Water column baseline assessment for offshore CCS sites: field data from the Goldeneye storage complex

M. Esposito, M. Martinez-Cabanas, P. Linke,
M. Schmidt, E.P. Achterberg

STEMM-CCS Open Science Meeting and 4th International Workshop on Offshore Geological Storage 11th – 13th February 2020 Bergen, Norway

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Why baseline?

- Resolve natural variability of parameters crucial for detection of potential CO_2 leakage
- Distinguish with confidence a leakage signal from the natural variability
- Reduce erroneous attribution of CO_2 anomalies to CCS activities
- Help to ensure that offshore CO_2 storage is long-term and environmentally safe

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Site description

Goldeneye – depleted gas field in the UK sector of the Central North Sea

- High variable environment e.g. tidal variations, seasonal stratification, storm events…
- High anthropogenic disturbances e.g. oil and gas production, fishing activities, trawling…

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Baseline data collection

3 RV Poseidon cruises

POS518 (25 Sept – 28 Oct 2017)

POS527 (15 Aug – 3 Sept 2018)

POS534 (1 – 29 May 2019)

James Cook RV

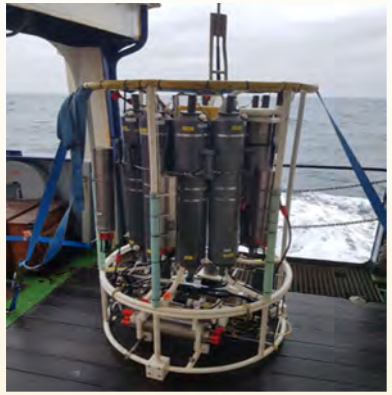
JC180 (25 April – 30 May 2019)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Sampling strategy

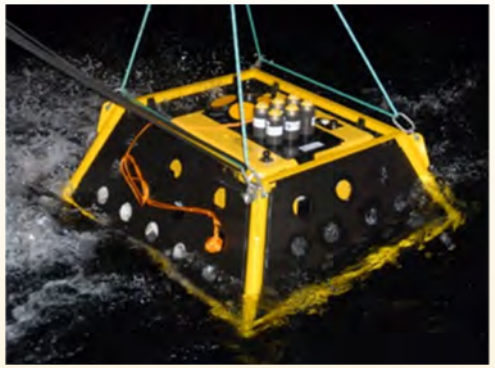
Discrete sampling of water column

Traditional CTD/rosette

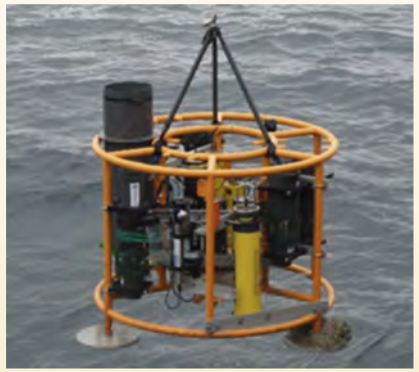


Towed
Video
pump-CTD

Automated measurements of near-seafloor hydrochemistry and carbonate chemistry parameters



Develogic Lander

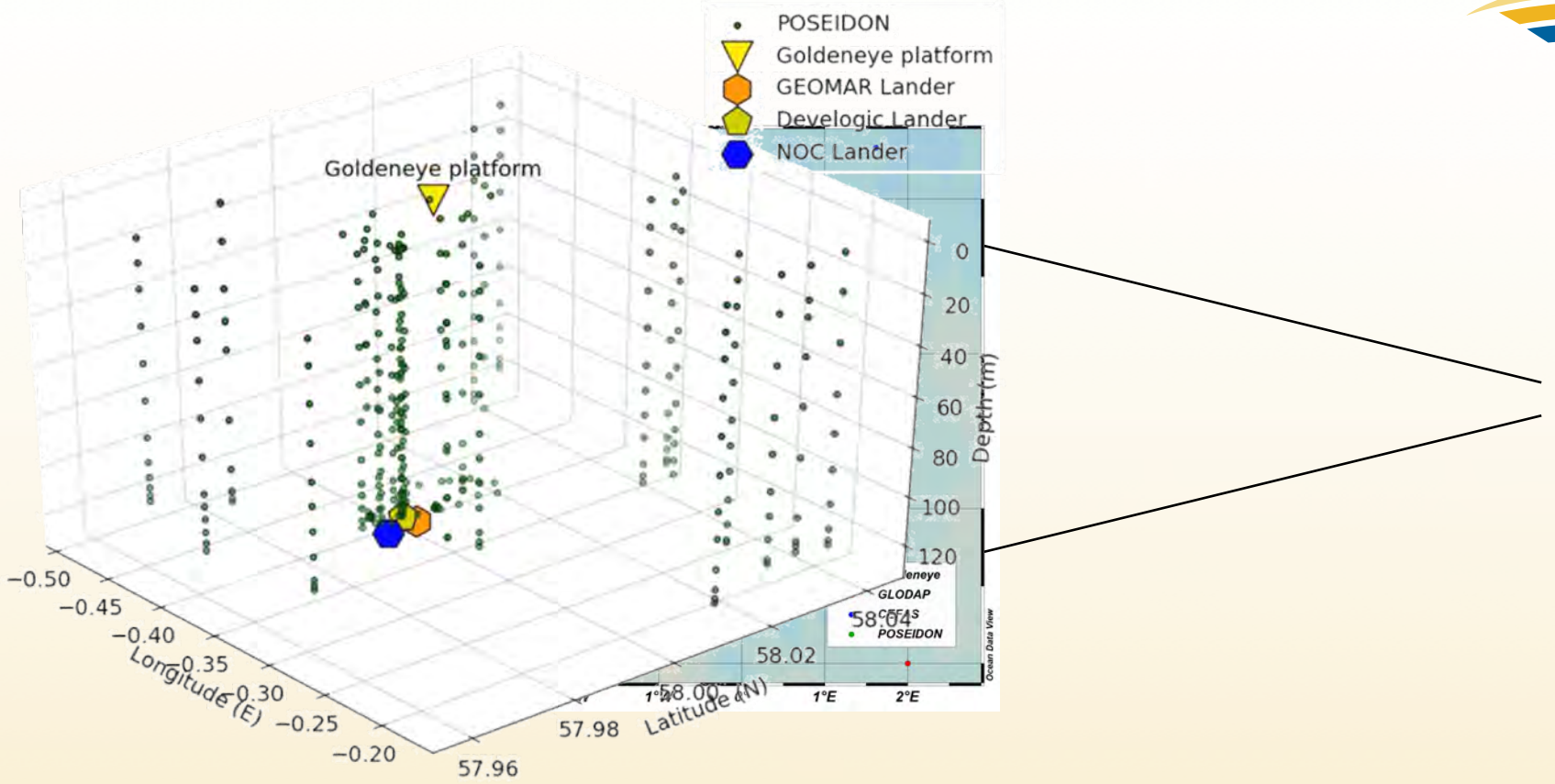


NOC Lander

GEOMAR Lander

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Sampling resolution



Historical published data
- 45 vertical profiles
- 230 water samples

STEMM-CCS discrete samples
- 35 full depth vertical profiles
- 422 water samples

Landers
- Over 1 MM high-resolution data points

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Data availability

STEMM-CCS cruises

POS518 (October 2017) – https://doi.org/10.1594/PANGAEA.907801
POS527 (August 2018) – https://doi.org/10.1594/PANGAEA.907809
POS534 (May 2019) – https://doi.org/10.1594/PANGAEA.907815
Landers data - https://doi.org/10.1594/PANGAEA.909624
https://doi.org/10.1594/PANGAEA.908935
https://doi.org/10.1594/PANGAEA.909291
https://doi.org/10.1594/PANGAEA.908919

