Quantification of the ocean carbon sink using surface ocean observations

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and all >100 SOCAT and SOCOM contributors

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

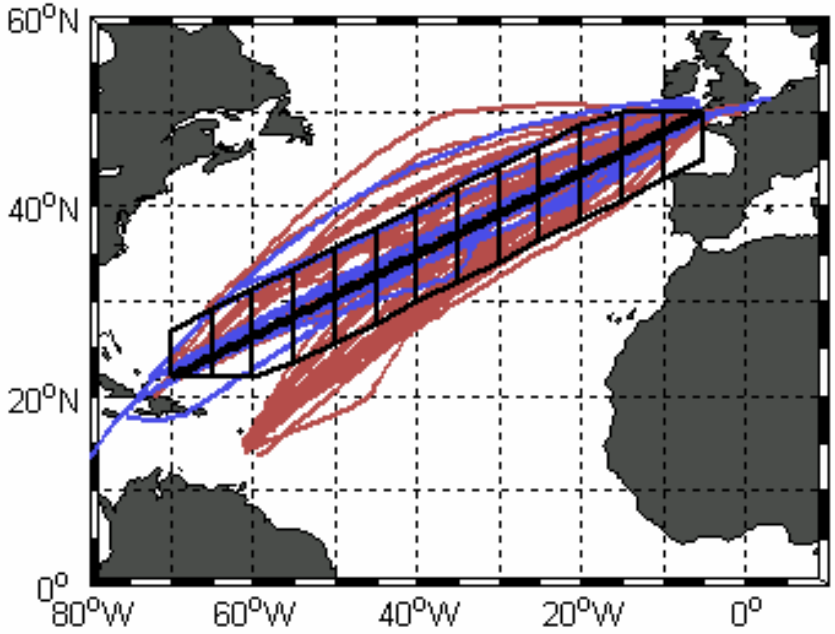
Atmosphere
4.5 Pg C yr^{-1}
(44%)

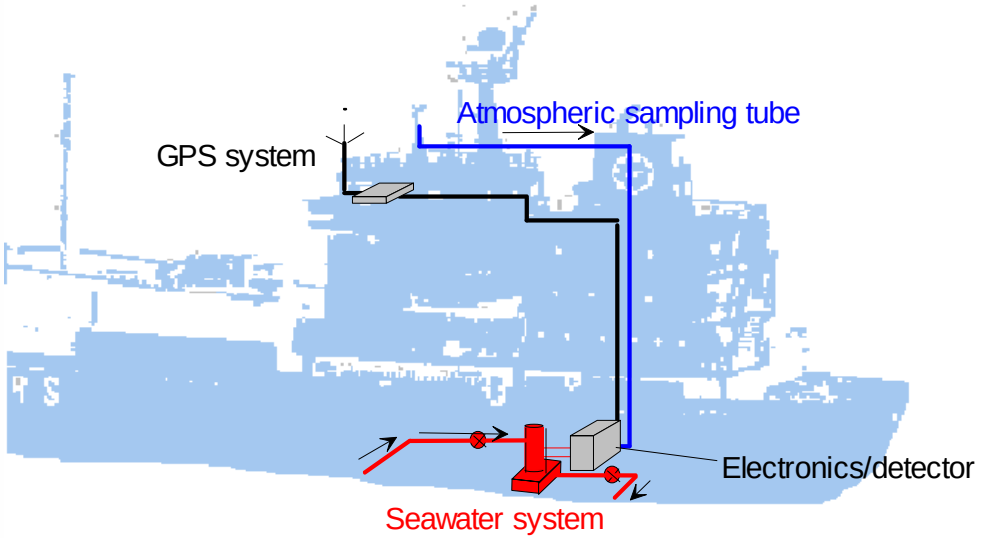
Ocean sink
2.6 Pg C yr^{-1}
(26%)
(Anthropogenic C_{ant})

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)

