ICOS INTEGRATED CARBON OBSERVATION SYSTEM

An introduction to the Ocean Thematic Centre of the European RI ICOS

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NORCE

Bjerknes Centre for Climate Research BCDC Bjerknes Climate Data Centre

National Oceanography Centre NATURAL ENVIRONMENT RESEARCH COUNCIL

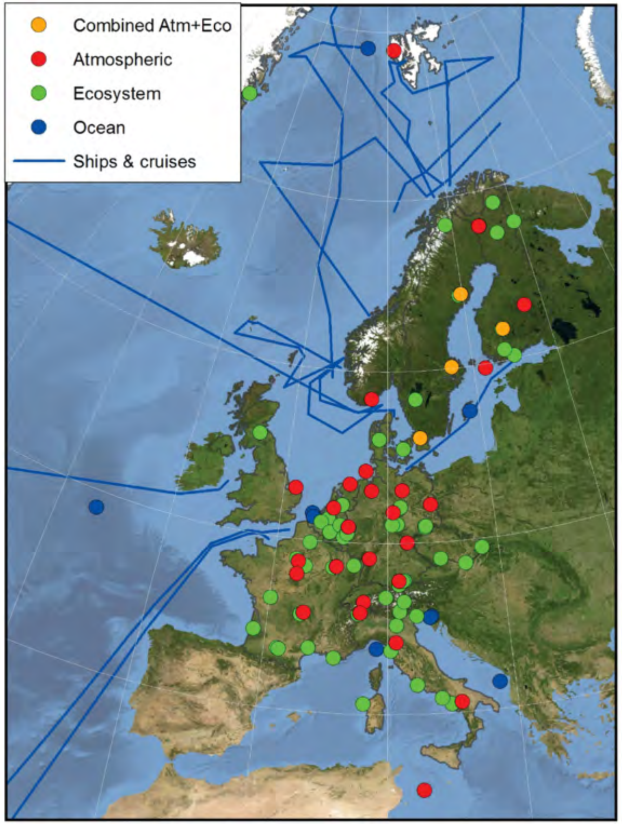
University of Exeter

Integrated Carbon Observation System (ICOS)

Scientific Mission:

- Increase fundamental understanding of carbon cycle, greenhouse gas budgets and perturbations, and underlying processes
- Increase ability to predict future changes
- Verify the effectiveness of policies aiming to reduce greenhouse gas emissions
- Foster technical and scientific innovation
- Contribute in education and capacity building

ICOS Stations



134 Measurement stations
12 Member countries

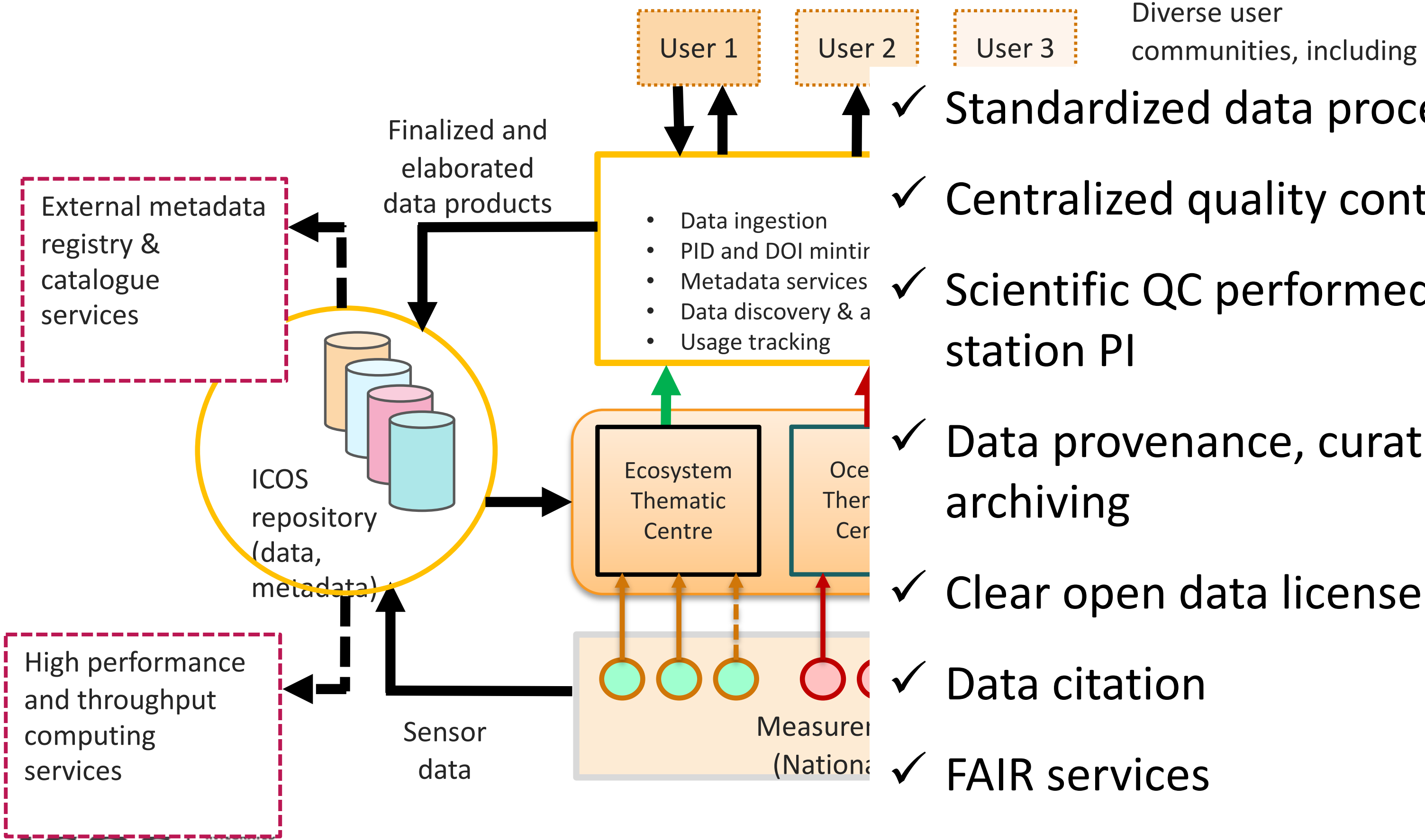
80 Ecosystem stations

33 Atmosphere stations

21 Ocean stations

including two stations in Greenland,
one in French Guyana, La Reunion, Cape Verde
(not visible here)

ICOS Data Flow



- ✓ Standardized data processing
- ✓ Centralized quality control
- ✓ Scientific QC performed by the station PI
- ✓ Data provenance, curation and archiving
- ✓ Clear open data license
- ✓ Data citation
- ✓ FAIR services

