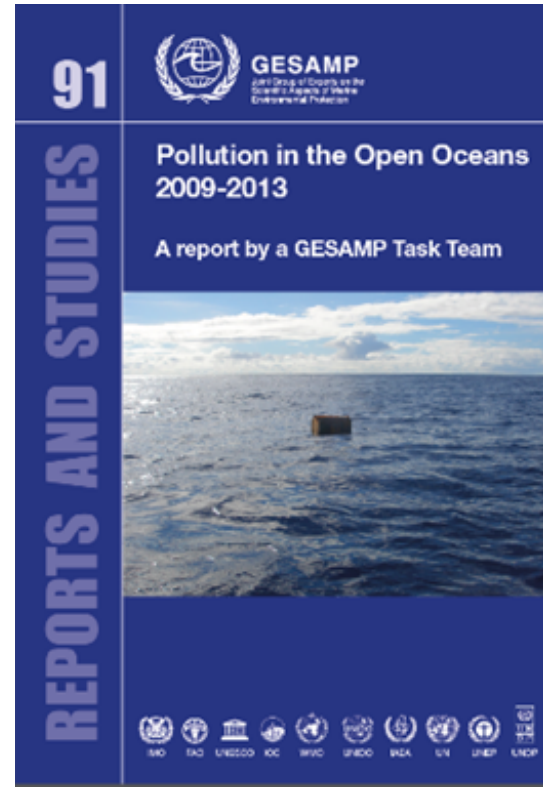
Ocean biogeochemistry data initiatives in a high CO_2 world

University of East Anglia

- Aim: Quantifying ocean biogeochemistry and the processes controlling it in a high CO_2 world.
- GLODAP – Global Data Analysis Project
- SOCAT – Surface Ocean CO_2 Atlas
- SOCOM – Surface Ocean CO_2 Mapping Intercomparison
- Essential Ocean Variables (EOVs)
- Other marine biogeochemistry data need a home (BioArgo, moorings, gliders, etc).
- Global Data Assembly Centre (GDAC) for Marine Biogeochemistry

Dorothee Bakker (d.bakker@uea.ac.uk) with contributions from many colleagues.



SOCAT · SURFACE OCEAN CO_2 ATLAS ·

SOCOM SURFACE OCEAN pCO_2 MAPPING INTERCOMPARISON

glodap v2

The Global Carbon Budget (2006-2015)

Sources

Fossil fuel & cement sources
9.3 Pg C yr^{-1} (91%)

Land-use change (9%)
1.0 Pg C yr^{-1}

Sinks

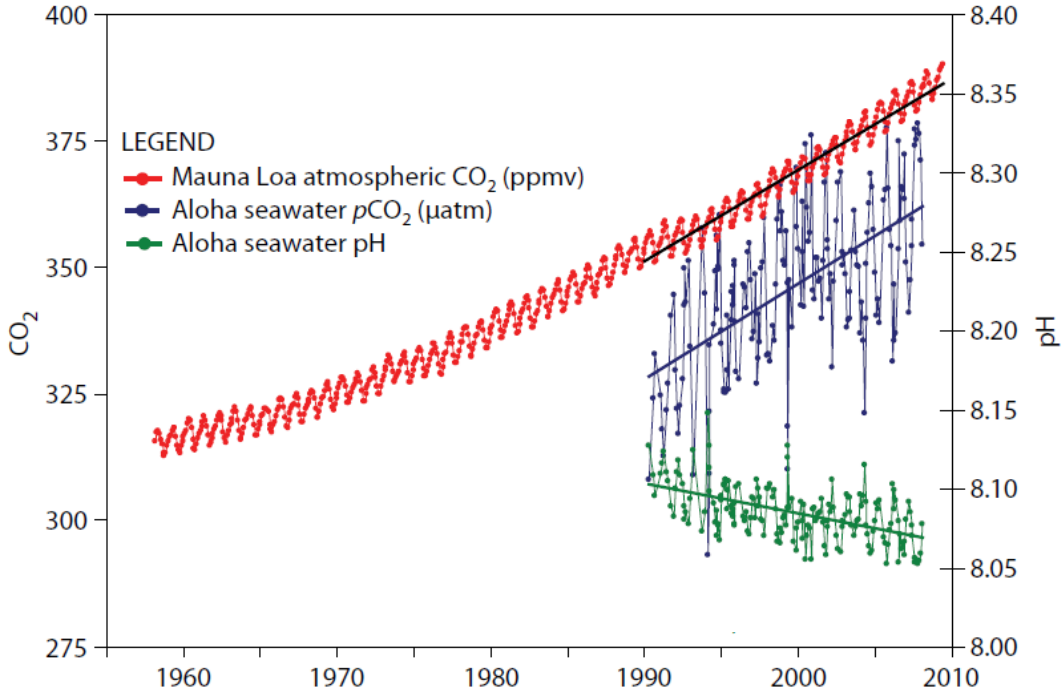
Atmosphere (44%)
4.5 Pg C yr^{-1}

Ocean sink (26%)
2.6 Pg C yr^{-1}

Land sink (residual)
3.2 Pg C yr^{-1}
(31%)

(CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2016; Global Carbon Budget 2016)

Ocean CO_2 uptake promotes ocean acidification (OA)

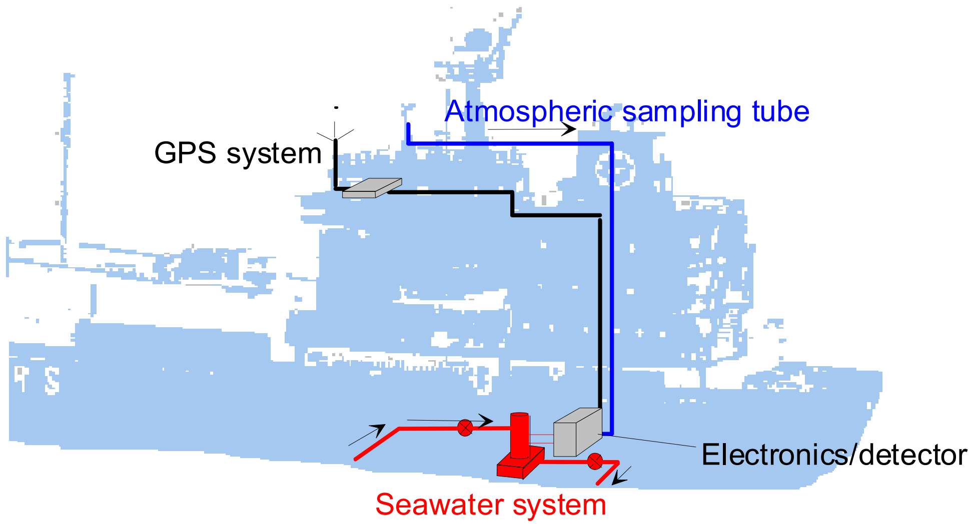


Measurements near Hawaii: Surface ocean pH has decreased by 0.002 units per year since 1990.

(Caldeira and Wickett, 2003; Feely et al., 2009)

- Ocean CO_2 uptake decreases pH and saturation state Ω for calcium carbonates ($CaCO_3$).
- Surface ocean pH has decreased by 0.1 pH unit since 1750 (model).
- pH will decrease by 0.3 pH units by 2100 ('business as usual').
- OA will continue long after CO_2 emissions stop. OA will continue under geo-engineering, unless the latter reduces CO_2 emissions.

Ocean carbon observations



Dissolved inorganic carbon (DIC), total alkalinity (TA), pH

fCO_2 (fugacity) $= \gamma\ pCO_2$ (partial pressure), ($\gamma \sim 0.996$-0.997)

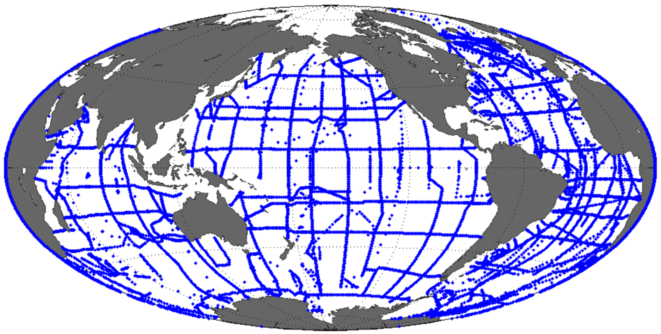
Air-sea CO_2 flux $= k\ K'_0\ (fCO_{2water} - fCO_{2air})$

Carbon VOS:	Surface water fCO_2, DIC, TA
Fixed Stations:	Surface water fCO_2, DIC, TA, pH
Deep sections:	Interior ocean DIC, TA

(U Schuster, PJ Brown, DCE Bakker)

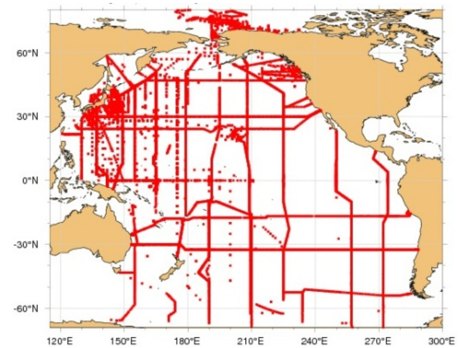
Global Data Analysis Project Version 2
(**Interior ocean** carbon and other observations)

