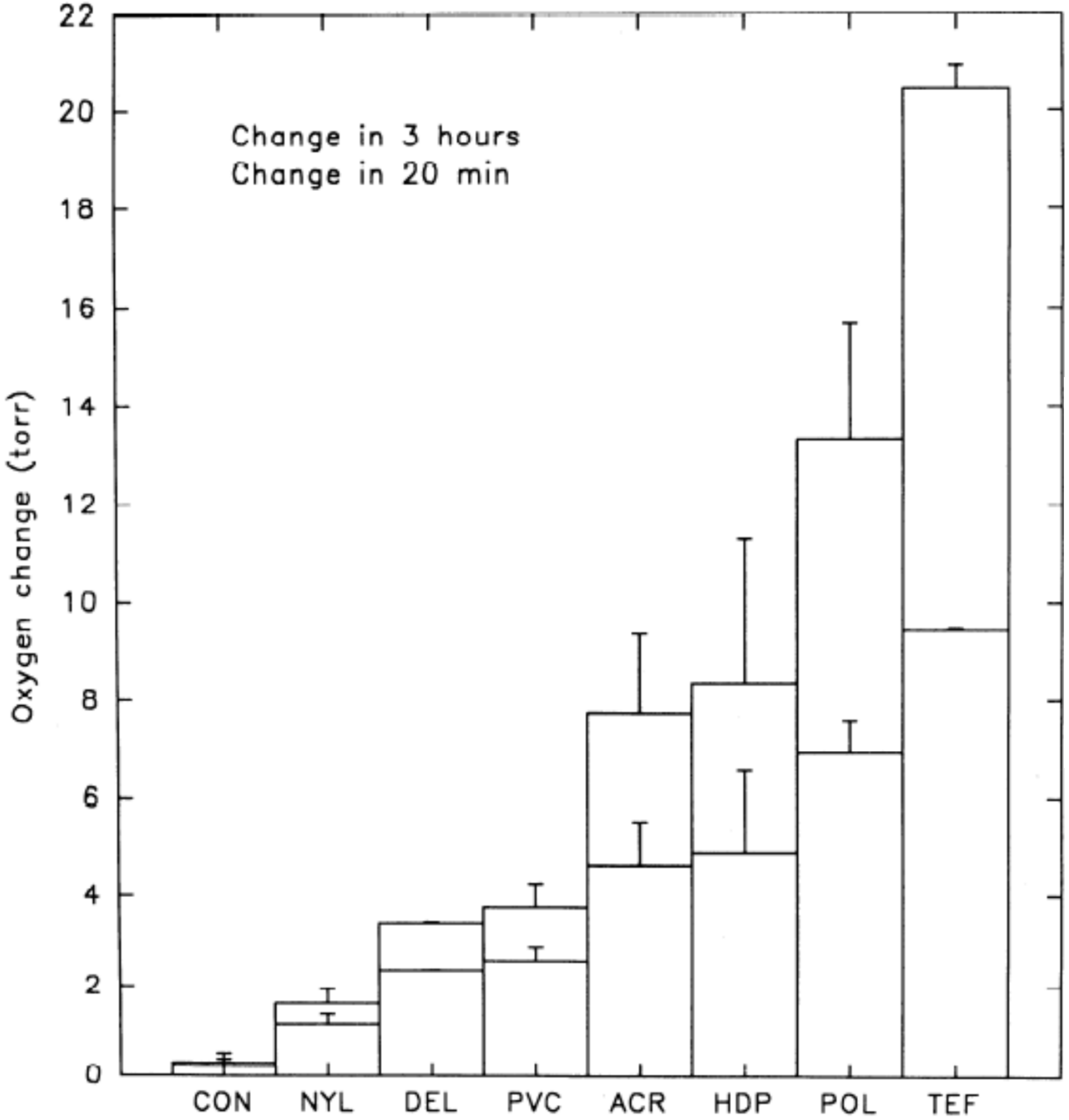
Incubation Chambers in Polycarbonate

Plastic Materials have “memory” effects on O2. Plastic materials should be avoided for profiling and if high accuracy/precision is needed.