GLODAP database

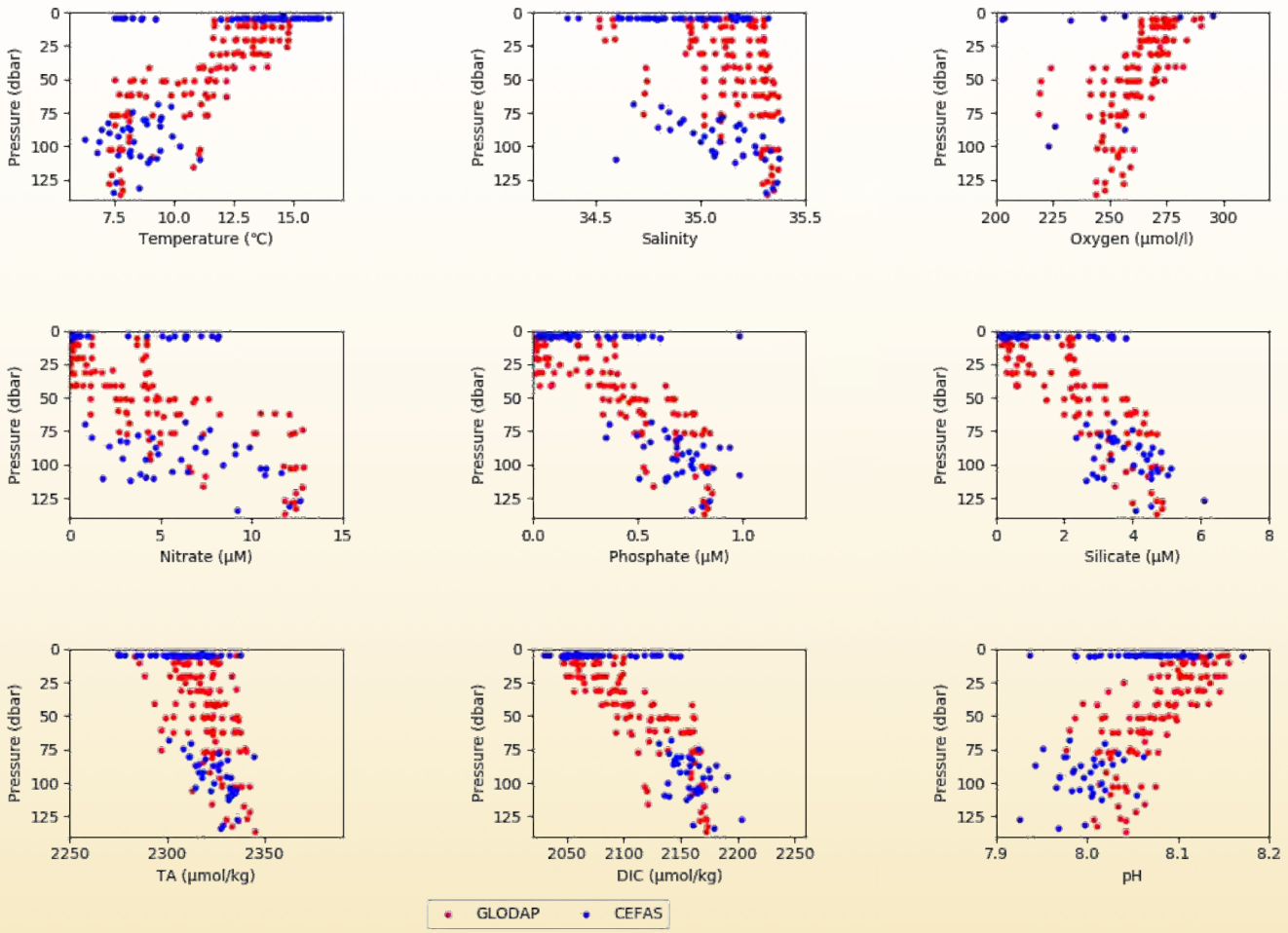
Hydrographic and Carbonate chemistry data (Aug-Sept 2005)
https://doi.org/10.1594/PANGAEA.441686

CEFAS

UK - Shelf Sea Biogeochemistry project (2014-2015)
https://doi.org/10.1594/PANGAEA.852643

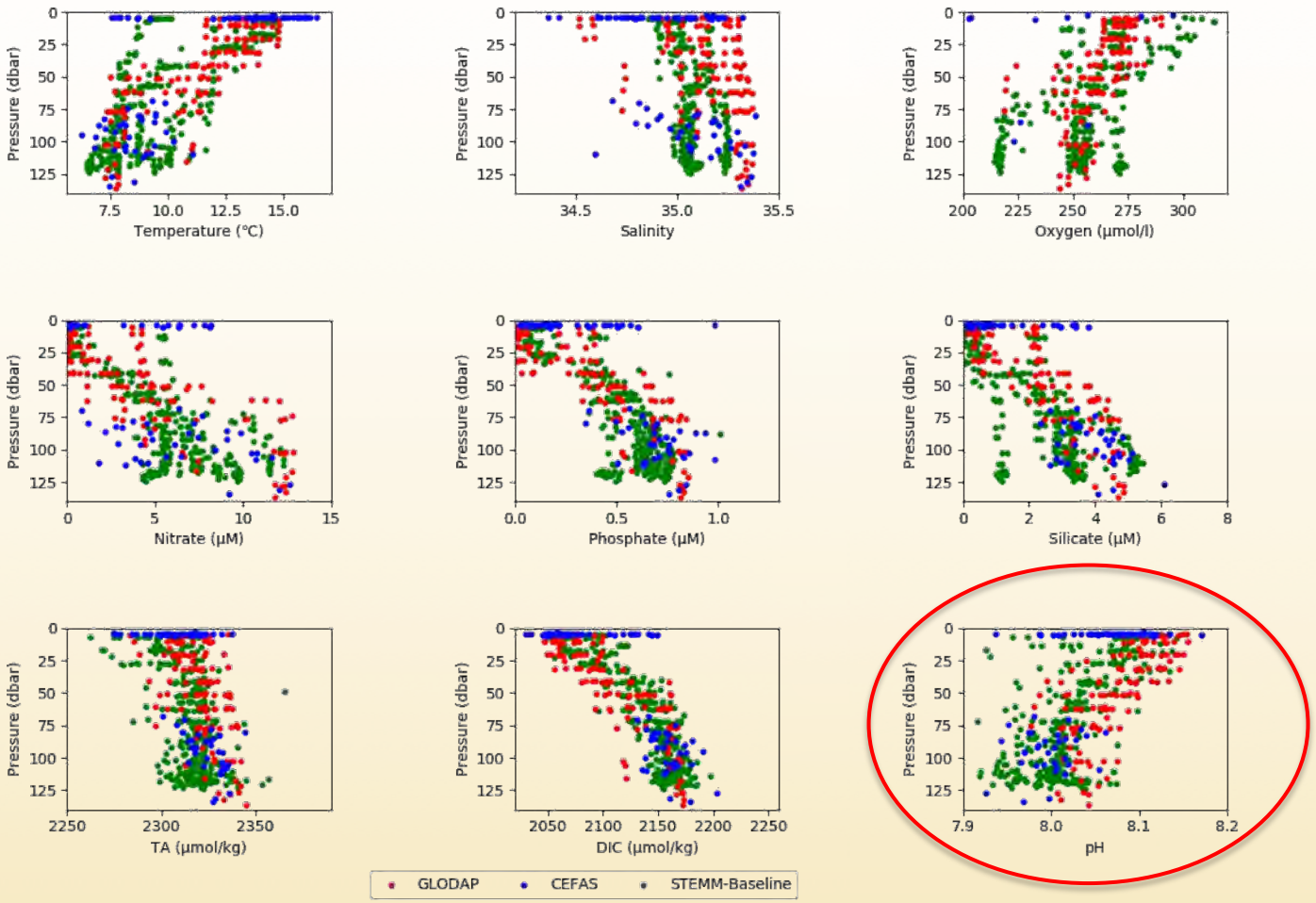
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Water column structure : Historical