GLODAP (1985-1999)
(Key et al., 2004)



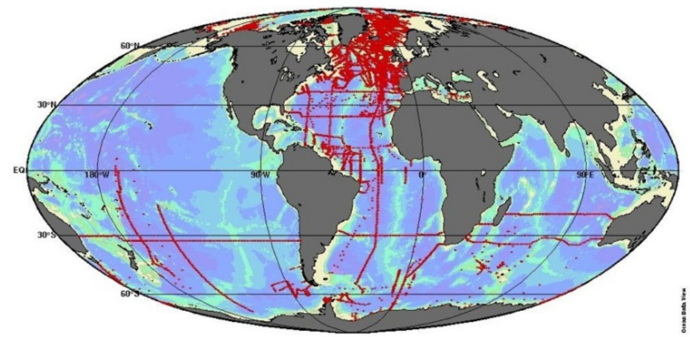
95 cruises

PACIFICA
(Suzuki et al., 2013)



322 cruises

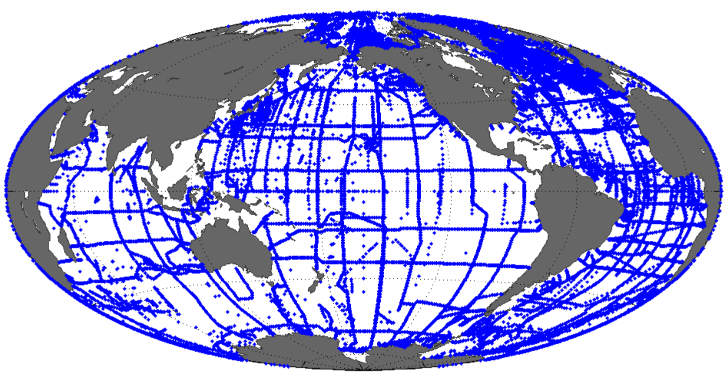
CARINA (1977-2006)
(Tanhua et al. 2009)



188 cruises

+168 cruises

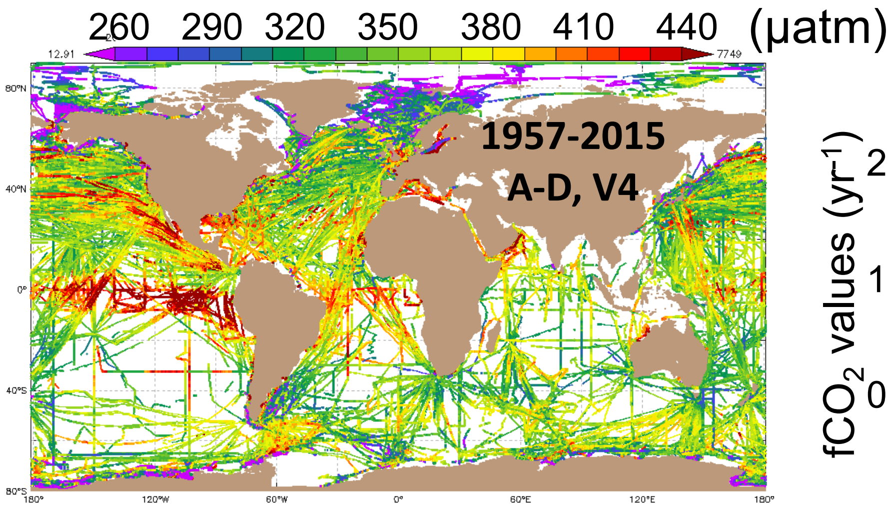
GLODAPv2 (1972-2013)
(Olsen et al., ESSDD, 2016)

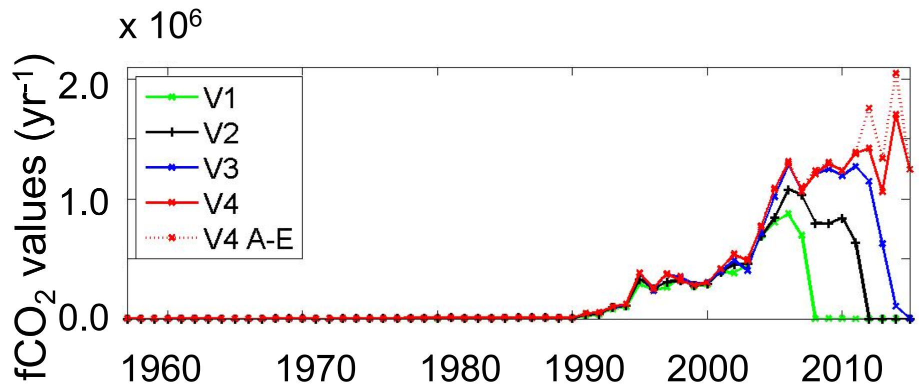


- 724 cruises, uniform, bias corrected;
- **Core: T, S, DIC, Alk, oxygen, nutrients, freons**;
- Also: pH, carbon isotopes, organic carbon and nitrogen, tritium, helium;
- Public

Surface Ocean CO_2 Atlas (version 4)

www.socat.info





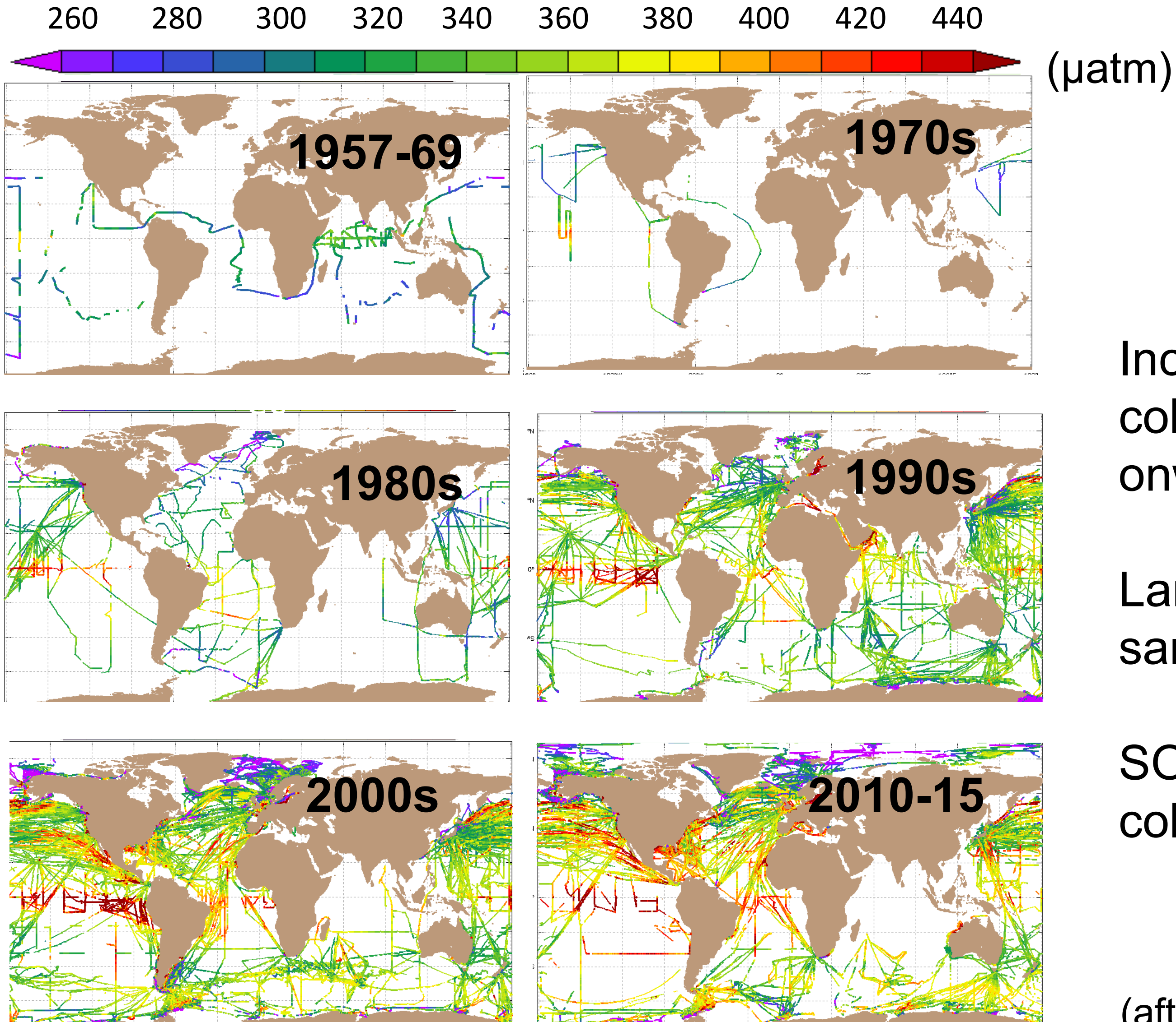
Global synthesis and gridded products of surface ocean fCO_2 (fugacity of CO_2) in uniform format with quality control;

- V4: 18.5 million fCO_2 values, accuracy < 5 μatm from 1957-2015;
- Plus calibrated sensor data (< 10 μatm);
- Online viewers;
- Downloadable (text, NetCDF, ODV, Matlab);
- Documented in ESSD articles;
- Fair Data Use Statement;
- **Community activity** with >100 contributors worldwide.