Plastic/Polycarbonate incubators dissolve high amounts of oxygen. Have to ventilated for hours prior to incubation in Hypoxic environments → Artifacts



Stevens, E. Don (1992) Use of plastic materials in oxygen-measuring systems. Journal of Applied Physiology, 72(2): 801-804.

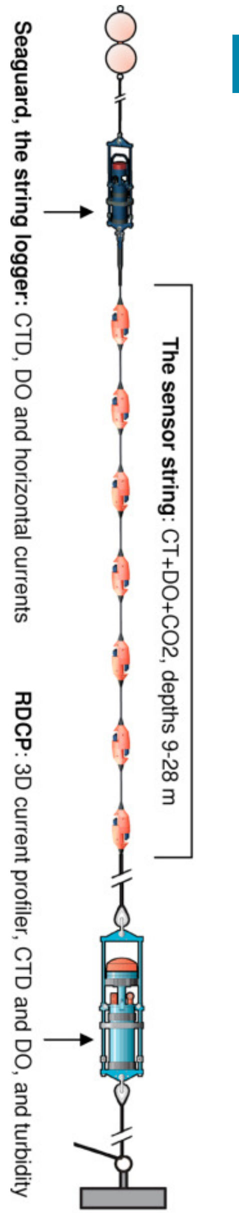


Stevens, E. Don (1992) Use of plastic materials in oxygen-measuring systems. Journal of Applied Physiology, 72(2): 801-804.

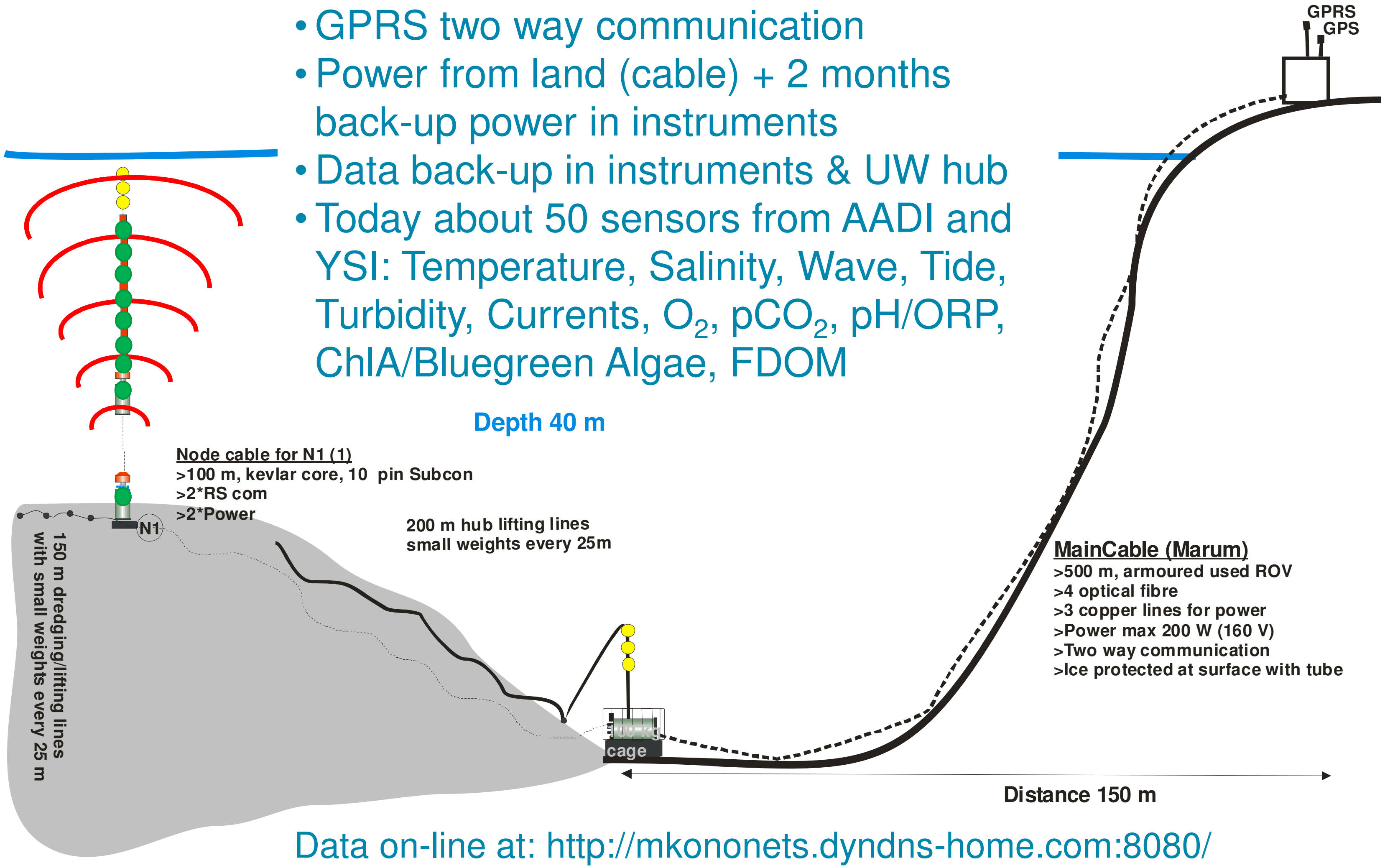
Plastic Materials have "memory" effects on O2. Plastic materials should be avoided for profiling and if high accuracy/precision is needed.