The North Atlantic carbon sink





1994/95 & 2002/05

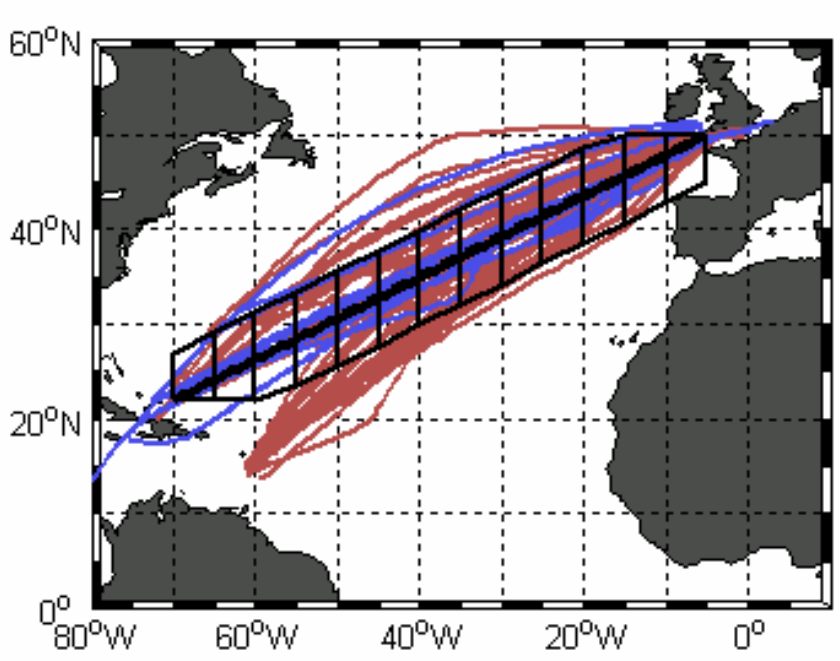
fCO_2 (fugacity) = γ pCO_2 (partial pressure), (γ ~ 0.996-0.997)

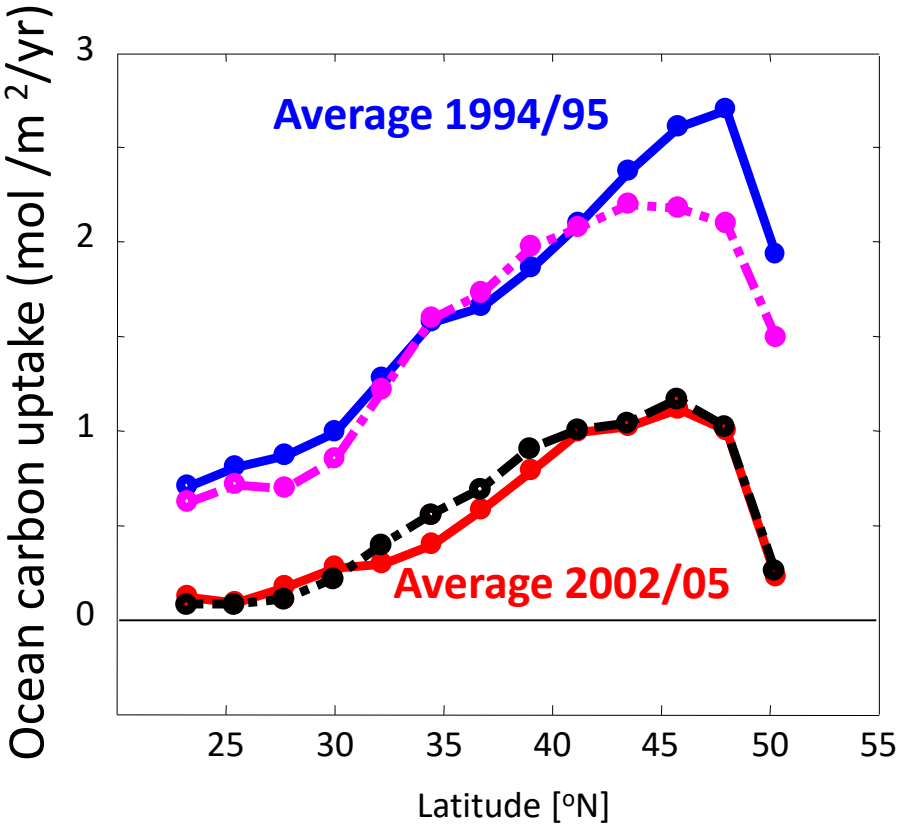
Air-sea CO_2 flux (C_{net}) = k K'$_0$ ($fCO_{2water} - fCO_{2air}$)

(Schuster and Watson, JGR, 2007)

A decreasing North Atlantic carbon sink (C_{net}) from 1994/95 to 2002/05

Decadal variation or long term trend?