(Bakker et al. 2016, ESSD)

Surface water fCO_2 per decade (v4)

www.socat.info



Increase in fCO_2 data collection from 1990s onwards.

Large regions are not sampled.

SOCAT welcomes new collaborators!

(after Bakker et al., 2016 ESSD)

Annual releases upon automated data upload (v4)

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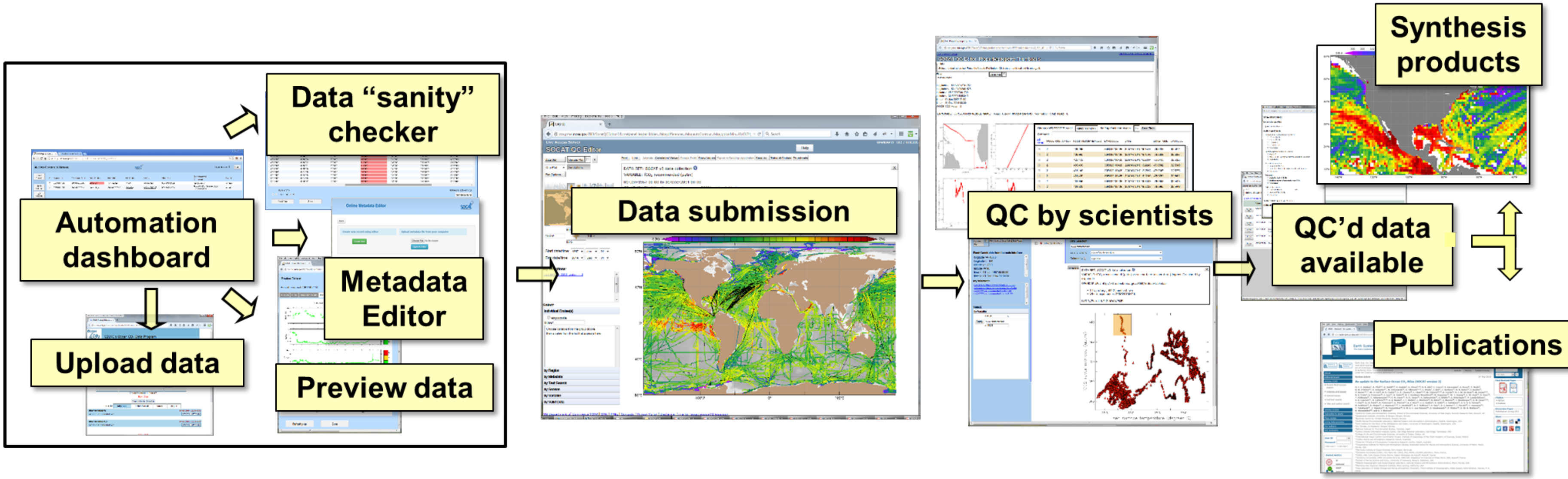

- Automation of data upload enables annual SOCAT releases.
- SOCAT data is discoverable, accessible and citable.

Future:

- Automation of metadata upload.
- Access to additional parameters (no quality control).
- Discussions on CH_4 and N_2O with MEMENTO in progress.

(O'Brien et al., in prep.)

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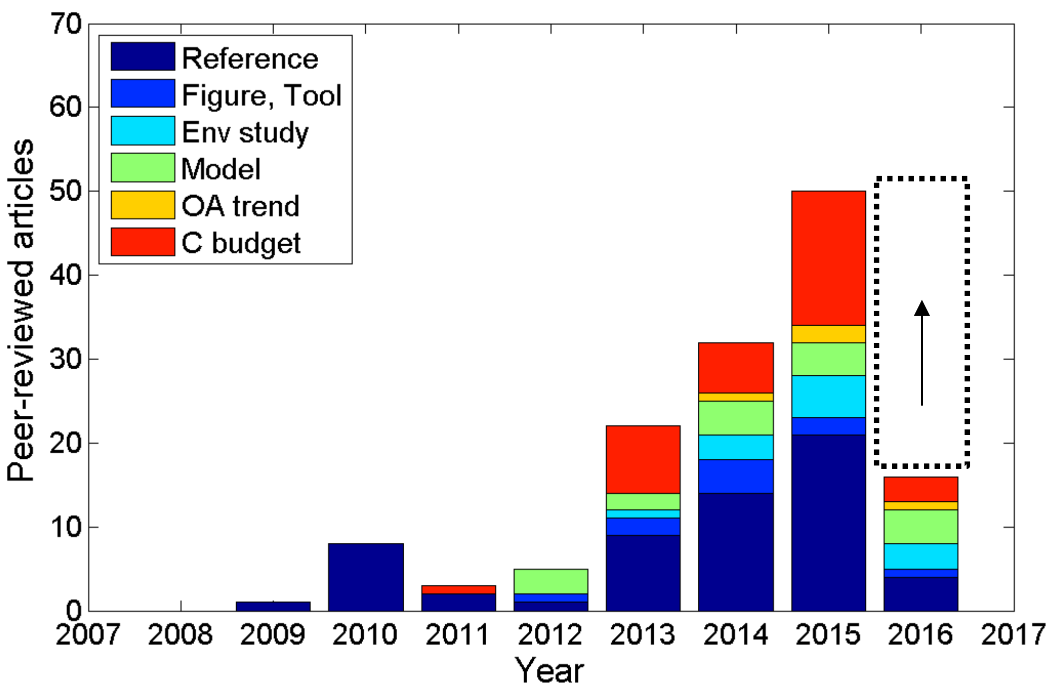
Applications in peer-reviewed articles



SOCAT is named or cited in >>150 peer-reviewed articles

- **Ocean carbon budgets**,
- **Ocean acidification studies**,
- **Model evaluation**,
- Environmental studies,
- Figures or tools,
- Reference to SOCAT.

Figure of 22 April 2016
(Bakker et al., 2016 ESSD)

Model evaluation

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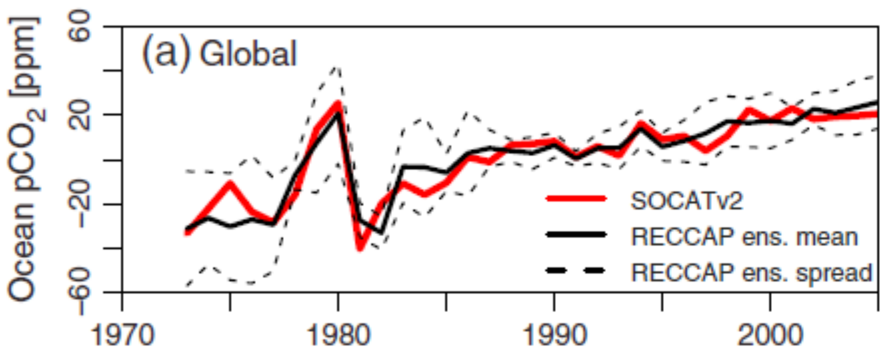
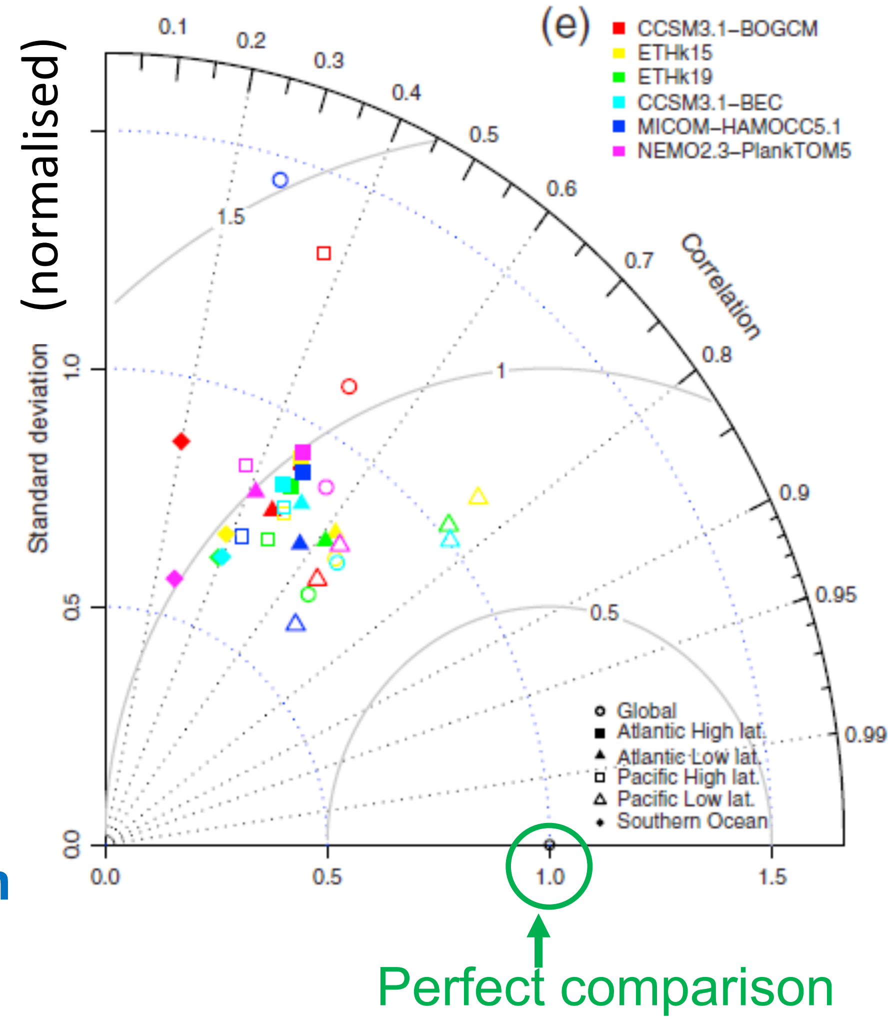