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Water column structure : Historical + STEMM baseline



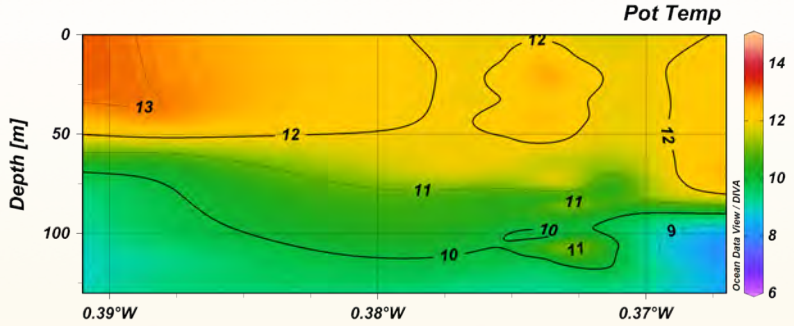
Measured parameters within range of historical values

Average 0.04 pH decrease
Possible effect of ocean acidification over 14 years

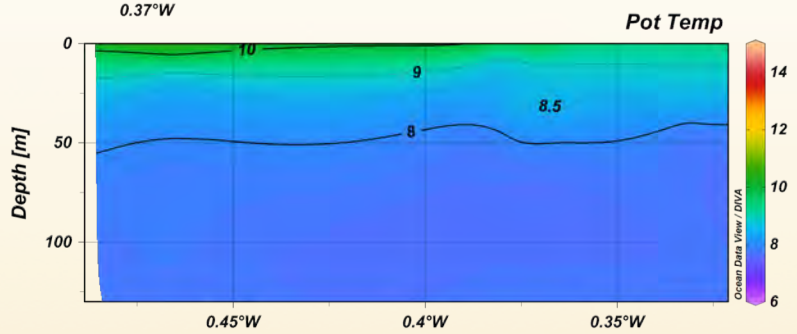
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Seasonality: A year in the Goldeneye area

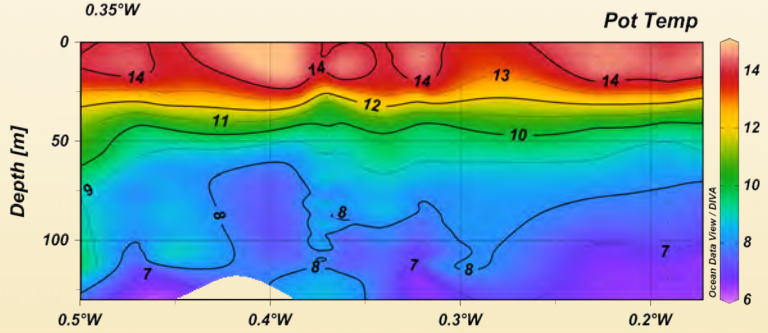
Temperature variability



Autumn (POS518)
weak stratification residual
from summer conditions,
towards fully mixed winter waters