1994/95 with 2002/05 SST

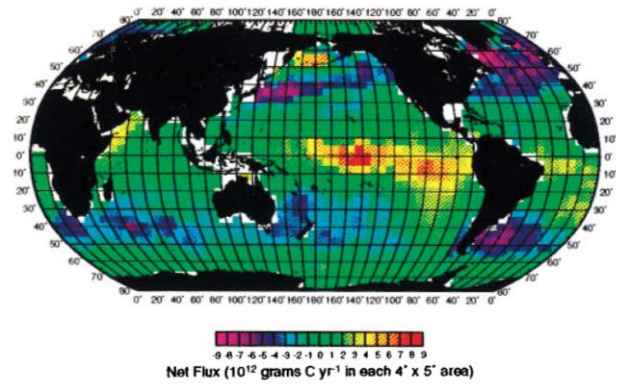
2002/05 with 1994/95 wind speed

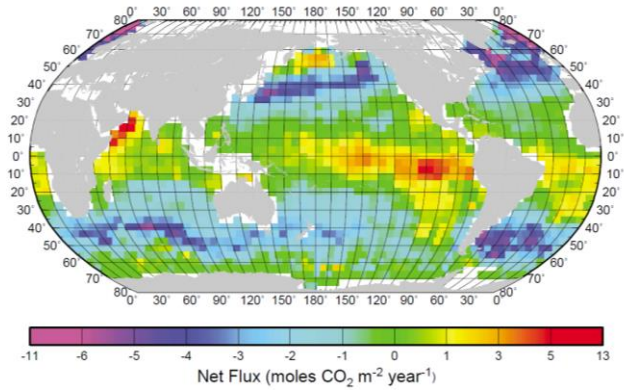
(Schuster and Watson, JGR, 2007)

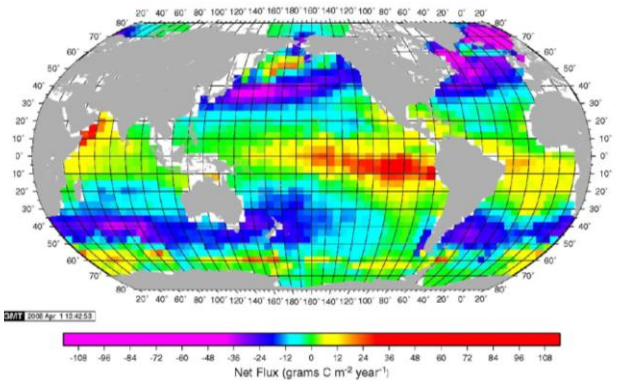
Ocean carbon sink from climatologies

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

Air-sea CO_2 flux (C_{net}) + Riverine carbon outgassing =
Anthropogenic ocean carbon sink (C_{ant})







For 1990
0.60-1.34 Pg C yr^{-1} (C_{net})
0.25 million pCO_2 values
(Takahashi et al., 1997)

For 1995
2.0 ± 0.6 Pg C yr^{-1} (C_{net})
0.94 million pCO_2 values
(Takahashi et al., 2002)

For 2000
1.6 ± 0.9 Pg C yr^{-1} (C_{net})
2.0 ± 1.0 Pg C yr^{-1} (C_{ant})
3 million pCO_2 values
(Takahashi et al., 2009)

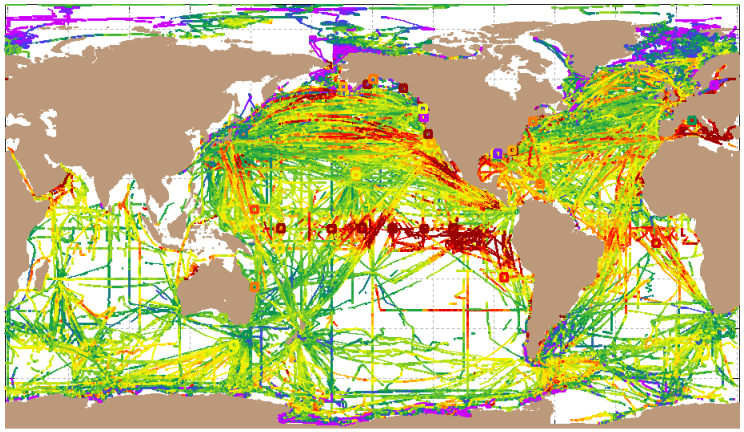
Also for 2005, 6 million pCO_2 values
(Takahashi et al., 2014)