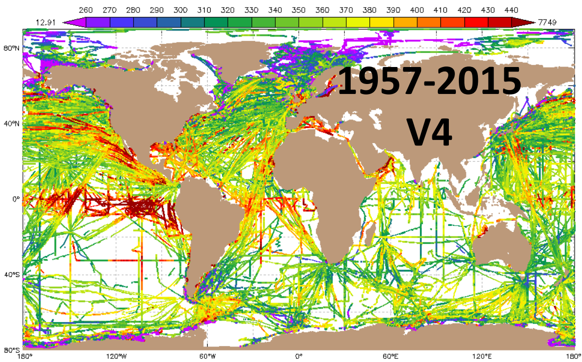


- Subsampling of 6 ocean-only CMIP5 models to SOCAT v2 fCO_2 values;
- Comparison of annual mean anomalies;
- **Models underestimate the variation in surface ocean pCO_2.**

- SOCAT in Obs4MIP and ESMVal for IPCC.

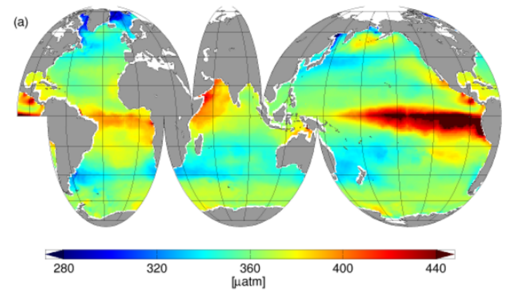
(Séférian et al., 2014, GRL; Eyring et al., 2016, GMD)

Mapping (gap filling) of surface ocean pCO_2 observations



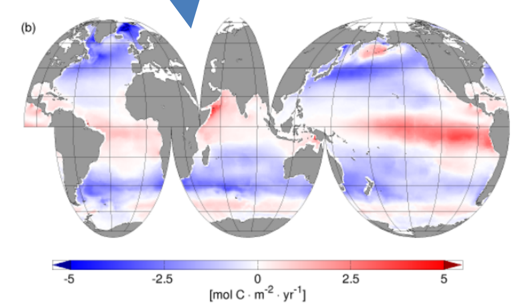
A synthesis data product (here SOCAT v4)

Mapping technique



Surface water pCO_2 (here 1998-2011)

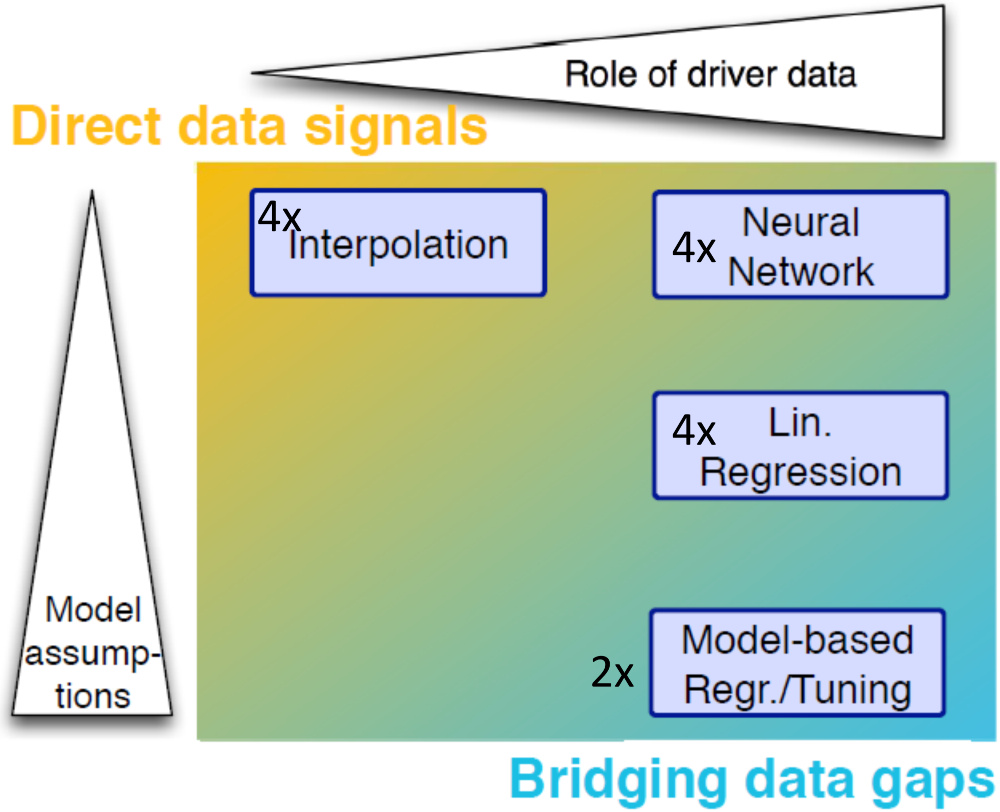
Flux = k * ΔpCO_2(w-a)
Gas transfer parameterisation, wind speed product



Air-sea CO_2 flux (here 1998-2011)

(Bakker et al., 2016 ESSD; Landschützer et al., 2014 GBC; Rödenbeck et al., 2015, BG)

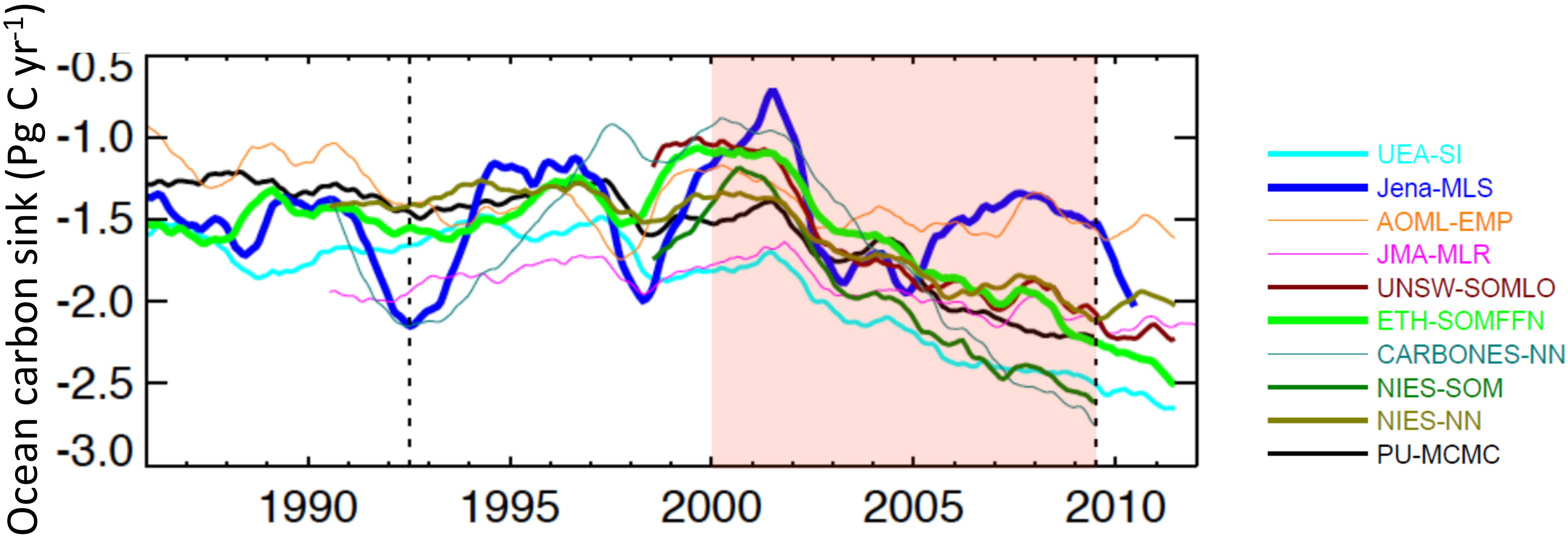
Surface Ocean pCO_2 Mapping intercomparison



- 14 data-based mapping methods, incl. 10 using SOCAT
- Methods differ in forcing and driver data sets.
- SOCOM welcomes new methods.
- **http://www.bgc-jena.mpg.de/SOCOM/**

(Rödenbeck et al., 2015 BG)