Spring (POS534)
8°C whole water column
still mixed from winter

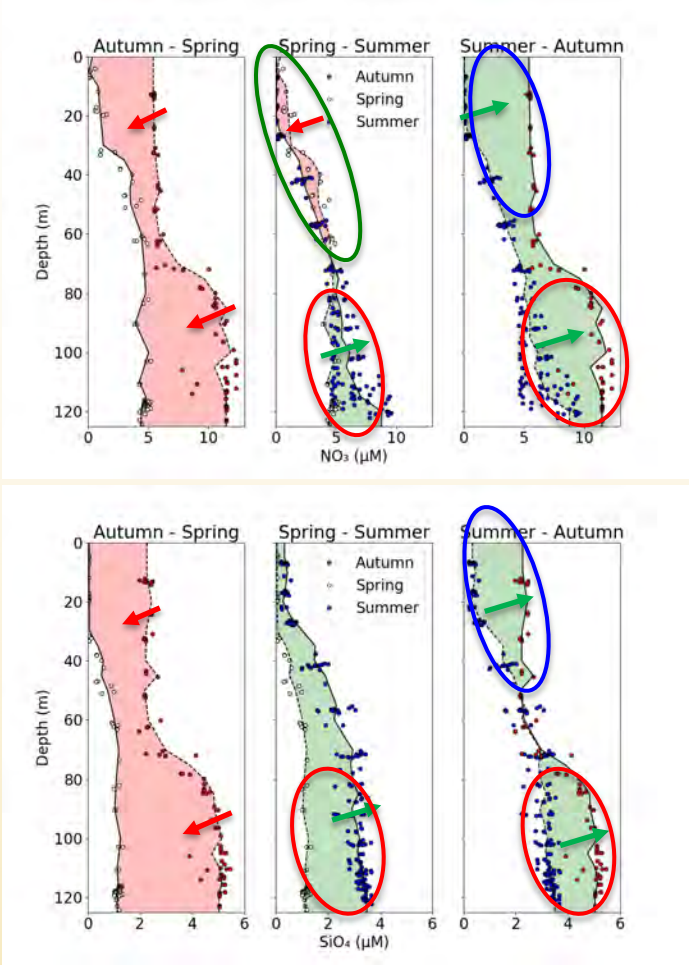


Summer (POS527)
high stratification
ΔT(surface-bottom) ~ 8°C

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

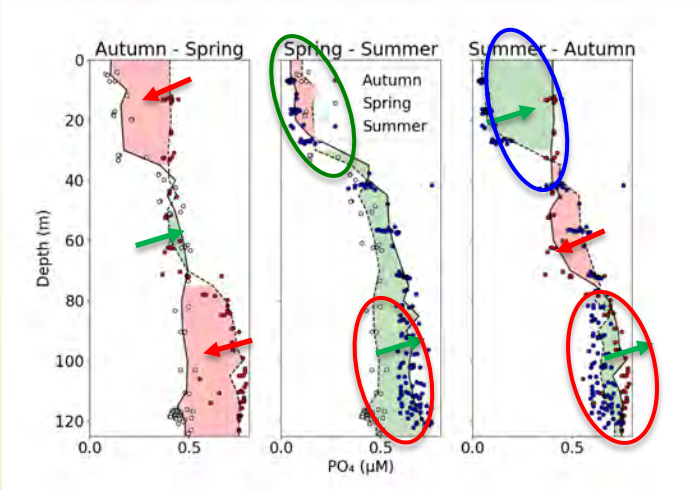
Seasonality: A year in the Goldeneye area

Seasonal transitions in inorganic nutrients



Red areas: ↓ nutrients

Green areas: ↑ nutrients



Nutrients changes

⇩

Reflect effects of
primary production
at surface

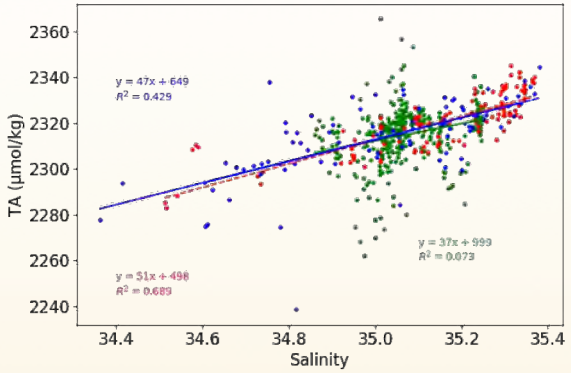
remineralisation
at depth

and
vertical mixing

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Carbonate chemistry

physical and biological forcings on the carbonate system



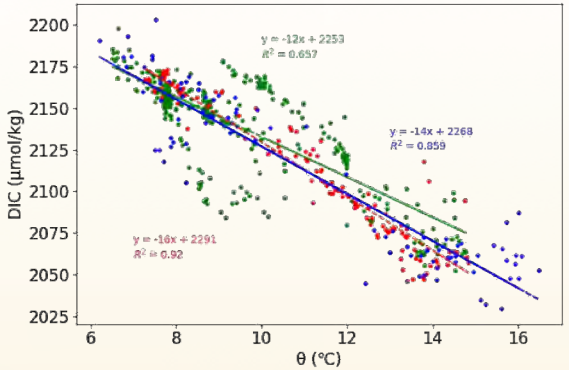
Total Alkalinity distribution reflects water salinity

One unit of S corresponds to average 45 µmol/kg TA increase

Good correlation between DIC and θ

Decreased solubility of CO_2 with increasing temperature at surface

Higher carbon in colder (and deeper) waters



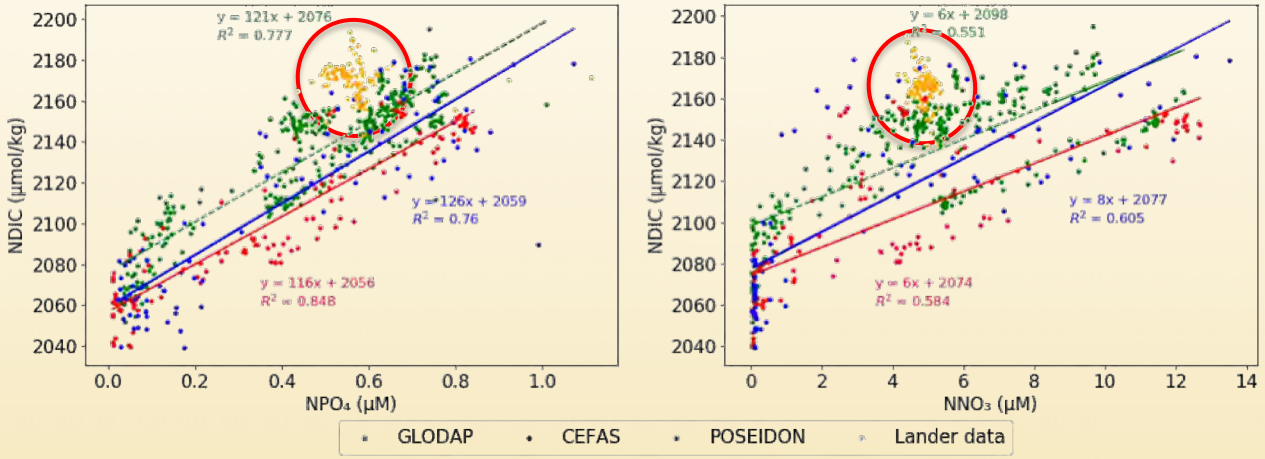
Effect of primary production and biological pump on the DIC distribution

Strong linear correlations for both PO_4 and NO_3

Constant Redfield:

C : N : P = 121 : 18 : 1

Comparable to North Atlantic ratio (Körtzinger et al., 2001; Takahashi et al., 2000)