Koljoe fjord observatory: Located on the Swedish west coast in a system of fjords that suffer from frequent low oxygen conditions. In operation since April 2011

Koljoe fjord observatory: structure



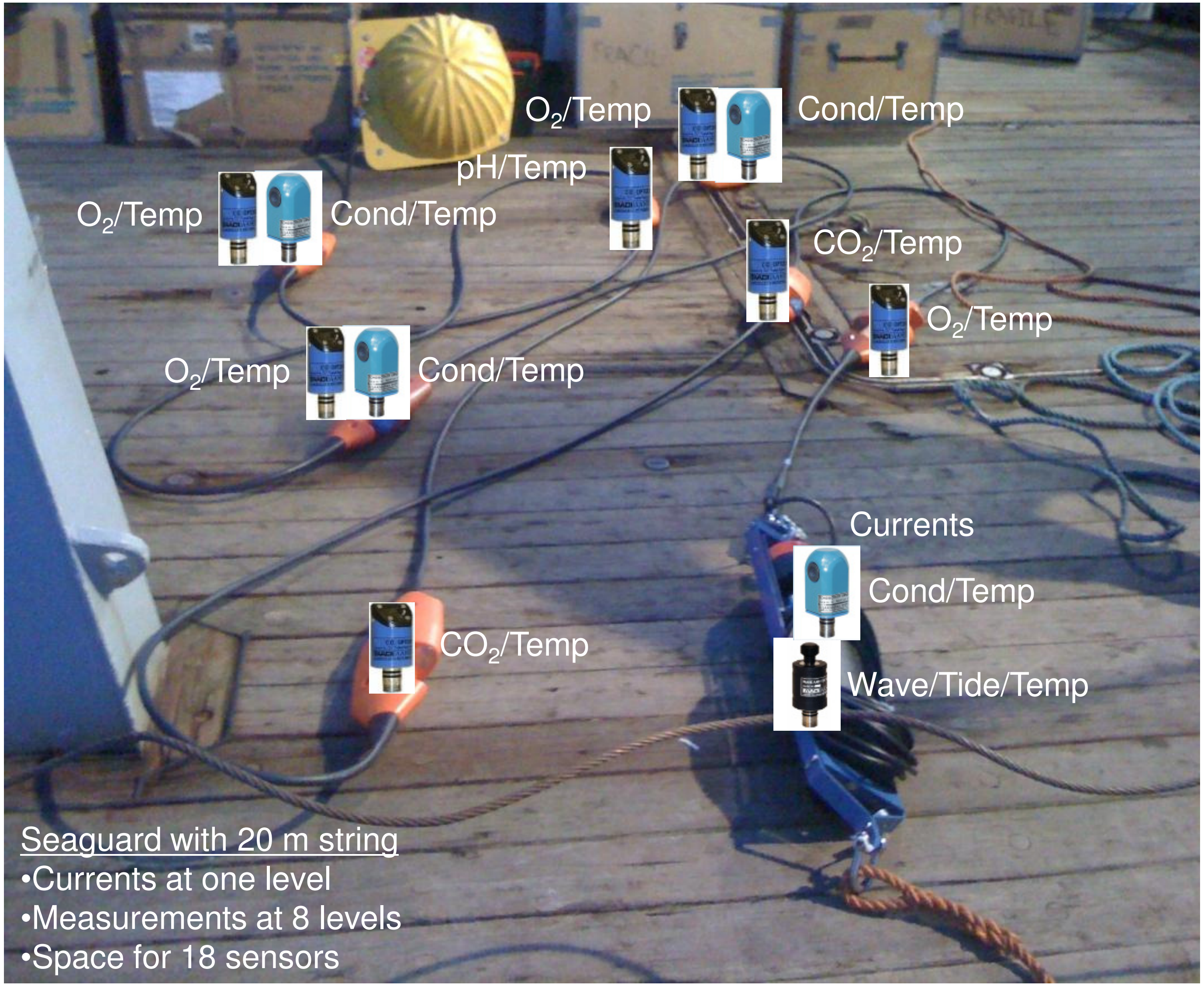
- Real time 2-30 min interval
- GPRS two way communication
- Power from land (cable) + 2 months back-up power in instruments
- Data back-up in instruments & UW hub
- Today about 50 sensors from AADI and YSI: Temperature, Salinity, Wave, Tide, Turbidity, Currents, O_2, pCO_2, pH/ORP, ChlA/Bluegreen Algae, FDOM