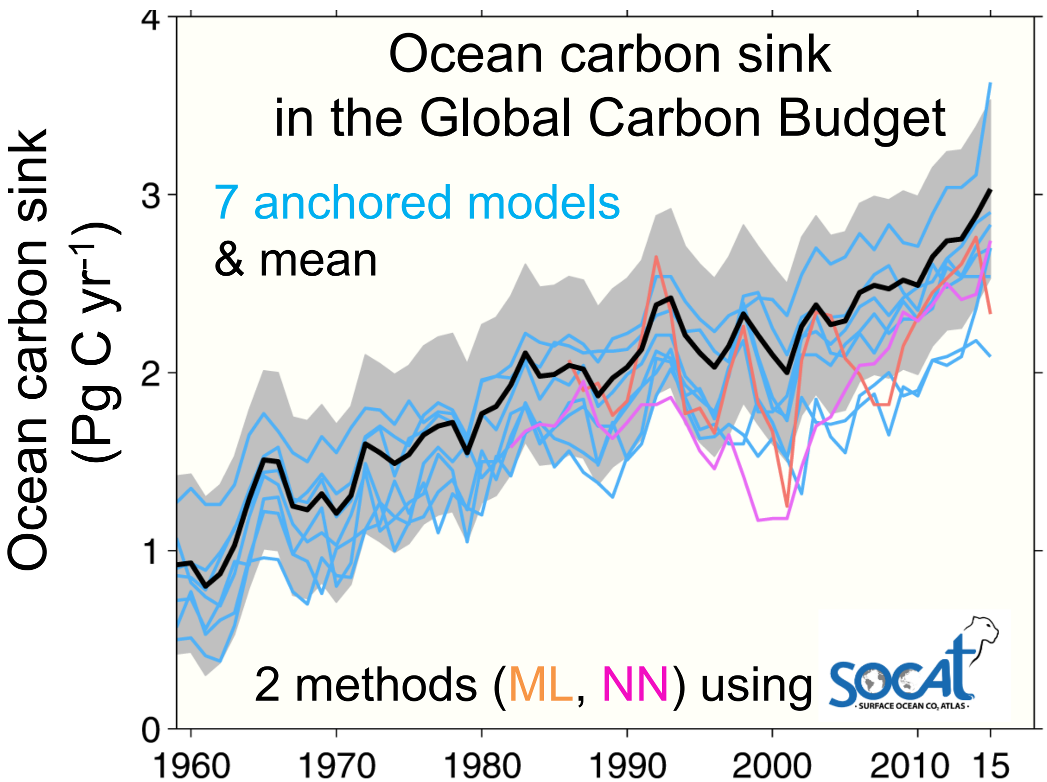
Global ocean carbon sink in 10 mapping methods

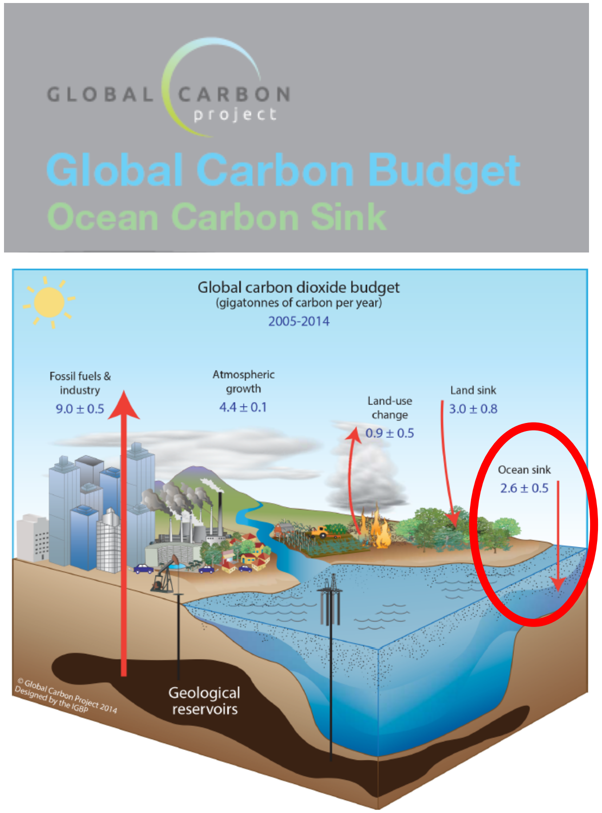


- Differences between 10 methods (7 using SOCAT);
- Low decadal change before 2000, **increasing sink after 2000**;
- Year-to-year and decadal variation in ocean carbon sink;
- Models underestimate variation in the ocean carbon sink.

(Rödenbeck et al., 2015 BG)

High Impact

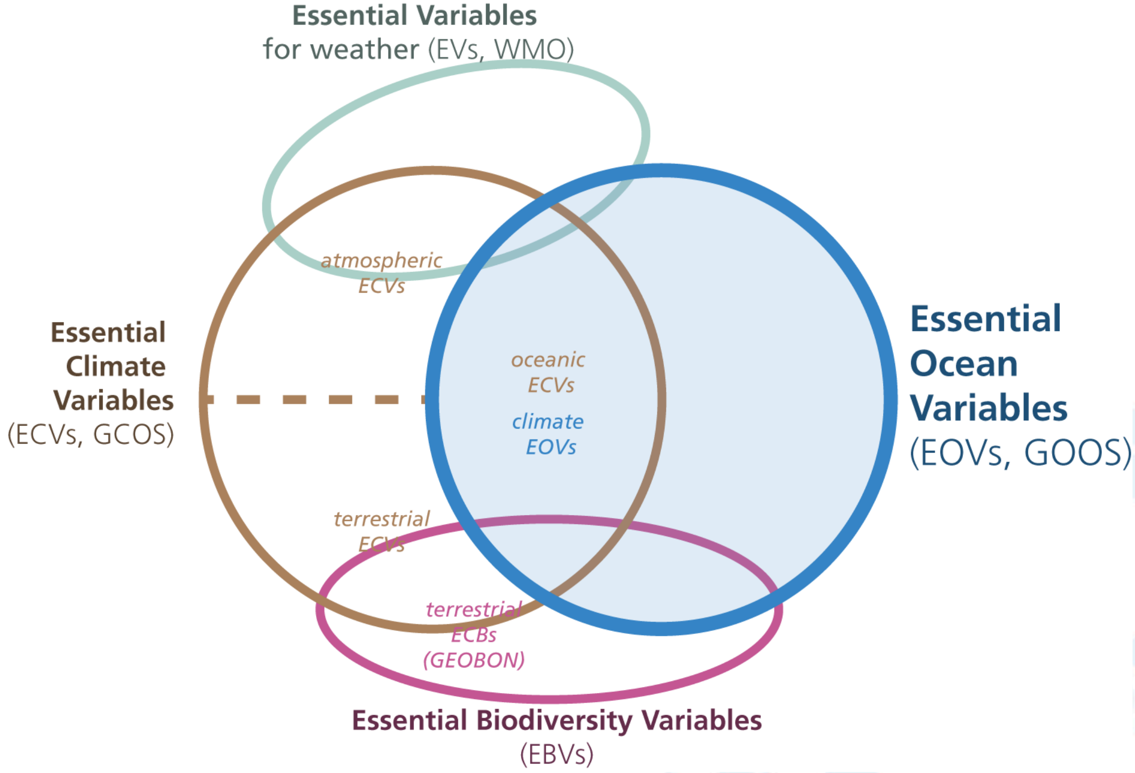




- **Quantification of the ocean and land carbon sinks and ocean acidification**,
- **Evaluation of ocean carbon models** (Obs4MIP & ESMVal for IPCC),
- Year-to-year and decadal variation in the ocean carbon sink,
- Models underestimate the variation in the ocean carbon sink.

(Landschützer et al., 2016; Rödenbeck et al., 2015; Le Quéré et al., 2016)

Essential Ocean Variables (EOVs)



- **We cannot measure everything, nor do we need to**
- Driven by high-level requirements, negotiated with feasibility
- Allows for innovation in the observing system over time

Slide from Maciej Telszewski (IOCCP)

IOCCP Position Paper on Global Ocean Biogeochemistry Data Management

The IOCCP Scientific Steering Group would like to announce its position with regards to the Global Ocean Biogeochemistry Data Management. You can read the full position paper on our website, and also download it as a pdf.
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THE INTERNATIONAL OCEAN CARBON COORDINATION PROJECT

A joint project of Scientific Committee on Oceanic Research and Intergovernmental Oceanographic Commission of UNESCO and an affiliate program of the Global Carbon Project.