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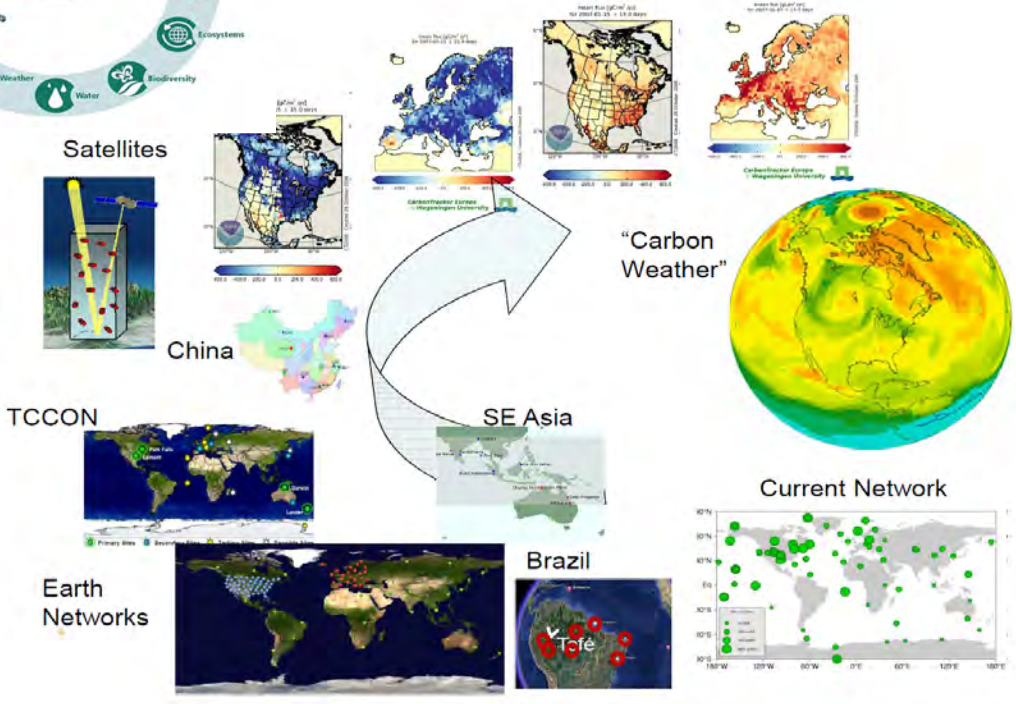
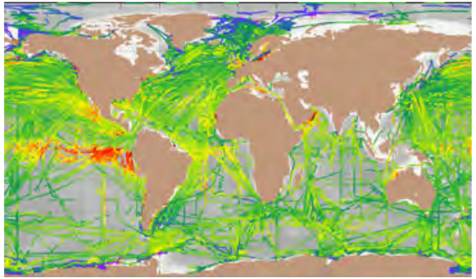
Global integration



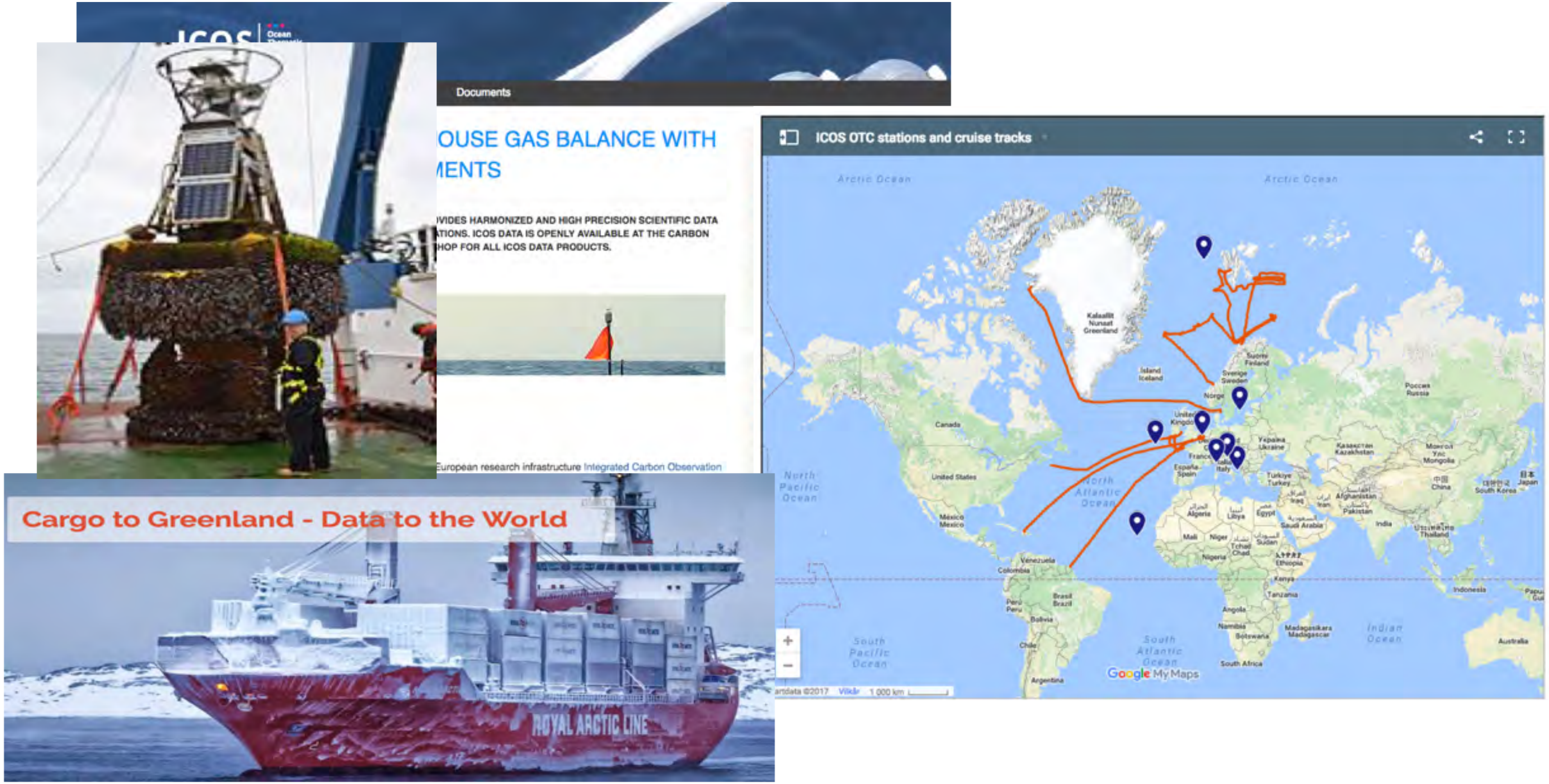
FLUXNET
A Global Network

GLOBAL ATMOSPHERE WATCH

SOCAT
· SURFACE OCEAN CO_2 ATLAS ·



The Ocean Thematic Centre



Who we are:

Leadership and management

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Data unit

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Network liaison and design

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Technical support

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Technical innovation

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OTC tasks and mission

1. Leadership and management
2. Labelling and station liaison
3. Technical support
4. Technical innovation
5. Data unit
6. Network liaison and design

Labelling scheme for ocean stations

"ICOS shall provide harmonised and high-precision scientific data on carbon cycle and greenhouse gas budget and perturbations"

For the ocean this means

Quantifying air-sea CO_2 fluxes

Requires pCO_2 measurements

Most suited for Carbon-VOS

Assessing variability and drivers

Requires pCO_2, one of A_T, pH, or DIC, dissolved oxygen/nutrients

Most suited for Fixed Ocean Stations

Labelling scheme

	Carbon-VOS (Voluntary Observing Ship)	FOS (Fixed Ocean Sta<tion)
Class 2 (minimum required variables)	pCO_2 (± 2 ppm)	pCO_2 (±10 ppm) Alkalinity or DIC Oxygen
Class 1 (additional variables)	Alkalinity of DIC Oxygen	Surface: Nutrients (nitrate, silicate, and phosphate)

*DIC = Dissolved Inorganic Carbon
In addition, variables for validation must be sampled

Which precision do we actually need?