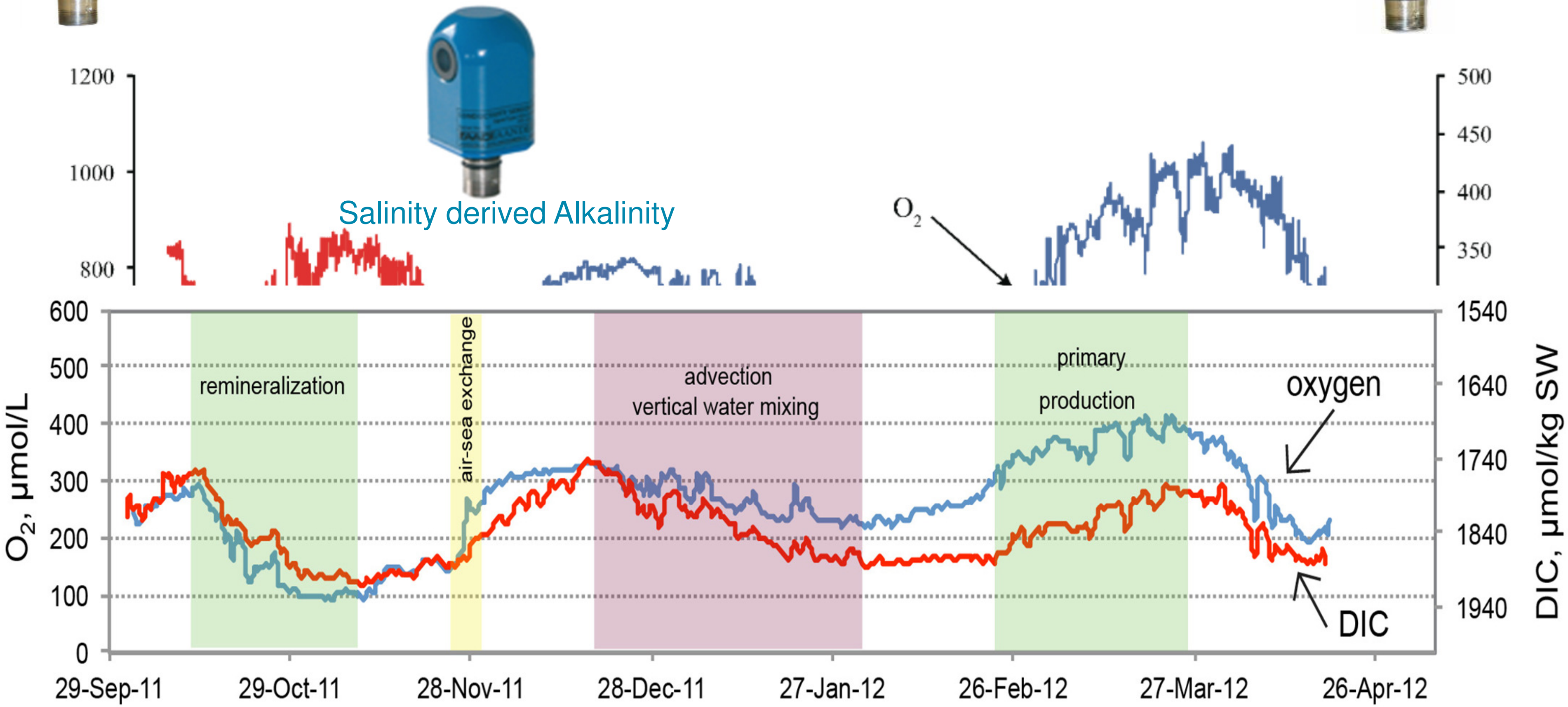
Data on-line at: http://mkononets.dyndns-home.com:8080/