Surface Ocean CO_2 Variability and Vulnerabilities Workshop

UNESCO, Paris, 11-14 April 2007

"Strong scientific need for a gridded ocean CO_2 product in modelling community. **'Surface Ocean CO_2 Atlas'?** eg. 1° x 1°, per year monthly means (+ standard deviation + number of data), global, no interpolation, annual update. Chris Sabine has offered to host this activity …"

SOCAT · SURFACE OCEAN CO_2 ATLAS ·



at 10!

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

International Ocean Carbon Coordination Project — IOCCP — UNESCO/IOC and SCOR

IMBER — Integrated Marine Biogeochemistry and Ecosystem Research

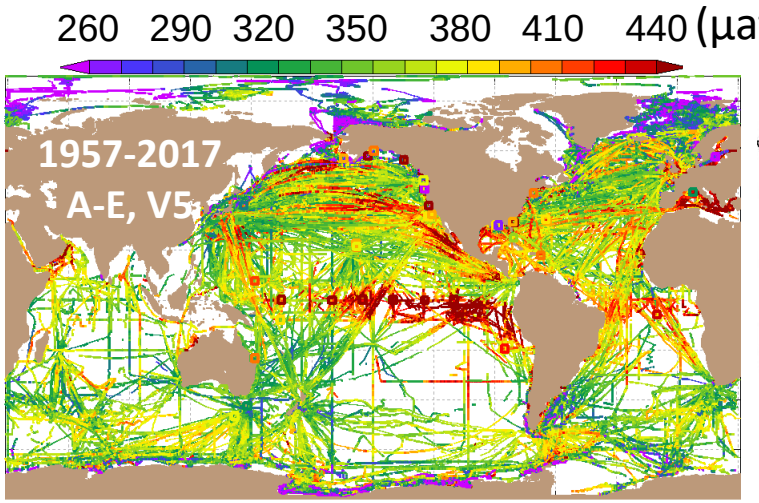
Global Carbon Project

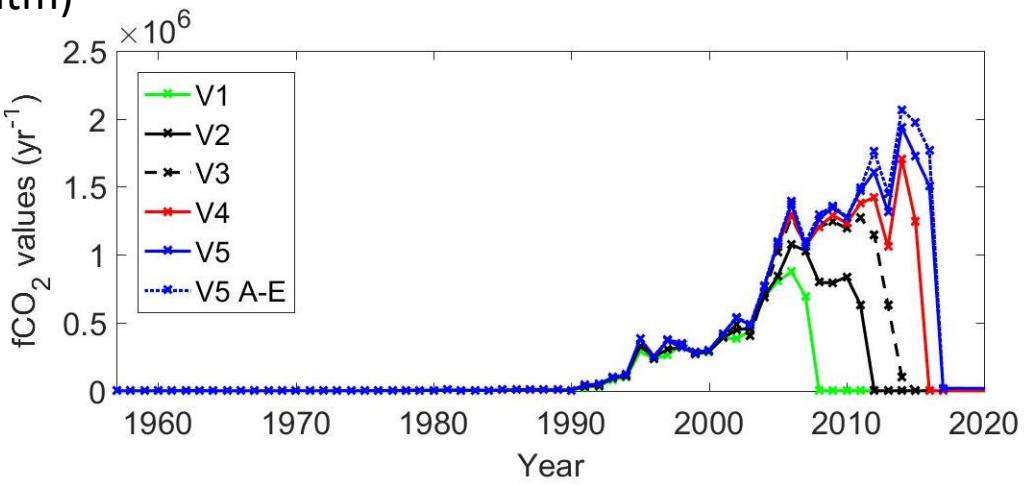
solas — surface.ocean lower.atmosphere.study

International Council for Science — Scientific Committee on Oceanic Research

Surface Ocean CO_2 Atlas at 10!

www.socat.info





Global synthesis and gridded products of surface ocean fCO_2

(fugacity of CO_2) in uniform format with quality control;

No gap filling; Annual public releases;

V5: 21.5 million fCO_2 values from 1957-2017, accuracy < 5 µatm (flags A-D);

Plus calibrated sensor data (< 10 µatm, flag E);

Online viewers, downloadable (text, NetCDF), ODV;

Documented in ESSD articles;

Fair Data Use Statement;

Community activity with >100 contributors worldwide.