GOA-ON Global Ocean Acidification Observing Network

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

Target 14.3:
minimize and address the impacts of ocean acidification

Which precision do we actually need?

The weather goal

- relative spatial patterns and short-term variations
- supporting mechanistic response to and impact on local, immediate ocean acidification dynamics.

Implies an uncertainty of:

- pH ~0.02
- TA, DIC ~10 μmol kg^{-1}
- pCO_2 ~2.5% relative uncertainty

The climate goal

- to assess long-term trends with a defined level of confidence,
- supporting detection of the long-term anthropogenically driven changes in hydrographic conditions and carbon chemistry over multi-decadal time scales.

Implies an uncertainty of :

- pH ~0.003
- TA, DIC ~2 μmol kg^{-1}
- pCO2 ~0.5% relative uncertainty

FOS:

- Validation in-situ
  - Preferably monthly discrete samples from station site
  - At minimum, discrete samples during deployment and when the instruments are retrieved
  - Important with a sufficient amount of parallel samples (TRIPLICATES)
- Use of discrete samples for validation of pCO_2
  - Use the pair [TA + pH] or [DIC + pH], do NOT use [TA + DIC]
  - Use K1 and K2 from Lueker et al. (2000) - Best practices from Dickson et al. (2007)
  - Use up to date calculation program
  - If you want to include error calculation (error.m) from Orr et al. (2018) you also need to use his CO2sys.m
- Discrete samples of TA, DIC, and/or pH - quality
  - OTC need statement from each laboratory regarding quality of measurement (accuracy of samples and how this is achieved, e.g. CRM from Dickson)

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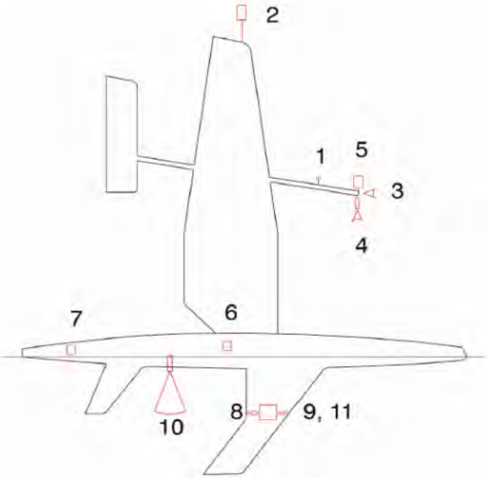
Saildrone

- Saildrone (Canadian) – 7 m long vessel
- Wind and wave driven, 2 to 8 knots
- Equipped with sensors for pCO_2, O_2, SST, SSS, wind, pH, etc.

(https://www.saildrone.com/)



Sensor	Height / Depth frm Waterline	Manufacturer & Model
1. PAR Sensor	2.2 m	LI-Cor LI-192SA
2. 3D Ultrasonic Anemometer 20 Hz	4.5 m	Gill Windmaster
3. Cameras: Up/Down/Left/Right—wide angle	2.2 m	Saildrone Custom Design
4. SST IR Pyrometer	2.2 m	Heitronics KT15 II
5. AT/RH - S3 with Radiation Shield	2.2 m	Rotronic HC2
6. Barometric Pressure	0.2 m	Vaisala PTB 210
7. Magnetometer	0.2 m	Bartington MAG 648
8. Dissolved Oxygen	0.5 m depth	Aanderaa 4831
9. Thermosalinograph	0.5 m depth	Teledyne Citadel
10. Fluorometer chlm fluorescence and backscatter	0.2 m depth	Wetlabs Triplet
11. PMEL-provided CTD	0.5 m depth, strapped to keel	Seabird SBE37SM

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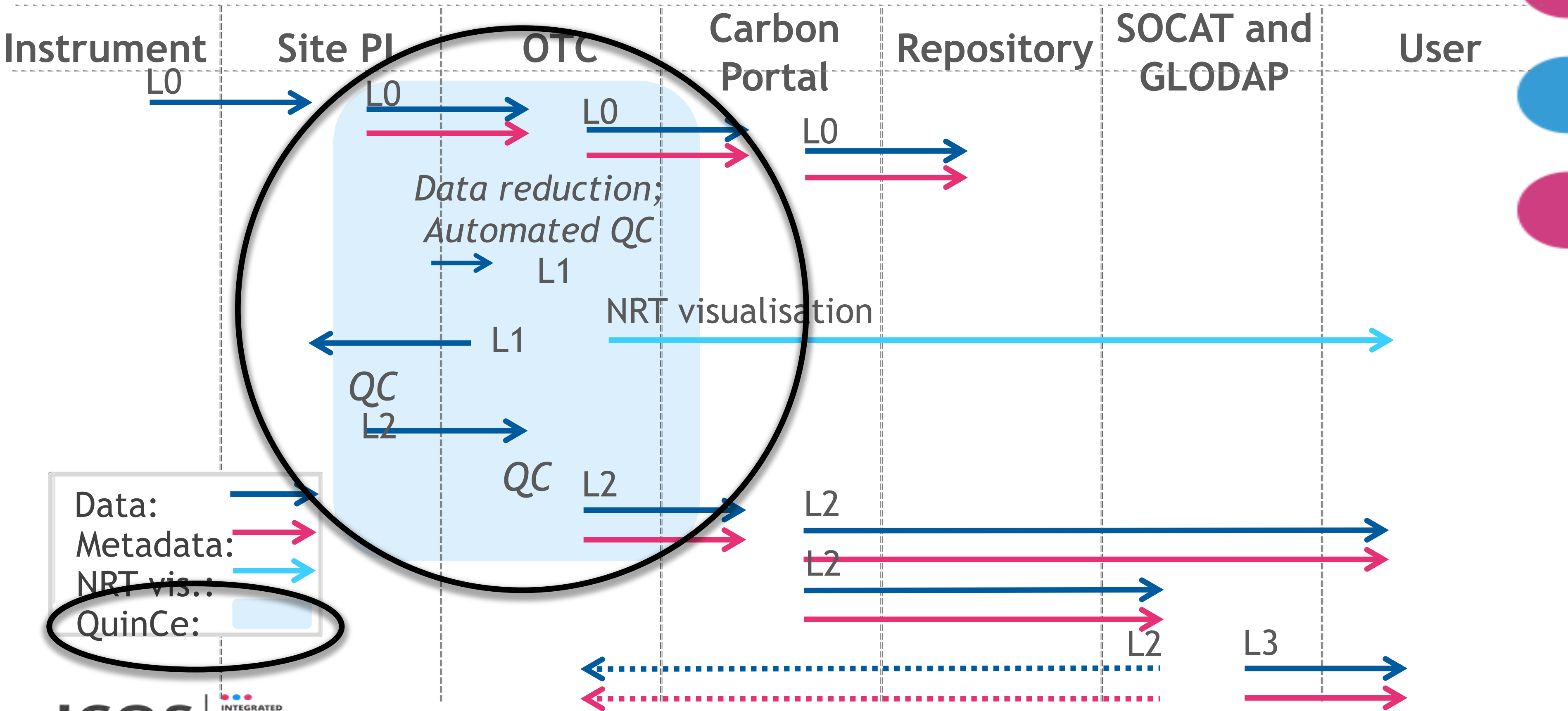
Saildrone - in situ validation of FOS