RDCP
Seaguard
String with sensors

Seaguard string



Koljoe Fjord cabled observatory
pCO_2 sensor and O_2 optode at the depth of 12.6 m
7 months time-series, 30 min measuring interval



Redfield scaled plots. Atamanchuk et al. (2013)

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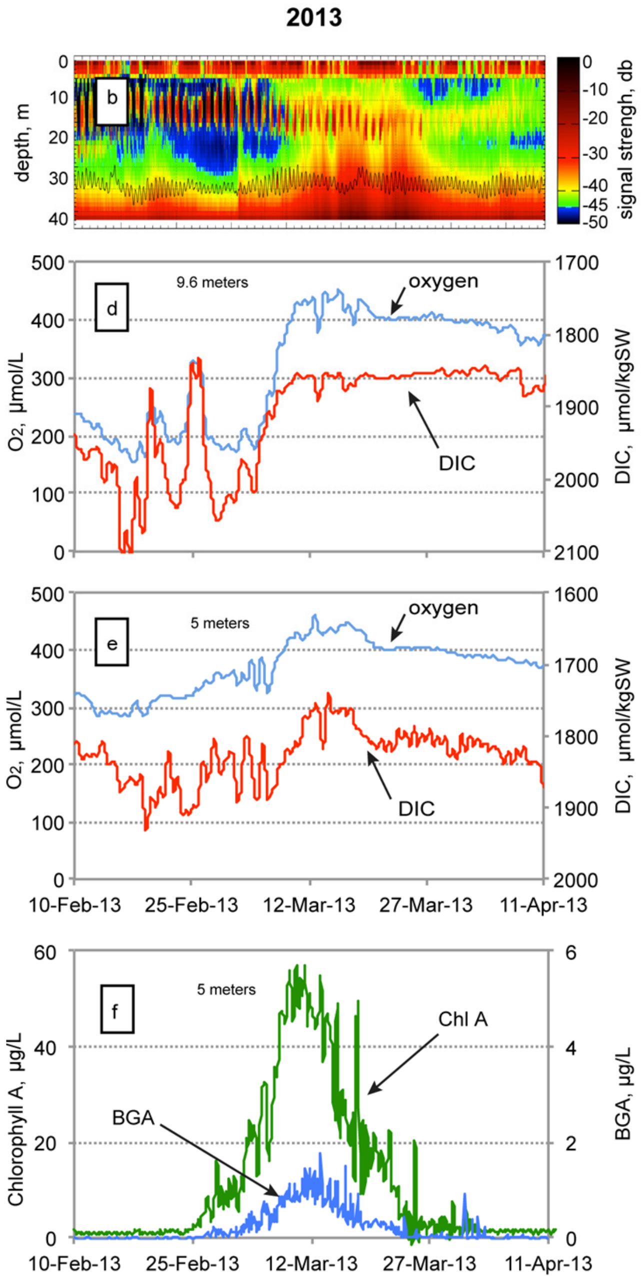
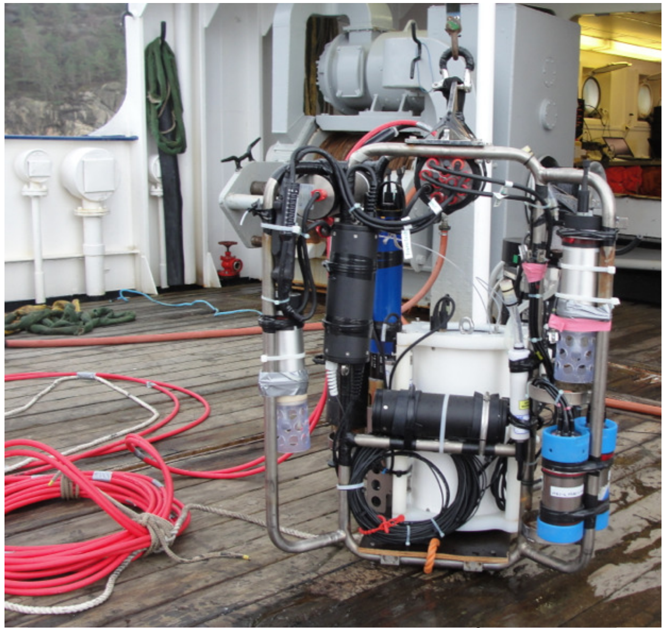
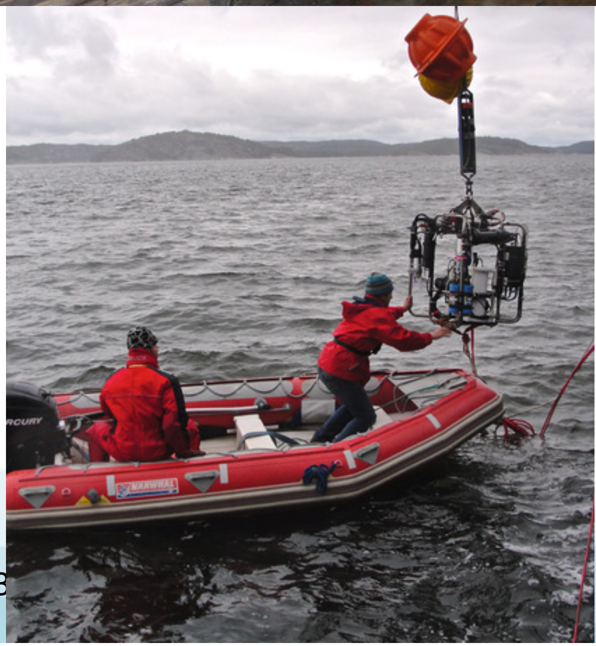
Combining Seaguard and EXO2