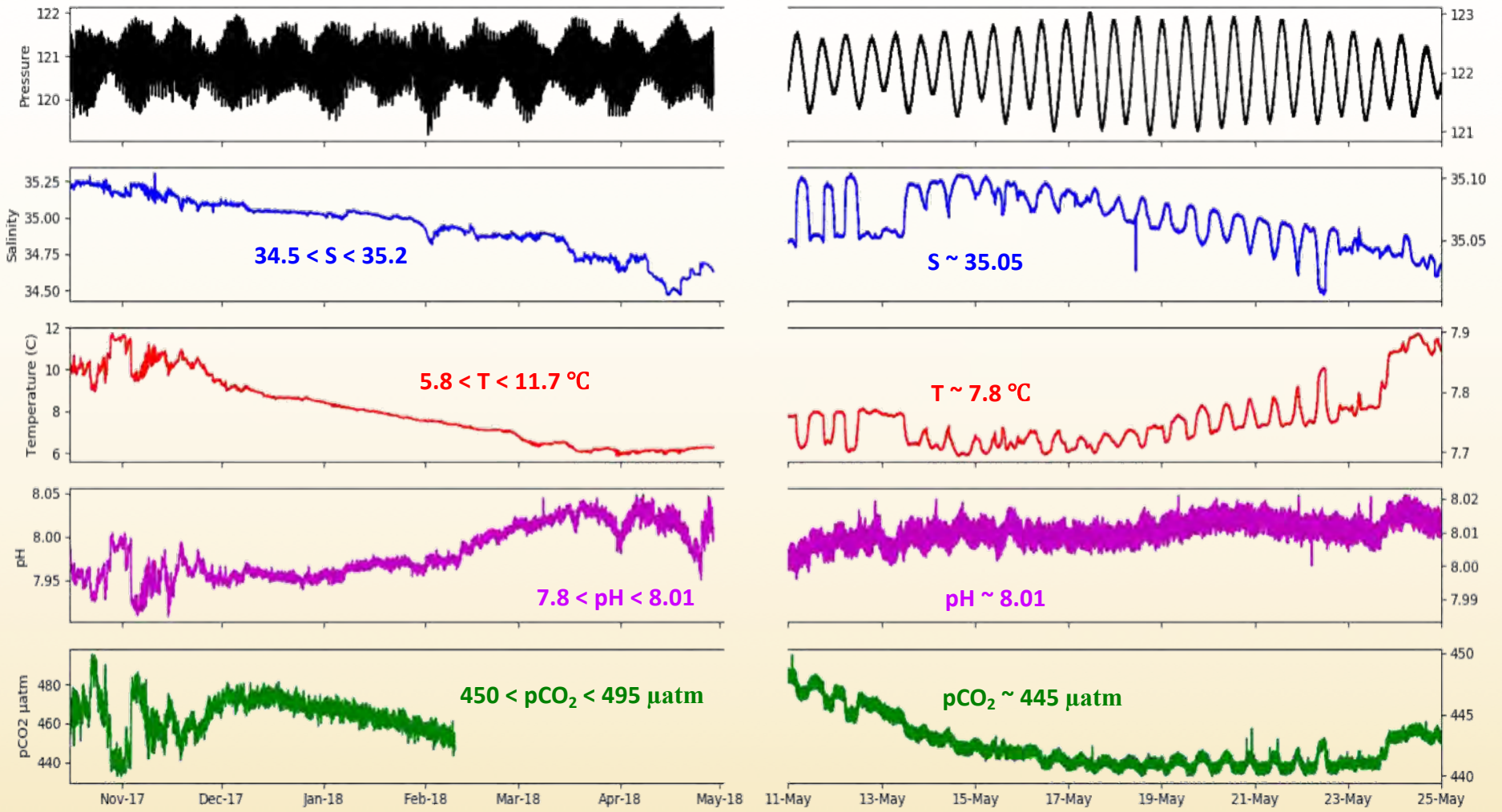
Excess C relative to N at depths from landers Redfield ratio in May:

C : N : P = 121 : 10 : 0.9

weak vertical mixing and denitrification processes

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Near-seafloor water column – Landers



October to April

⇩

Shift from post-summer waters to more stable winter conditions

May

⇩

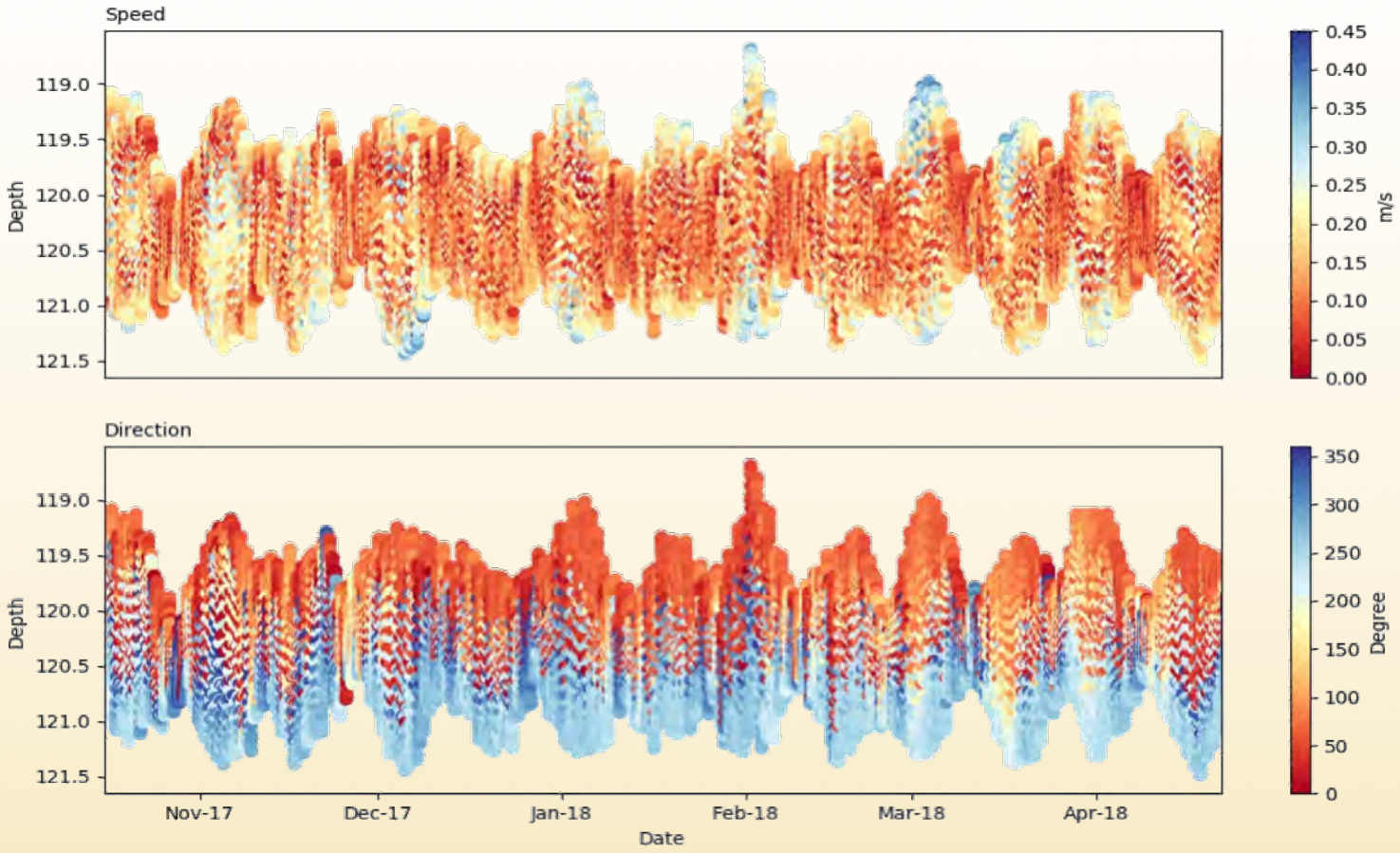
Narrow ranges

and also effects of tides

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Water currents at Goldeneye

Data from Develogic lander (Oct 2017 – April 2018)