- Joint proposal (Geomar/Cape Verde Observatory and OTC) submitted to Saildrone Nov 2018
- Aim to use Saildrones, equipped with calibration instruments to validate Fixed Ocean Stations within ICOS
- Mission supported by Saildrone
- Start in Cape Verde 1 November 2019
- Will arrive in Mediterranean early 2020 and Italian stations approx. February 2020

Data Lifecycle Within OTC



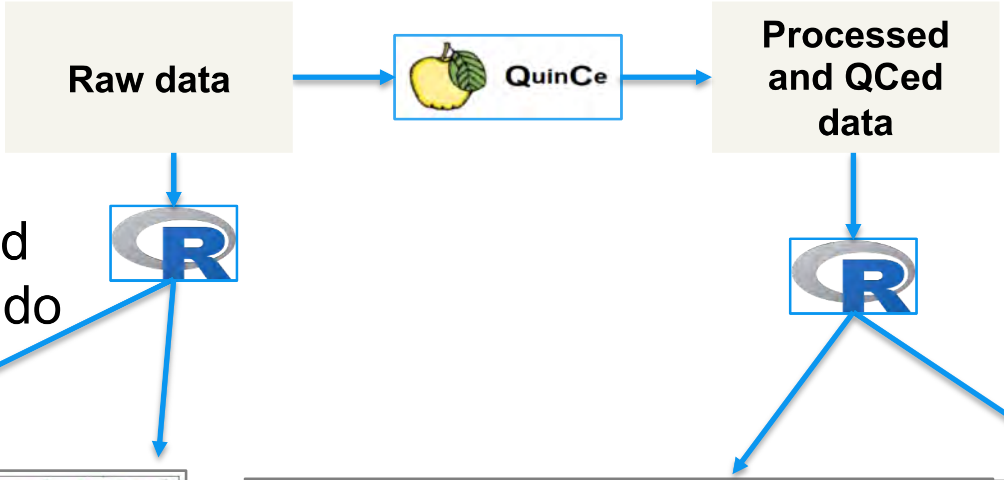
QuinCe – general overview

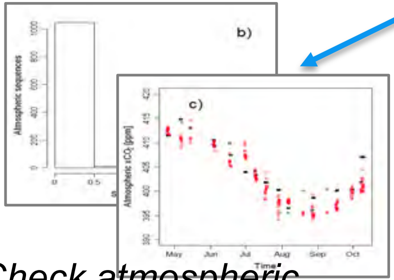
- online tool developed by OTC for the submission, processing, data reduction, quality control and dissemination of data
- receives raw data directly from the stations' instruments, performs all necessary calculations and performs automated quality control routines to highlight data that is likely to be of poor quality (like range checks and spike detection)
- station PI can review the data and perform their own quality control before approving it for submission to the OTC.
- once submitted, the data will automatically be archived at the CP and made available to other relevant external third level data products (e.g. the SOCAT - Surface Ocean CO2 Atlas, CMEMS).

Automatic data checks

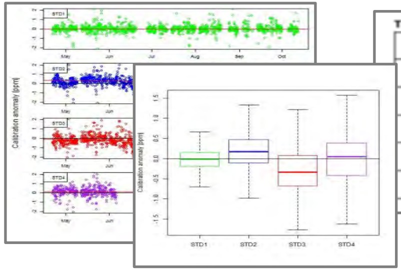
1. Use QuinCe for automatic QC and data processing

2. Use the raw data and output from QuinCe to do more checks with R





Check atmospheric CO_2

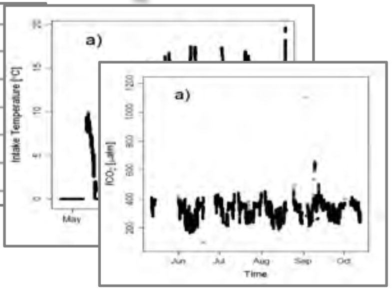


Check drift in standards

Table 4.2: Results from the automatic data check.

QC Message	# of rows	% of rows
Longitude/Latitude is missing	10553	12.51%
Intake Temperature standard deviation is too large	1	0.00%
Intake Temperature changes too quickly	1	0.00%
Equilibrator Temperature standard deviation is too large	91	0.11%
Intake and Equilibrator Temperature constant for too long	10 485	12.43%

Summarise QC results



Plot data

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Quality Control for Biogeochemical Data - Workshop
September 24 and 25 at NOAA/PMEL in Seattle, WA

Objectives

- Workshop deliverables will be guidance that can be applied by the ICOS OTC and NOAA OAP developer groups towards an implementable solution
- Determine what degree of level 1 and level 2 quality control is acceptable for which variables, and what can be implemented by developer groups
- Determine what degree of QC automation is possible for both level 1 and level 2.
- SOCAT, GLODAP, ICOS, NOAA OAP, US BGC ARGO networks participated

ICOS | Ocean Thematic Centre

Save the date

1st ICOS OTC pCO_2 instrument inter-comparison exercise

When? 24. August - 04. September 2020

Where? Flanders Marine Institute (VLIZ) in Oostende/Belgium

What? In the recent years new technologies are involving and a whole new generation of sensors and instruments measuring pCO_2 the surface ocean and below entered the market. This spans from «classical» equilibrator based systems with new CO_2 detectors to membrane based sensors that can be submerged.

The aim of this exercise is

- the comparison of instruments and sensors that are (or will be) used within the ICOS community over a range of temperatures and pCO_2.
- to engage instrument suppliers to work together with the observational community to reach a high level of standardization in operating pCO_2 sensors and instruments.
- to give answers to the community of choosing the appropriate sensor for their application.