(**Pfeil et al., 2013; Sabine et al., 2013; Bakker et al., 2014, 2016, all in ESSD**)

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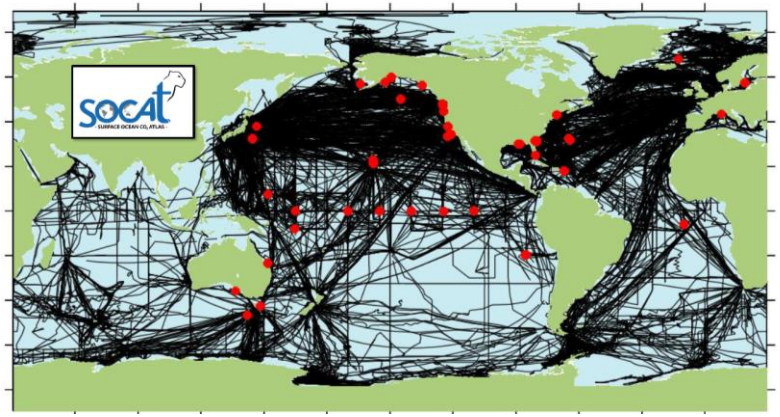
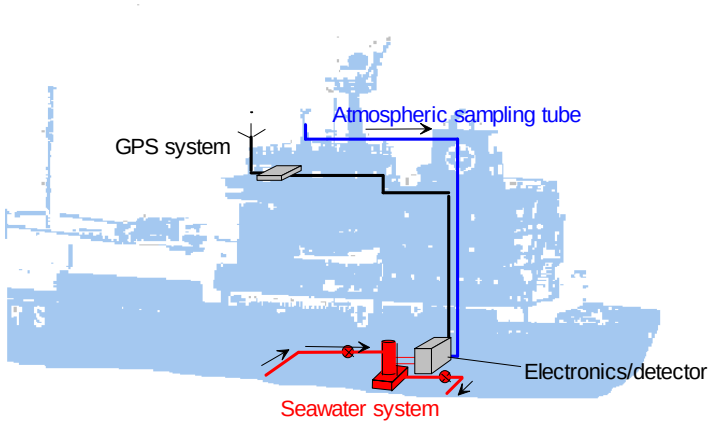
Surface ocean fCO_2 measurements





SOCAT has:

- **Surface ocean fCO_2 measurements** from moving and fixed platforms (i.e. no fCO_2 calculated from pH, TA, DIC, no profiling data);
- **Original fCO_2** from the data originator (i.e. not from a data product);
- Checked sea surface temperature and salinity, but these checks do not meet physical oceanographic quality checks for temperature and salinity.

Submit your surface ocean fCO_2 measurements, if you would like them to be considered for SOCAT!

(U Schuster, A Sutton)