Tidal impact

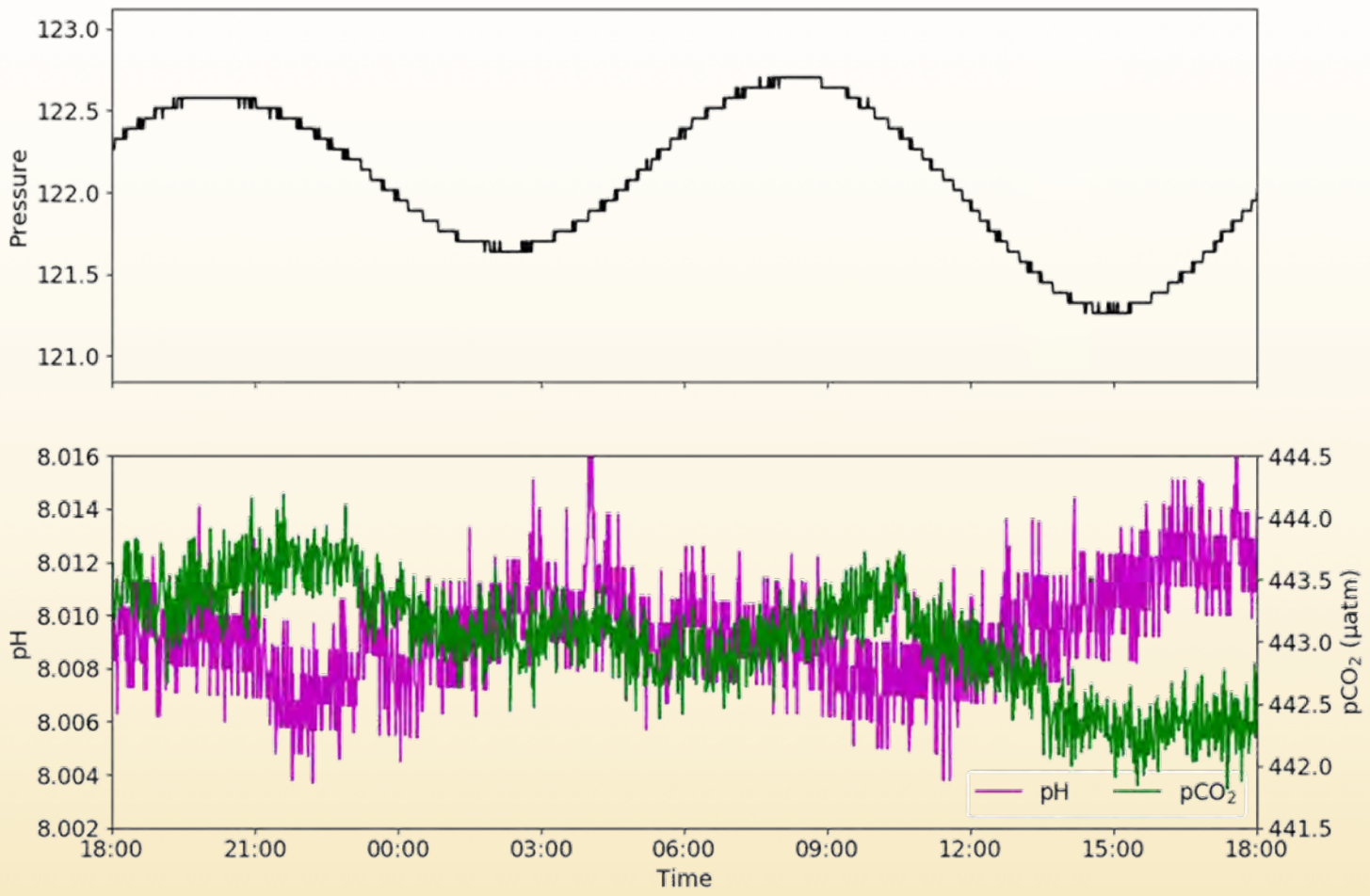
Regular change between southerly and north-easterly current directions

Average velocity = 0.2 m s^{-1}

In general below 0.4 m s^{-1}

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Near-seafloor pH and pCO_2 – GEOMAR Lander



Sampling frequency: 10 s

Detection and quantification of tidal effect on the carbonate chemistry

Over one tidal cycle

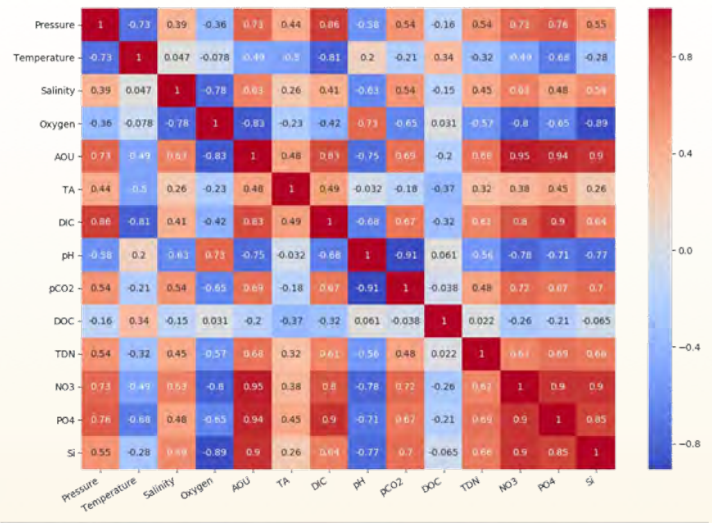
⇩

pH ± 0.008

pCO_2 ± 1.5 µatm

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Co-variability of baseline parameters



Under ”normal ” baseline conditions:

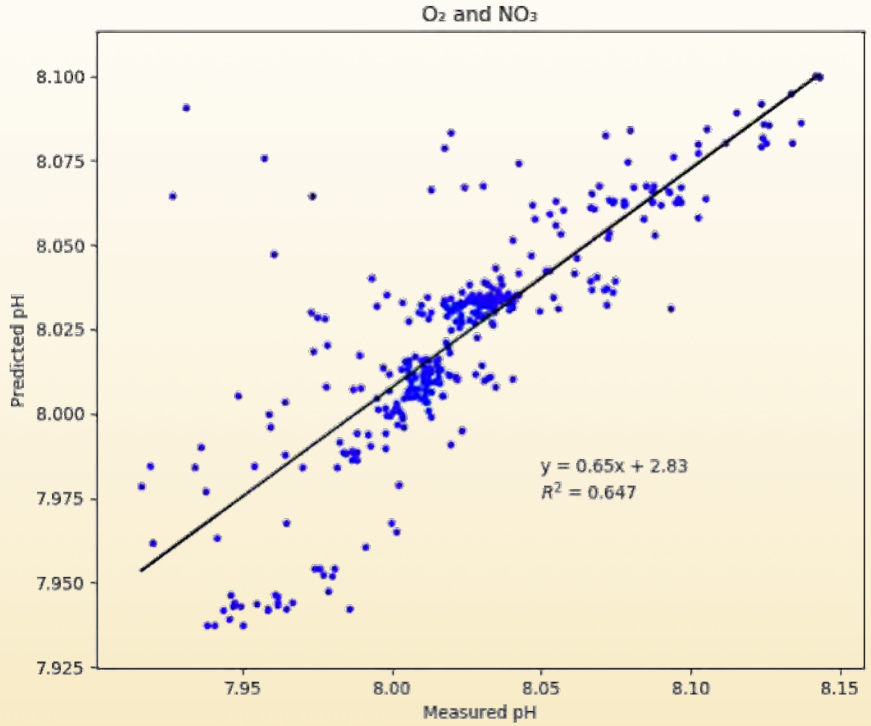
Strong positive correlation between DIC and nutrients