Contact:
ICOS OTC, Tobias Steinhoff
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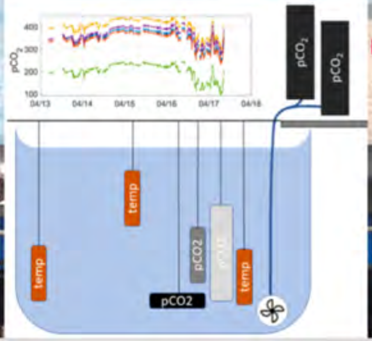
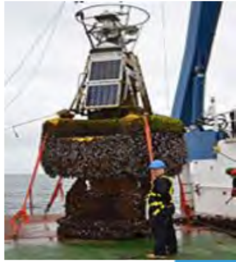
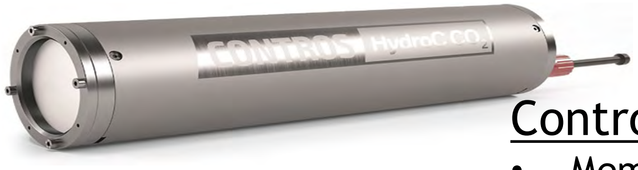


Here you can sign up and find updated information:

Thank you!
For more information please visit
https://otc.icos-cp.eu

ICOS Oceans CO_2 sensors - moorings





Contros HydroC CO_2
- Membrane equilibration
- IR CO_2 detection
- Auto zeroing
- Pre/post calibration necessary

Sunburst SAMI-CO_2
- Membrane equilibration
- colorimetric reagent method

Pro Oceanus CO_2-Pro
- Membrane equilibration
- IR CO_2 detection
- Auto zeroing

Photos: http://sunburstsensors.com, http://pro-oceanus.com, https://www.kongsberg.com

Recommendations for ocean stations

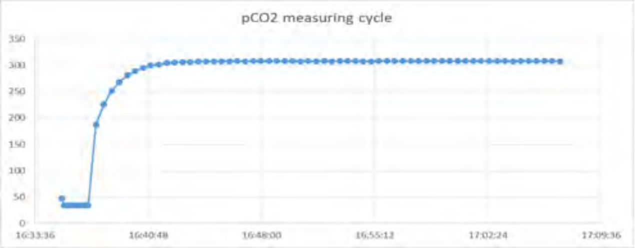
- If a station does not follow SOPs, the station must provide evidence that their station meet the OTC requirements

Carbon-VOS

- Calibration frequency
  - Temperature and pressure sensors - every two years at calibration facility, in-house every two years
  - LICOR - every five year at calibration facility
- Equilibrator pressure
  - Should be measured by an absolute pressure sensor in the Wet Box /equilibrator
- Atmospheric xCO_2 measurements
  - Compared with nearby atmospheric station (Global View)
  - Wait for outcome from RINGO
- Atmospheric pressure
  - Changed to a core parameter, accuracy $\pm$1 mbar

Fixed Ocean Station (FOS):

- pCO_2 accuracy
    - Changed from ±5 µatm to ±10 µatm
- Dissolved oxygen - requirements released to 2%
- Calibration frequency
    - pCO_2 - at factory or calibration facility prior to deployment (Contros, Pro-Oceanus, SAMI)
    - Post deployment calibration for Contros
    - O_2/temperature/salinity - prior to deployment
- Equilibration time for pCO_2 sensor (Contros and Pro-Oceanus, IR detection)
    - If no equilibration evidence during deployment, such evidence should be provided from a laboratory test prior to deployment



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Network design

-Evolve the network towards a state of high level robustness and optimal structure

<u>-Deliverable Network Design (continuous):</u>

Production and implementation of a roadmap aimed at helping the MSA produce a robust and optimally structured network.

-refreshed annually

Accuracy of measurements

According to GOOS EOV's and the GOA-ON (Newton et al., 2014):

The "**weather**" goal is defined as measurements of quality sufficient to identify

- relative spatial patterns and short-term variations,
- supporting mechanistic response to and impact on local, immediate ocean acidification dynamics.

This implies an uncertainty of:

pH ~ 0.02

TA and DIC ~10 μmol kg^{-1}

pCO_2 ~ 2.5% relative uncertainty

The "**climate**" goal is defined as measurements of quality sufficient

- to assess long-term trends with a defined level of confidence,
- supporting detection of the long-term anthropogenically driven changes in hydrographic conditions and carbon chemistry over multi-decadal time scales.

This implies an uncertainty of :

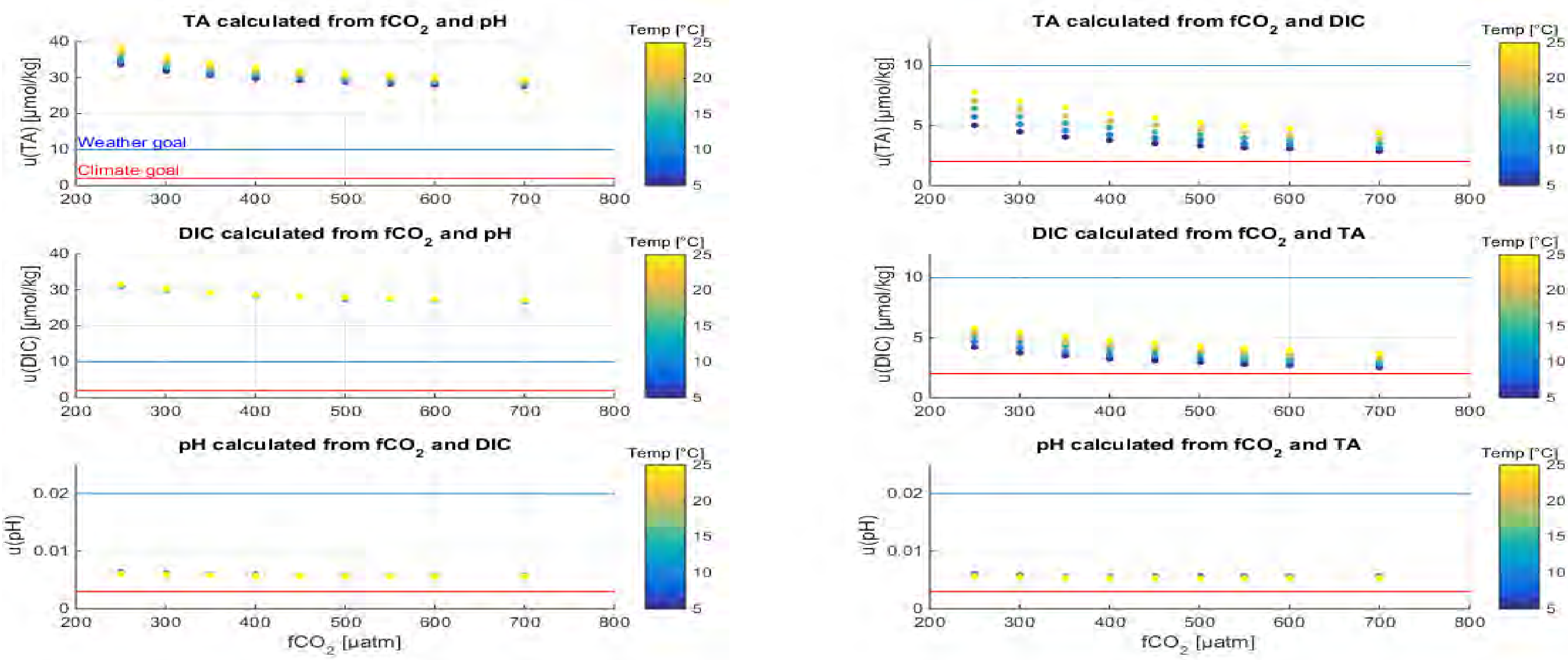
pH ~ 0.003

TA and DIC ~ 2 μmol kg^{-1}

pCO_2 ~ 0.5% relative uncertainty

Carbon-VOS

Calculated carbon system using fCO2 and a 2nd carbon variable and uncertainties $u(fCO_2)$ = 2 µatm, u(DIC) = u(TA) = 2 µmol kg^{-1}; u(pH) = 0.001