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Global Ocean Biogeochemistry Data Management
IOCCP Position Paper

The international ocean biogeochemistry community is mainly using and depending upon one global data center, the Carbon Dioxide Information Analysis Center ocean trace gases section (CDIAC-Oceans) at the U.S. Department of Energy's Oak Ridge National Laboratory, USA. CDIAC-Oceans provides data management support for ocean carbon

Benjamin Pfeil
Responsible SSG Member

Ocean biogeochemistry data need a home: Global Data Assembly Centre (GDAC)

Benjamin Pfeil

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glodap v2

Other Data products

VOS/SOOP U/D

Repeat Hydrography U/D

GDAC for Marine Biogeochemistry

Drifting Platforms U/D

Fixed Ocean Times Series U/D

'New' platforms Alternative sensors U/D

Other Cruises U/D

U = underway
D = discrete

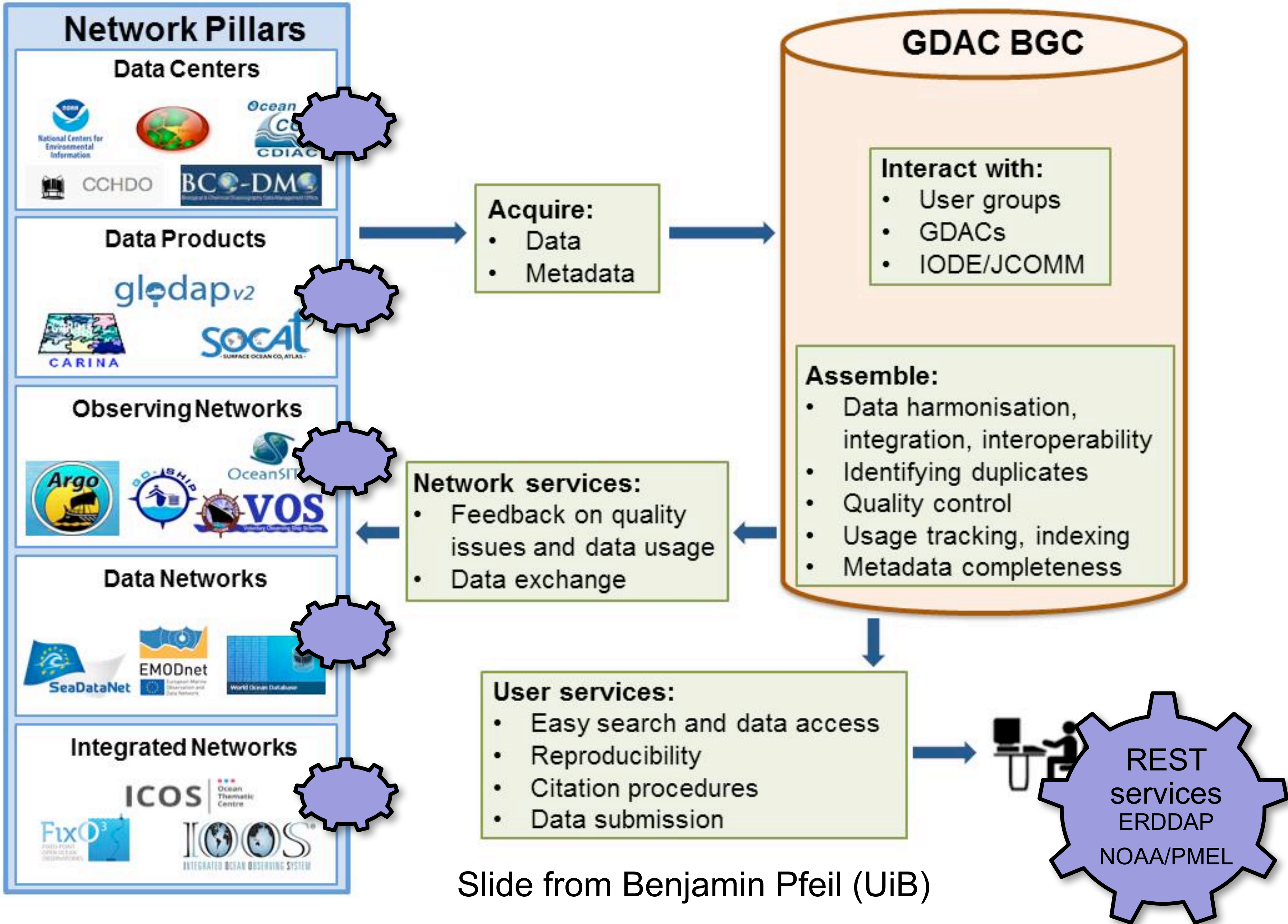
Global Data Assembly Centre for Marine Biogeochemistry (GDAC BGC)

Coordinator: Benjamin Pfeil; Scientific advisor: Are Olsen
Technical coordinator: Steve Jones (all UiB)

- Follows IOCCP Position Paper on Global Ocean Biogeochemistry Data Management
- Aim: Easy access to quality controlled Carbonate System EOV from data centres, data products, observing networks and integrated networks – All support the proposal.
- Collaboration with US by mirrored inventories.
- Need: IOC UNESCO GOOS and IODE, UNESCO/SCOR IOCCP, GEO Carbon and GHG Initiatives, GOA-ON, SOLAS, GCP's GCB, GO-SHIP, ATLANTOS, COPERNICUS, GDAC ARGO, Norwegian Environmental Agency.
- Time frame, money : 3 years, 750 kEuro – ambitious, realistic, feasible!
- Backup: Norway's Intended Nationally Determined Contributions.

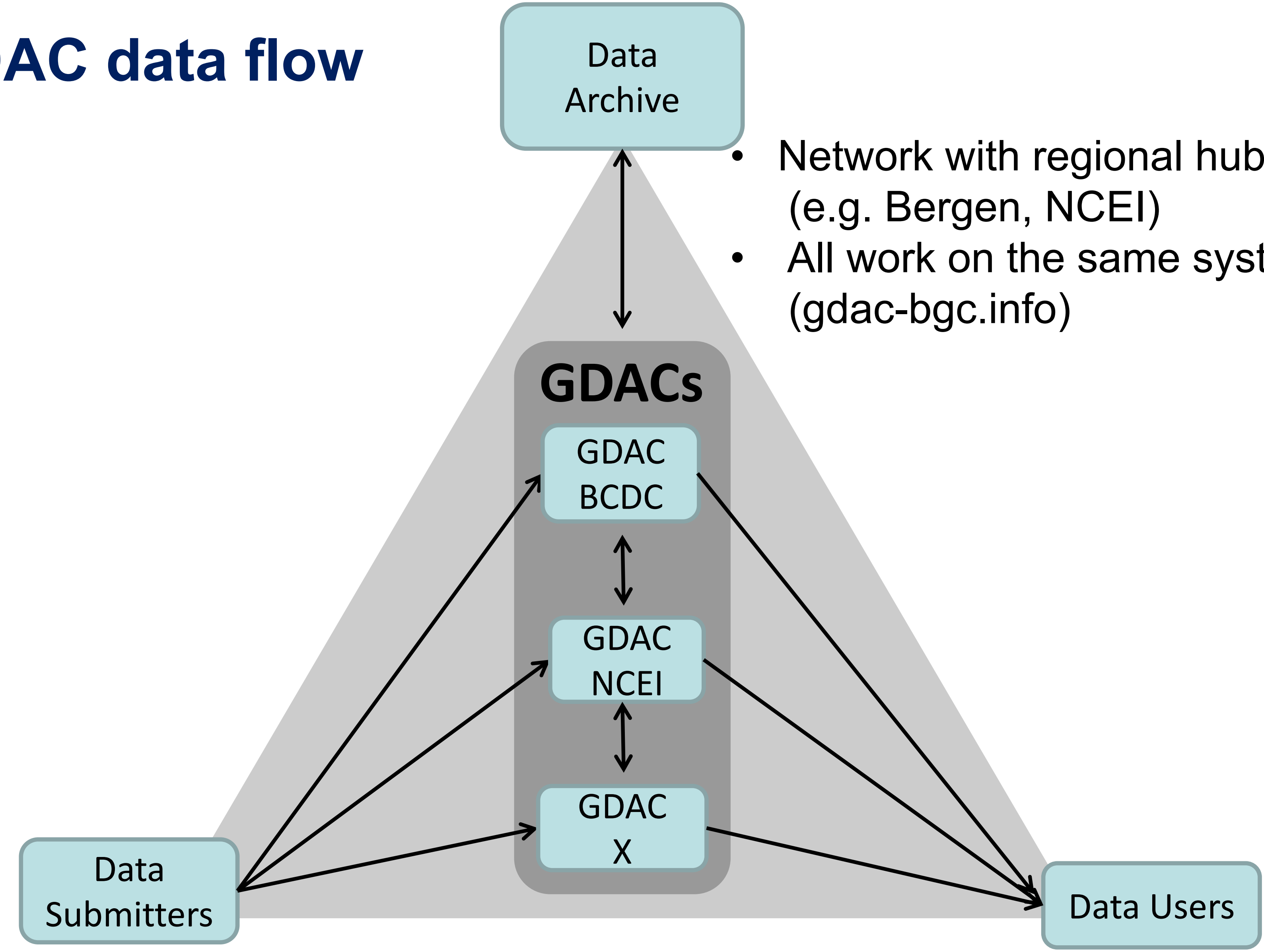
Slide from Benjamin Pfeil (UiB)

Tasks of the GDAC BGC



Slide from Benjamin Pfeil (UiB)

GDAC data flow



- Network with regional hubs (e.g. Bergen, NCEI)
- All work on the same system. (gdac-bgc.info)

Slide from Benjamin Pfeil (UiB)

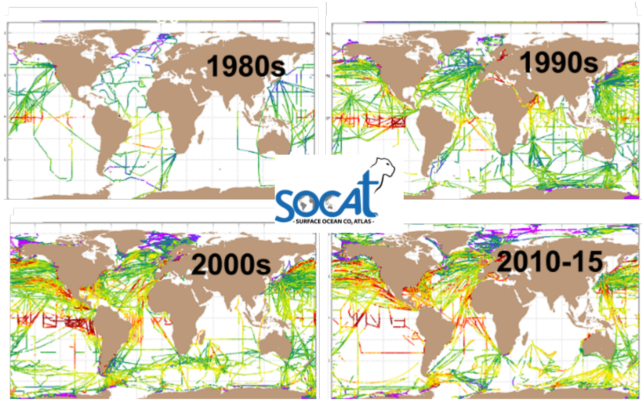
Long-term in situ ocean biogeochemical observations

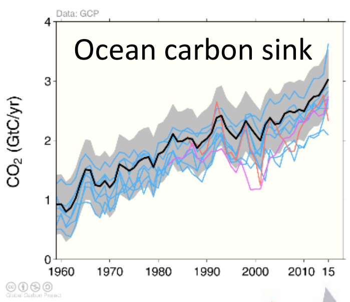
'No substitute exists for **adequate observations**.'