Anti-correlation between nutrients and O_2

pH correlated to O_2 and nutrients

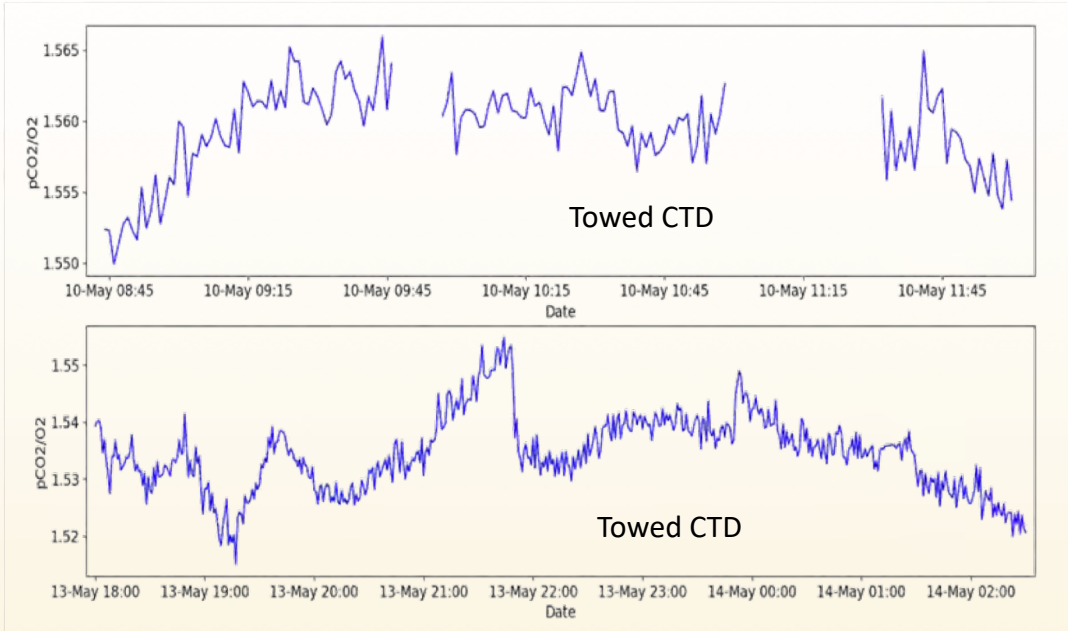
Use of multi-linear regression analysis to predict pH variabiliy at Goldeneye

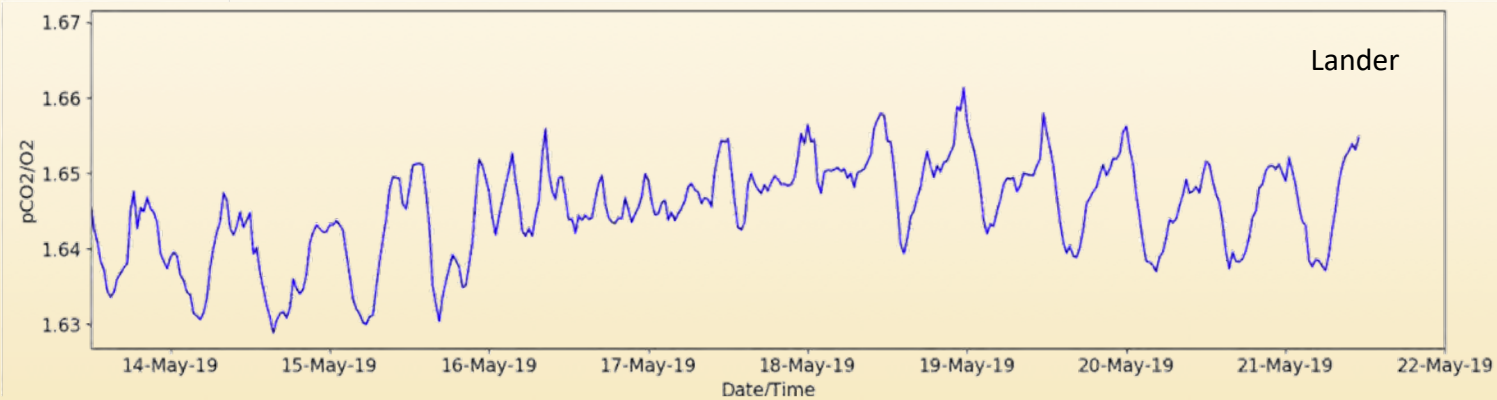
Variable 1	Variable 2	Predicted pH
Oxygen	Nitrate	65 %
Oxygen	Phosphate	62 %
Oxygen	Silicate	60 %



This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 654462

$pCO_2 : O_2$ ratio as potential method for CO_2 leak detection





$pCO_2 : O_2$ ratio for May 2019

⇩

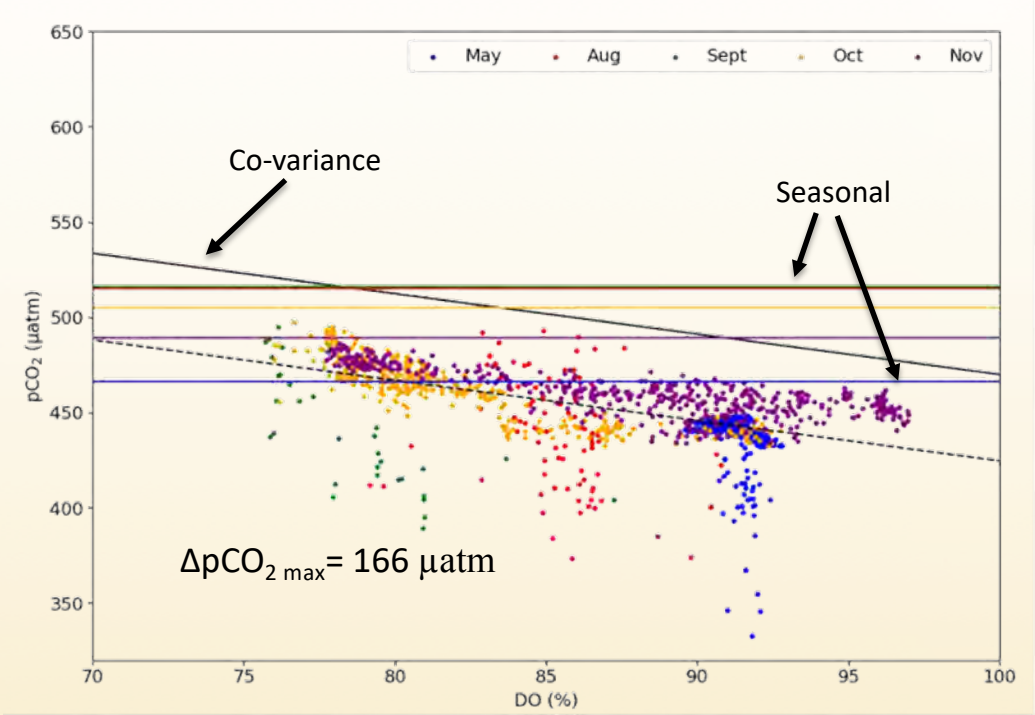
Ratio from lander comparable to ratios from towed CTD at the seafloor:

$1.50 < pCO_2 : O_2 \text{ ratio} < 1.65$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Natural pCO_2 variability – thresholds for leakage

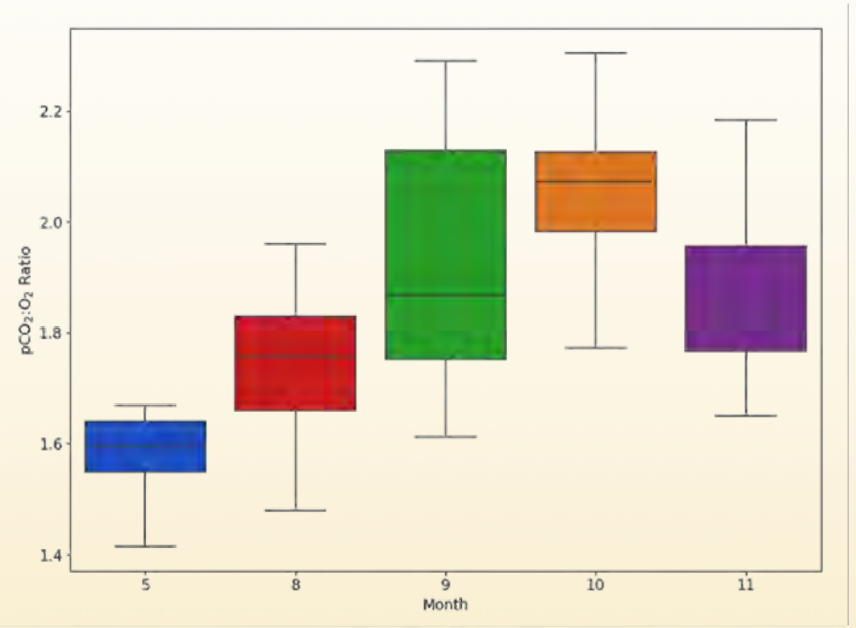
Threshold for anomalous pCO_2 (Uchimoto et al., 2018):



Co-variance threshold: ↑↑↑ ΔpCO_2

Seasonal threshold: ↓ ΔpCO_2

$pCO_2 : O_2$ monthly ratios



$pCO_2 : O_2$ varies according to season
Deviations from the ratio would indicate CO_2 leakage – see Poster

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Conclusions

- The natural variability at offshore CCS sites needs to be determined at both temporal and spatial scale
- The combination of established techniques and newly developed technologies provided a solid assessment of baseline conditions at Goldeneye
- Carbonate chemistry dynamics at Goldeneye are strongly driven by seasonality
- Deviations from seasonal stoichiometric ratios (e.g. pCO_2/O_2) can be used as potential indicator of CO_2 leakage

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

Thank you for listening
and
any questions?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462

References

- Kortzinger, A., Koeve, W., Kahler, P., and Mintrop, L., 2001. C:N ratios in the mixed layer during the productive season in the northeast Atlantic Ocean, Deep-Sea Research I., Vol. 48, pp. 661–688.
- Takahashi, Y., Matsumoto, E., Watanabe, Y. W. (2000). The distribution of δ13C in total dissolved inorganic carbon in the central North Pacific Ocean along 175°E and implications for anthropogenic CO2 penetration. Marine Chemistry 69, 237-251. https://doi.org/10.1016/S0304-4203(99)00108-5
- Uchimoto, K., Nishimura, M., Kita, J., Xue, Z. (2018) Detecting CO2 leakage at offshore storage sites using the covariance between the partial pressure of CO2 and the saturation of dissolved oxygen in seawater. International Journal of Greenhouse Gas Control 72, 130-137. https://doi.org/10.1016/j.ijggc.2018.03.020

Datasets

- Esposito, Mario; Linke, Peter (2019): Physical oceanography and carbonate chemistry measurements from lander deployment during POSEIDON cruise POS534. GEOMAR - Helmholtz Centre for Ocean Research Kiel, PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.909291
- Esposito, Mario; Martinez-Cabanas, Maria; Achterberg, Eric Pieter (2019): Hydrochemistry and carbonate chemistry during POSEIDON cruise POS527. PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.907809
- Esposito, Mario; Martinez-Cabanas, Maria; Schmidt, Mark; Linke, Peter; Achterberg, Eric Pieter (2019): Hydrochemistry and carbonate chemistry during POSEIDON cruise POS534. PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.907815
- Esposito, Mario; Saw, Kevin Antony; Monk, Samuel A (2019): Physical oceanography and carbonate chemistry measurements from Develogic lander at Goldeneye (North Sea) deployed during cruise POSEIDON POS518 and recovered during JAMES COOK cruise JC180. PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.909624
- Esposito, Mario; Linke, Peter; Achterberg, Eric Pieter (2019): Hydrochemistry and carbonate chemistry measured on water bottle samples during POSEIDON cruise POS518/2. GEOMAR - Helmholtz Centre for Ocean Research Kiel, PANGAEA, https://doi.org/10.1594/PANGAEA.907801
- Greenwood, Naomi; Pearce, David J (2016): Underway physical oceanography and carbon dioxide measurements during Cefas Endeavour cruise CEnd15/13. University of East Anglia, PANGAEA https://doi.org/10.1594/PANGAEA.852643
- Gros, Jonas; Esposito, Mario; Saw, Kevin Antony (2019): Devologic lander ADCP data at Goldeneye (North Sea) deployed during cruise POSEIDON POS518 and recovered during JAMES COOK cruise JC180. GEOMAR - Helmholtz Centre for Ocean Research Kiel, PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.908935
- Gros, Jonas; Linke, Peter (2019): ADCP lander data collected during POSEIDON cruise POS534. GEOMAR - Helmholtz Centre for Ocean Research Kiel, PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.908919
- Thomas, Helmuth; Borges, Alberto Vieira (2006): Hydrochemistry measured on water bottle samples during PELAGIA cruise 64PE239 https://doi.org/10.1594/PANGAEA.441686

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654462