Carbon-VOS

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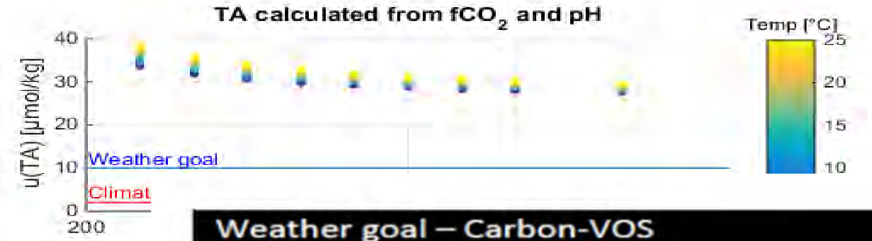
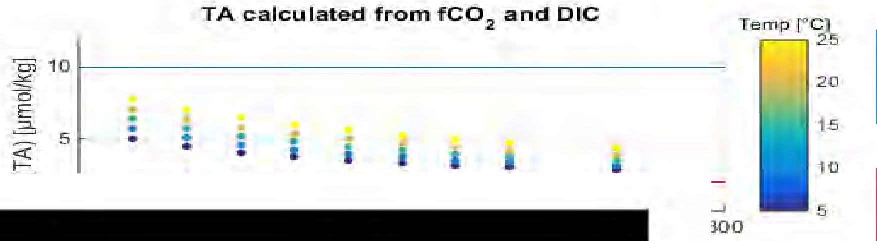
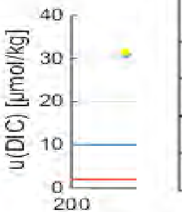
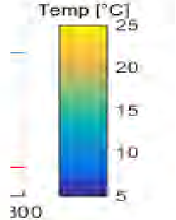
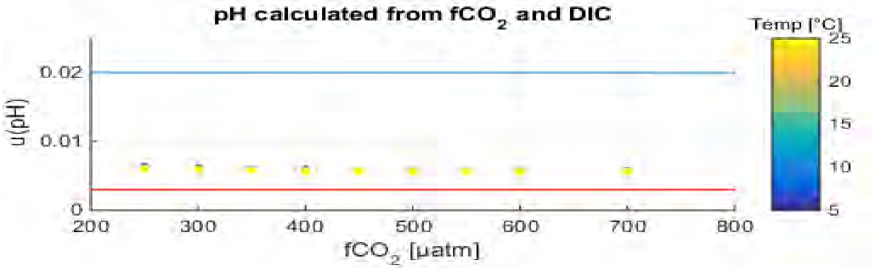


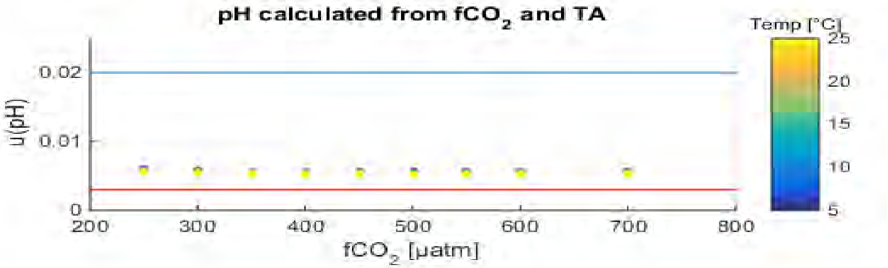






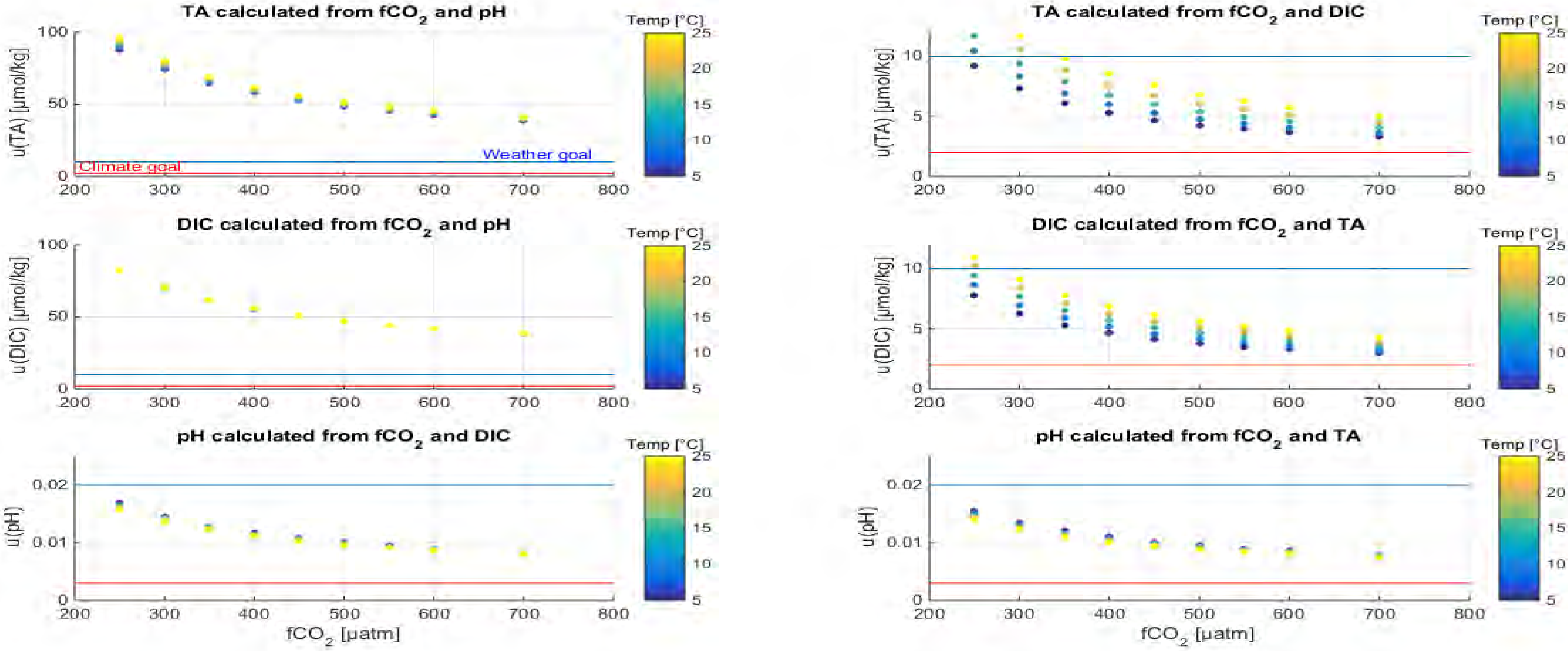
Weather goal – Carbon-VOS				
fCO2 +	Input max. uncertainty			
		pH	TA [µmol/kg]	DIC [µmol/kg]
DIC	5 µmol/kg	<0.0065	<10	
pH	0.001			
TA	10 µmol/kg	<0.0062		< 10