EXO2 sensors: C,T, D, O_2, FDOM, ChlA, pH, ORP, Cyanobact + wiper + cupper antifouling
Seaguard sensors: C, 5*T, D, Wave, O_2, 2*CO_2, Currents



Ongoing instruments tests at the Koljoefjord observatory: pCO_2 and pH sensors inter-comparison





4 different pCO_2 technologies from 5 manufacturers
4 different pH technologies from 5 manufacturers

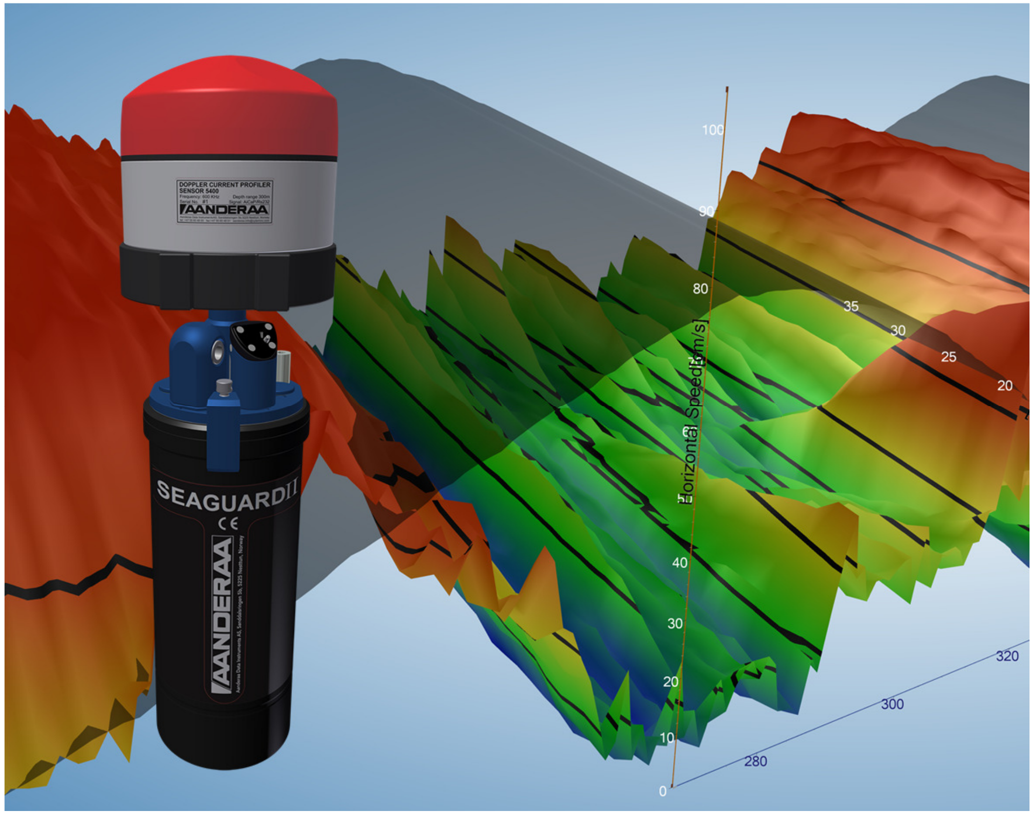
- Aanderaa Seaguard pH (optode), 2*pCO_2 (optode)
- Contros pCO_2 (IR) old
- Franatech pCO_2 (laser)
- Kimoto Electric Co 2*pH (electrochemical)
- Kyushu University 2*pH (ISFET), 2*pCO_2 (ISFET)
- PSI pCO_2 (IR) new
- PSI pCO_2 (IR) old
- Sensorlab pH (colorometric)
- YSI EXO pH (electrochemical)

- Background data from Aanderaa Seaguard (Currents, Sal, Temp, O_2 and YSI EXO with wiper and cupper guard (Sal, Temp, O_2, FDOM, ChlA, Blue green algae, Turb, ORP)

- Sampling 2 times per week for pH (spectrophotometric, meta-cresol-purple, Leif Anderson), DIC (IR-Licor, with Dickson water) and Alkalinity (pH titration + Grahn)

FIXED-POINT OPEN OCEAN OBSERVATORIES

Ongoing instruments tests at the Koljoefjord observatory: SeaGuardII DCP – the newly released 600kHz multiparameter system current profiler



Acoustic Doppler Current Profiling, Broadband vs Narrowband: data quality, range, power consumption referencing with single point sensors

4 beam vs 3 beam with automatic removal of faulty beam

Spread mode vs burst mode

Surface current measurement

Multi column with surface referred capability

Different cell sizes

Ongoing instruments tests at the Koljoefjord observatory: Response time of new “faster” non-transparent O_2 foils, response time with improved water circulation

New non-transparent foils have about 4 times faster response time keeping the same properties and ruggedness

Better water circulation can improve response time with a factor of 4

Upcoming instruments tests at the Koljoefjord observatory: O_2 contamination from using standard Niskin bottle.

Mounting optodes inside Niskin bottles. Mimicking typical sampling scenarios in OMZ, in fjords, in the Black Sea and in the Baltic Sea

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SCRIPPS, San Diego, June 12th , 2014

Thanks for your attention

Conclusions

- In-situ monitoring + quality control + modeling ➔ 3 essential components of understanding aquatic environments
- Optodes are robust, accurate, stable, flexible and have low power consumption
- Proven long-term stability + 5 years
- Used in a wide variety of applications, about 50 scientific publications
- Simple field methods can improve the absolute accuracy to ± 3 %
- Multipoint calibrations improve the absolute accuracy to ± 1.5 %
- Sacrificial anodes can induce artifacts
- Plastic materials have O_2 memory effects, should be avoided

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