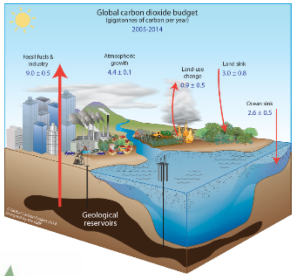
'Models will evolve and improve, but, without data, will be untestable, and observations not taken today will be lost forever.'

'Today's climate models will likely prove of little interest in 100 years. **But adequately sampled, carefully quality controlled and archived data** for key elements of the climate system will be useful indefinitely.'

Wunsch et al. (2013) PNAS 110 (12) 4435-4436; Bryden, H., 2014 Challenger Medal Lecture; Bakker et al., 2016; Le Quéré et al., 2016.







COP21

TOUS ENSEMBLE POUR LE CLIMAT

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Ocean biogeochemistry data initiatives – In conclusion

University of East Anglia

- Aim: Quantifying ocean biogeochemistry and the processes controlling it in a high CO_2 world.
- GLODAP – Global Data Analysis Project
- SOCAT – Surface Ocean CO_2 Atlas
- SOCOM – Surface Ocean CO_2 Mapping Intercomparison
- High-impact, community products.
- Acknowledgement of data providers essential.
- User feedback important.
- Sustained funding for data collection and synthesis is key.
- Essentisl Ocean Variables (EOVs)
- Other ocean biogeochemical data need a home, e.g. Bio-Argo, moorings, gliders, seal tags.
- Global Data Assembly Centre (GDAC) for Marine Biogeochemistry

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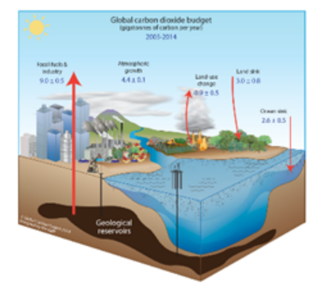
SOCOM SURFACE OCEAN pCO_2 MAPPING INTERCOMPARISON

glodap v2



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Global carbon cycle (2000-2009)

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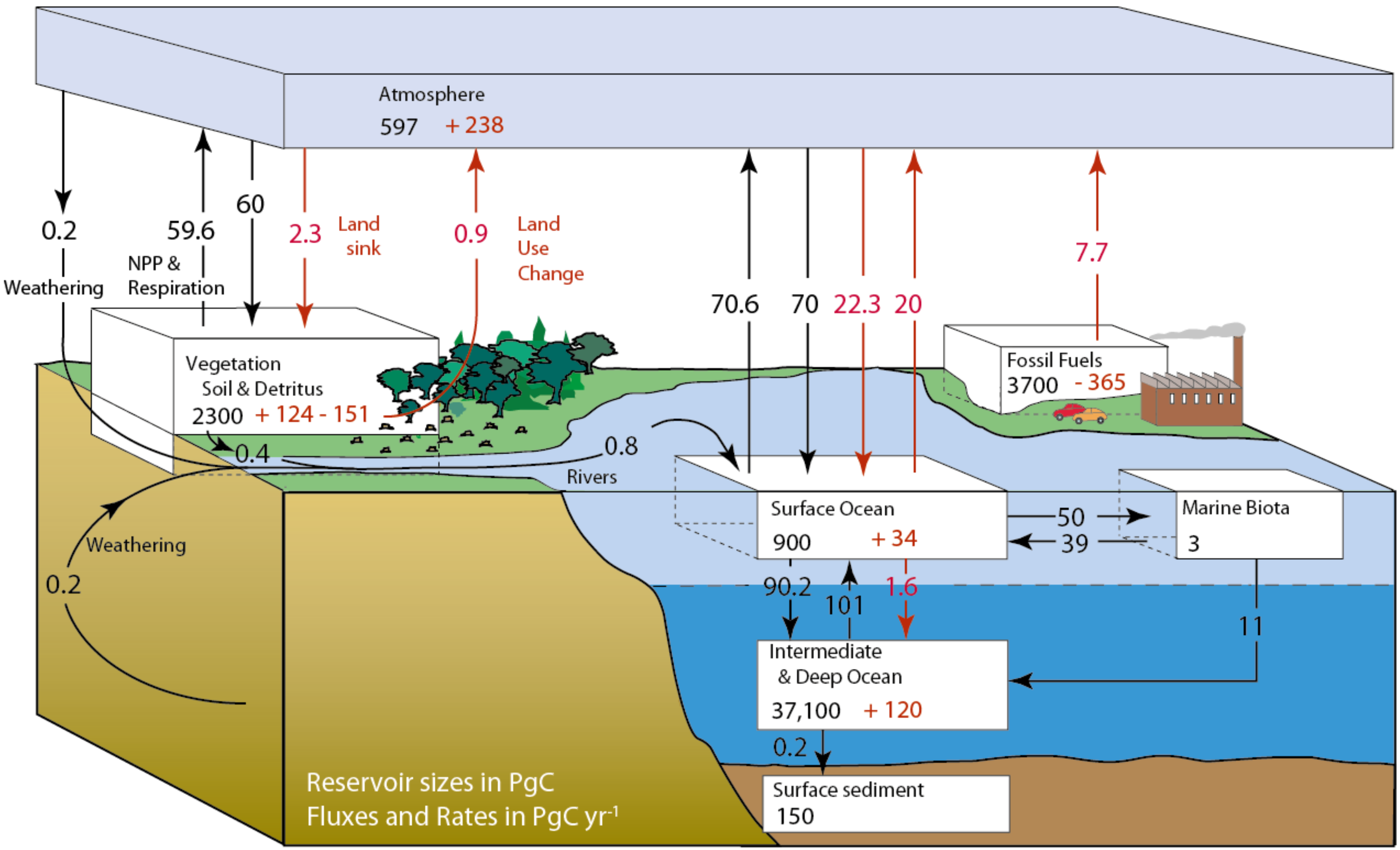
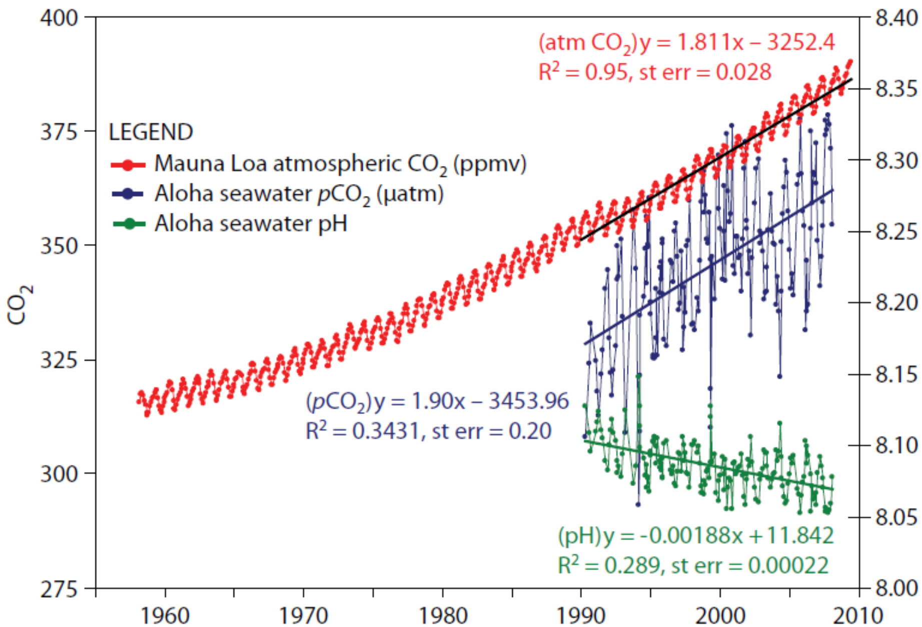


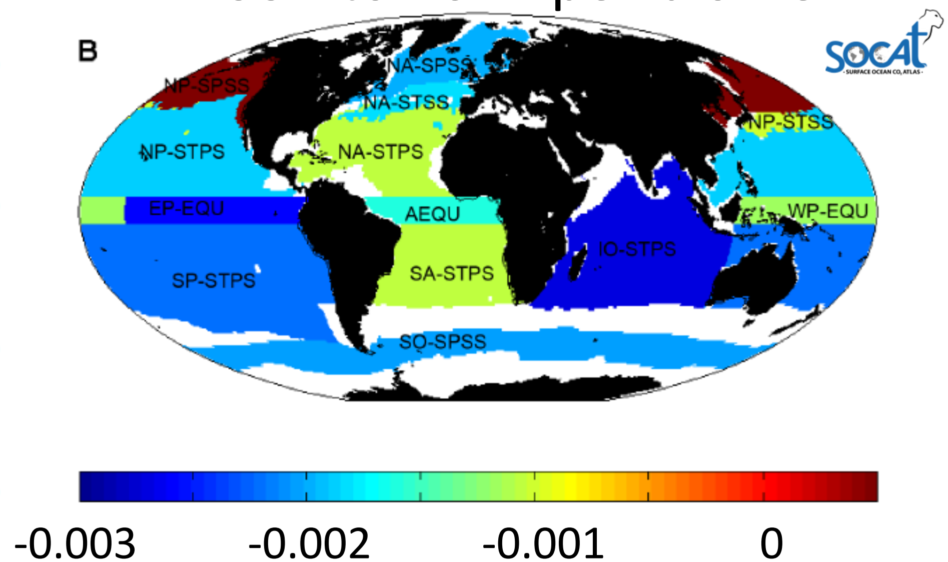
(Bakker et al., 2014, Springer Verlag)

Ocean acidification from SOCAT

www.socat.info



Surface ocean pH change for 1991 to 2011 per biome



- Combine SOCAT fCO_2 with salinity-derived alkalinity.
- Global surface ocean pH decreases by 0.002 $year^{-1}$ from 1991 to 2011.
- SOCAT enables quantification of regional trends in surface ocean pH.