FOS

Calculated carbon variables using fCO2 and a 2nd carbon variable and uncertainties u(fCO_2) = 10 µatm, u(DIC) = u(TA) = 2 µmol kg^{-1}; u(pH) = 0.001



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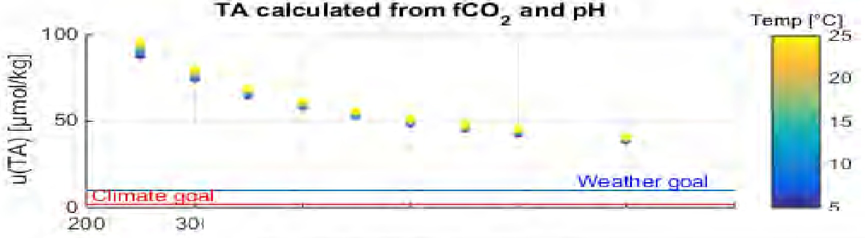
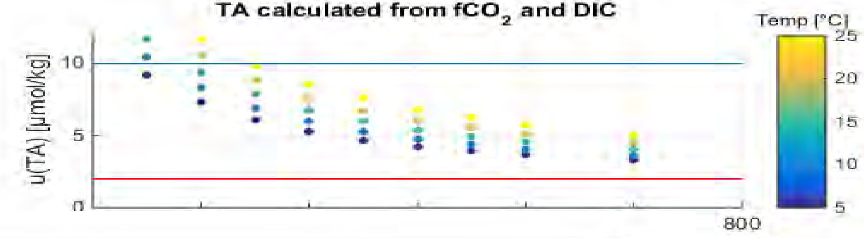
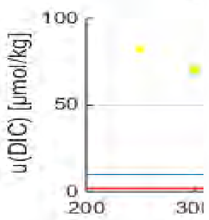
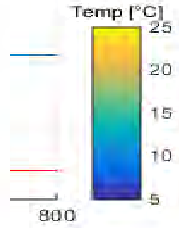


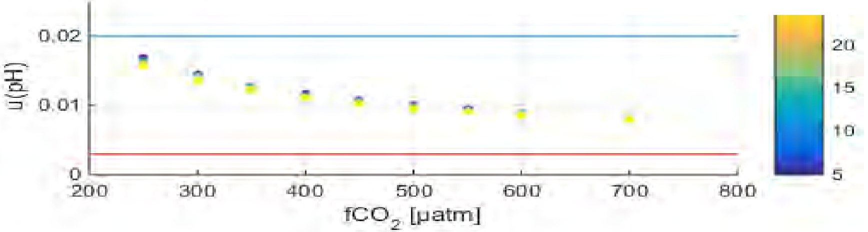


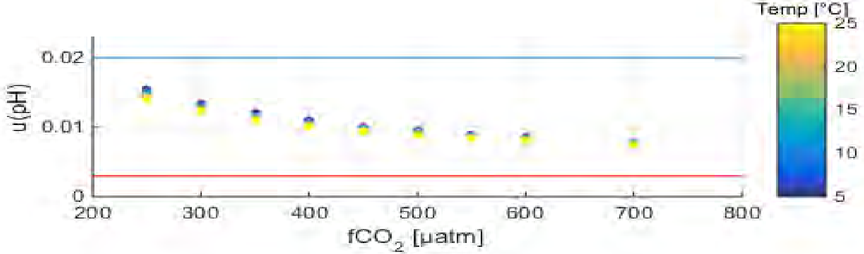


Weather goal - FOS				
fCO2 +	Input max. uncertainty			
		pH	TA [µmol/kg]	DIC [µmol/kg]
DIC	2 µmol/kg	<0.017	<10*	
pH	0.001			
TA	4 µmol/kg	<0.016		< 10**

*when fCO2 > 350 µatm;**when fCO2>300 µatm







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ICOS Oceans CO_2 sensors – Carbon-VOS

Water/air equilibrator based systems

- Standard: General Oceanics
- Several custom built systems
- Bubble/spray… equilibration
- IR CO2 detection (other detectors possible)

SubCtech OceanPack pCO_2

- Membrane equilibration
- IR CO_2 detection
- Auto zeroing, standard gases possible

Contros HydroC CO_2 FT

- Membrane equilibration
- IR CO_2 detection
- Auto zeroing
- Pre/post calibration necessary

QuinCe - *online tool for data reduction and quality control of surface ocean fCO2 data*

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QuinCe - Motivation

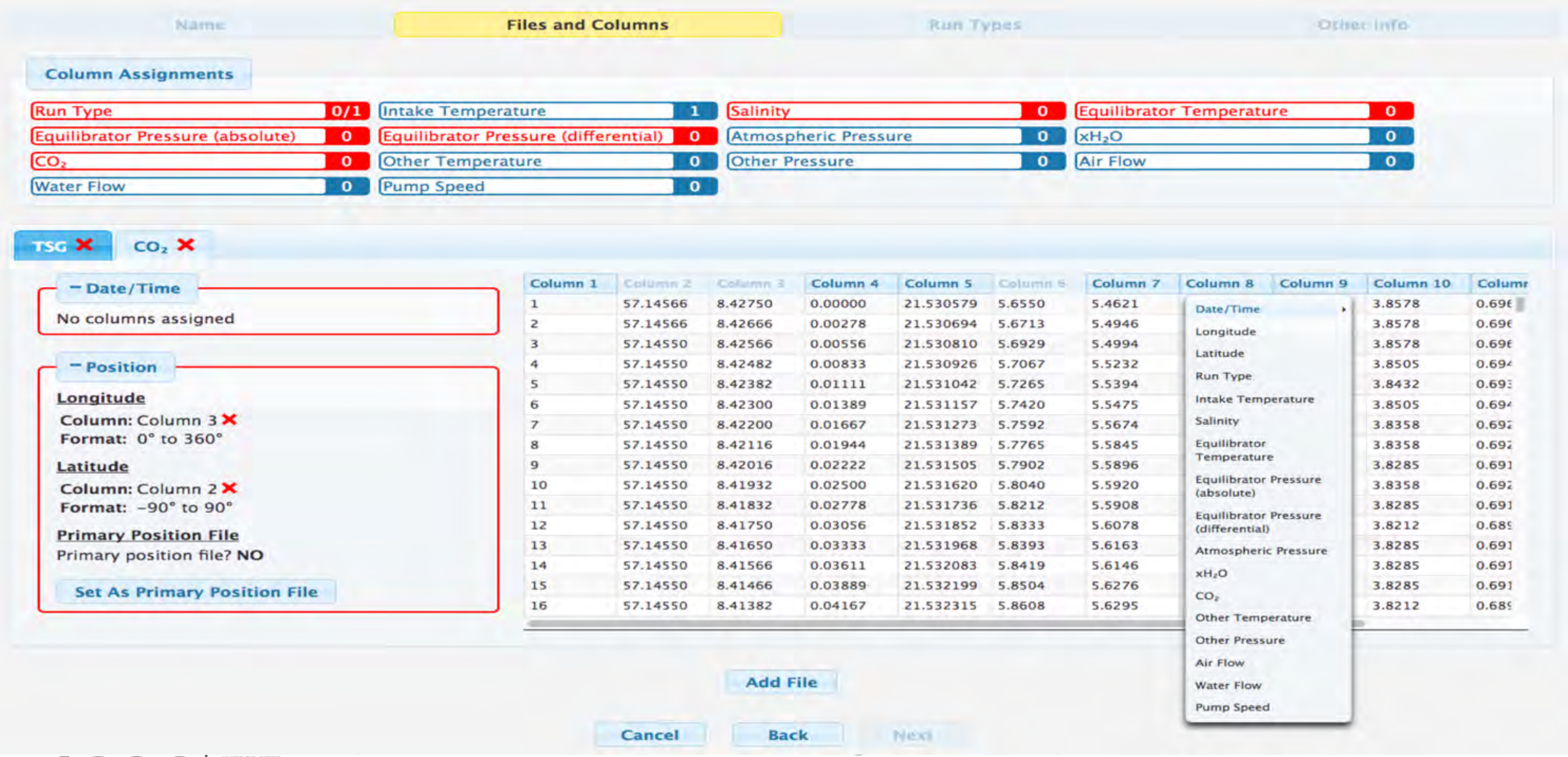
- A single, centralised tool - data from all sources is treated with the same community-approved algorithms
- Removes code development responsibilities from scientists
- Open Source code increases traceability and transparency
- Reduces data handling work required by scientists
- Flexible architecture will allow shorter development time for new projects using different types of data