(Feely et al., 2009; Lauvset et al., 2015 BG)

Reinvigoration of the Southern Ocean carbon sink

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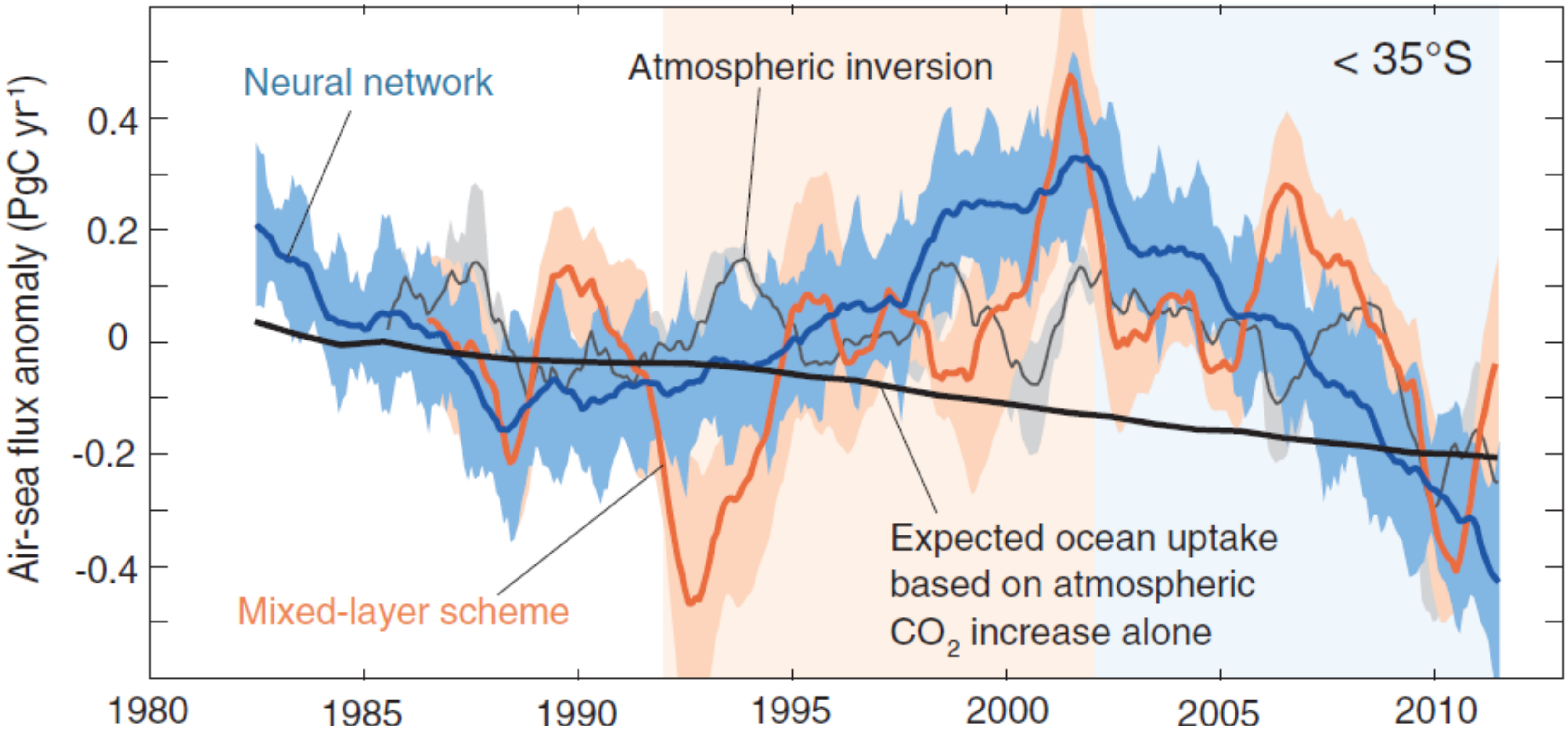

2 methods using SOCAT v2;
ΔpCO_2 trends dominate the sink variability;
ΔpCO_2 trends lead to a sink increase of >0.5 PgC/yr.

(Landschützer et al., 2015, Science 349 (6253): 1221-1224)

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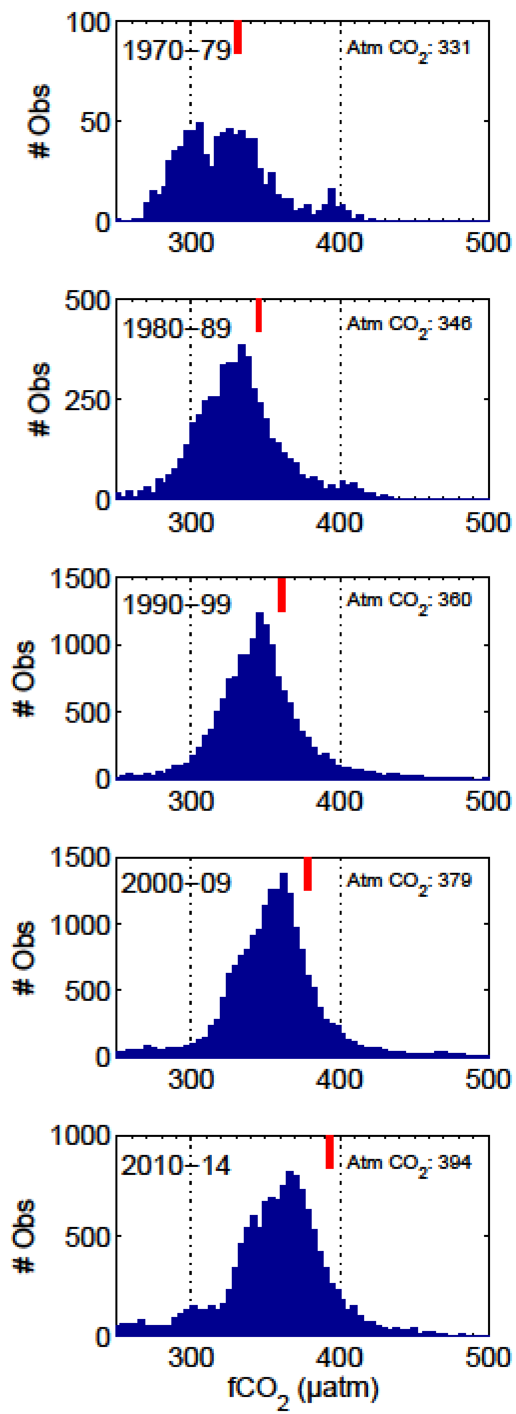
Surface water fCO_2 increases over time (v3)



(Bakker et al., 2016 ESSD)

Phenomena – e.g. Ventilation - EOVs

Societal Drivers	Scientific Questions	Biogeochemical Phenomena to Capture	EOVs
The role of ocean biogeochemistry in climate	How is the ocean carbon content changing?	Air-sea fluxes, Storage, Organic matter cycling, **Ventilation**, Upwelling	Dissolved Oxygen, Inorganic Macronutrients, Inorganic Carbon, Transient Tracers, Suspended Particulates, Stable Carbon Isotopes, Dissolved Organic Carbon
	How does the ocean influence cycles of non-CO_2 greenhouse gases?	Upwelling, **Ventilation**, Deoxygenation	Dissolved Oxygen, Nitrous Oxide
Human impacts on ocean biogeochemistry	How large are the ocean's "dead zones" and how fast are they changing?	Deoxygenation, **Ventilation**, Storage, Inorganic nutrient cycling	Dissolved Oxygen, Inorganic Macronutrients, Inorganic Carbon, Transient Tracers, Suspended Particulates, Nitrous Oxide
	What are the rates and impacts of ocean acidification?	Storage, Ocean acidification	Dissolved Oxygen, Inorganic Macronutrients, Inorganic Carbon, Transient Tracers, Suspended Particulates, Stable Carbon Isotopes, Dissolved Organic Carbon
Ocean ecosystem health	Is the biomass of the ocean changing?	Organic matter cycling, Inorganic nutrient cycling	Dissolved Oxygen, Inorganic Macronutrients, Inorganic Carbon, Suspended Particulates
	How does eutrophication and pollution impact ocean productivity and water quality?	Eutrophication, Deoxygenation, Organic matter cycling, Pollution	Dissolved Oxygen, Inorganic Macronutrients, Suspended Particulates, Nitrous Oxide, Dissolved Organic Carbon

Slide from Maciej Telszewski (IOCCP)