QuinCe - Features

- Upload data in any text format
- Individual sensor calibration adjustments can be applied
- Data reduction is performed automatically, with calibration to gas standards
- Automated QC routines detect common issues
- Extensive plotting and mapping tools for manual QC
- All QC decisions (automatic and manual) are recorded for future traceability
- Automatic submission to ICOS, CMEMS INSTAC and SOCAT
- Near Real Time processing allows fully automatic data flow from ship to publication within minutes

QuinCe - Future developments

- Complete metadata integration
- More intelligent automatic QC routines based on previous data sets and external data sources
- Uncertainty propagation
- Longitudinal study of instrument performance
- More variables (pH, O2 ...)



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- Excessive gradients during a certain period

Benguela Stream (Labelling) - Standard Concentrations

Deployment Date

Select the date on which the standards were deployed

2014-06-24

Standard Concentrations

Enter the concentration for each gas standard

Standard	Concentration
000	0.0
250	260.36
350	361.14
450	460.69

Save Cancel

Calibration Date

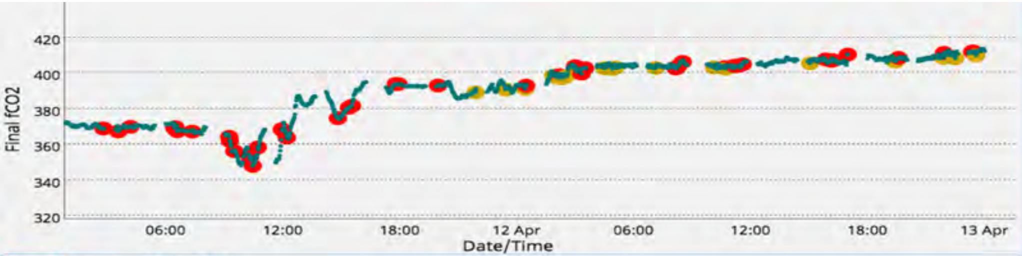
Select the date on which the calibration was performe

2015-04-28

Calibration coefficients

Enter the calibration coefficients for each sensor

Sensor	Intercept	x
Intake Temperature: Aanderaa	0.0	1.0
Salinity: Seabird	0.0	1.0
Equilibrator Temperature: PT100 (Top)	0.9721	9.8304
Equilibrator Temperature: PT2000 (Bottom)	0.0	1.0
Equilibrator Pressure: Omega	878.41	40.377



Date	Longitude	Latitude	Intake Temperature	Salinity	Equilibrator Temperature	Equilibrator Pressure (differential)	Ambient Pressure	xH2O	CO2	fCO2	Automatic QC
2019-04-14 12:03:07	-25.537	59.076	7.557	35.000	7.740	0.160	995.410	1.430	425.800	412.789	Good
2019-04-14 12:04:39	-25.526	59.078	7.575	35.000	7.780	-0.810	995.200	1.430	425.340	411.561	Good
2019-04-14 12:06:11	-25.515	59.079	7.563	35.000					425.030	408.524	Bad
2019-04-14 12:07:43	-25.505	59.081	7.563	35.000					425.310	411.816	Good
2019-04-14 12:09:15	-25.494	59.083	7.559	35.000					426.070	410.658	Questionable
2019-04-14 12:10:47	-25.483	59.084	7.558	35.000					426.710	411.097	Questionable
2019-04-14 12:12:19	-25.473	59.086	7.555	35.000					426.750	415.517	Good
2019-04-14 12:13:51	-25.463	59.087	7.559	35.000					426.930	412.960	Good
2019-04-14 12:15:23	-25.452	59.088	7.554	35.000					427.340	407.477	Bad
2019-04-14 12:16:55	-25.442	59.090	7.549	35.000					427.770	413.017	Good

Set WOCE flag for 4 rows

WOCE Flag: Bad

Comment:

Moisture value invalid

Save Cancel

Carbon-VOS

Variable	*Frequency*	*Accuracy*	*Required for Class*
Sea surface fCO_2	Quasi-continuous	±2 µatm	2
Intake temperature (SST)	Continuous	±0.05 °C	2
Water vapour pressure	Continuous	±0.5 mbar	2
Equilibrator pressure	Continuous	±2.0 mbar	2
Equilibrator temperature	Continuous	±0.05 °C	2
Delta-T (Intake/Equilibrator temperature difference)	Continuous	< 1.5 °C (normal) < 3 °C (ice edge)	2
Sea surface salinity (SSS)	Continuous	± 0.1 psu	2
Atmospheric xCO_2	Quasi-continuous	±1 µatm	1
Alkalinity (TA)			1**
Dissolved Inorganic Carbon (DIC)			1**
pH			1**
Dissolved oxygen		±2% #	1
Dissolved nutrients		±1%* #	1

* Currently no sensors available with this accuracy
** At least one of these variables must be measured
# At least one of these variables must be measured

ICOS INTEGRATED CARBON OBSERVATION SYSTEM

FOS

Variable	*Frequency*	*Accuracy*	*Required for Class*
Sea surface fCO_2	>1 day^{-1}/>3 day^{-1}	±10 µatm	2
Sea surface temperature	>1 day^{-1}/>3 day^{-1}	±0.02 °C	2
Sea surface salinity	>1 day^{-1}/>3 day^{-1}	±0.03 psu	2
Alkalinity			2**
Dissolved Inorganic Carbon			2**
pH			2**
Dissolved oxygen		±2%	1
Dissolved nutrients		±1%*	1

* Currently no sensors available with this accuracy
** At least one of these variables must be measured