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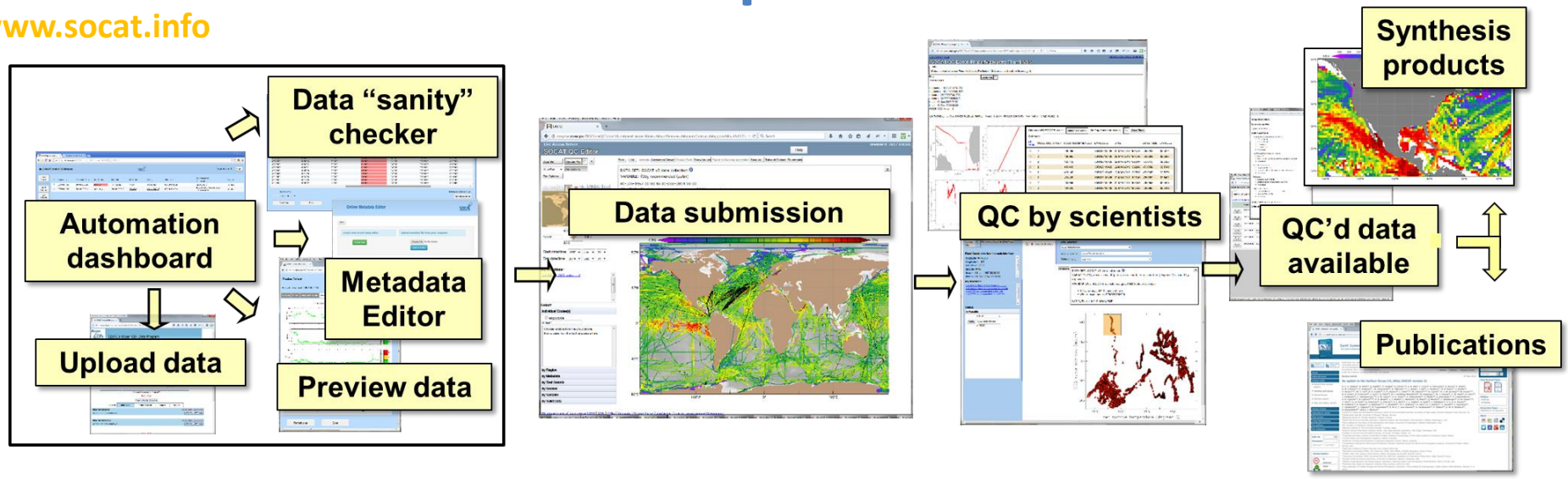
Annual public releases



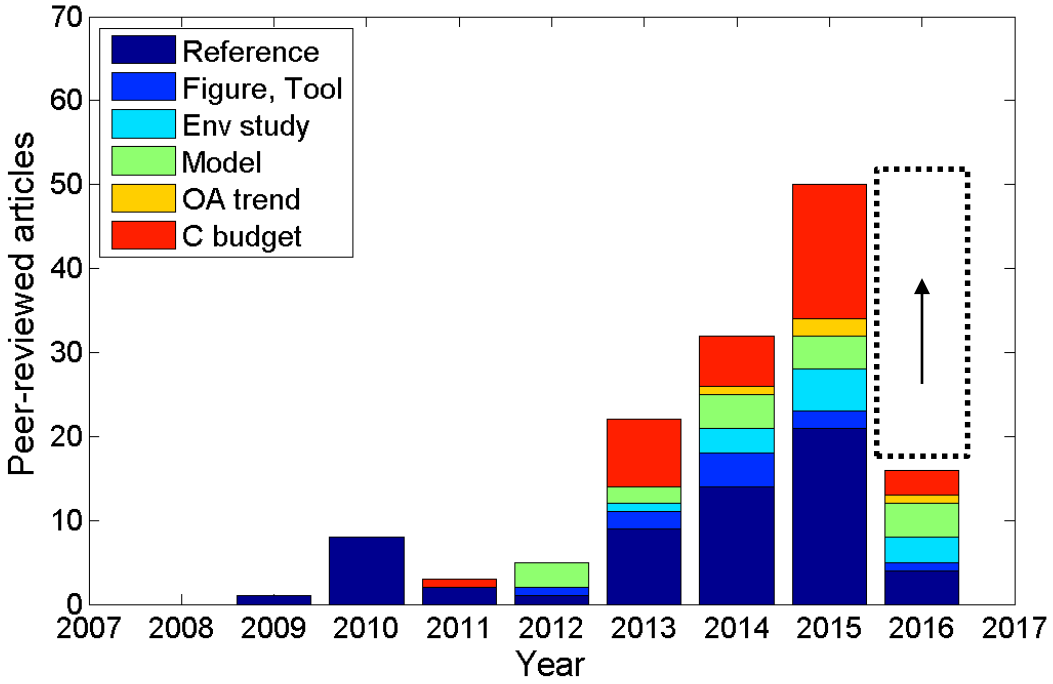
- Annual releases timed for the annual Global Carbon Budget.
- **User feedback** essential!
- Update of SOCAT website (**www.socat.info**, NEW)

SOCAT discussion today at 13:00-14:00 (IOCCP event) – **All welcome!**

- Other surface ocean parameters (DIC, TA, nutrients) – no quality control
- Surface ocean CH_4 and N_2O
- Atmospheric CO_2 – Value added?
- Should SOCAT accept calculated surface ocean fCO_2 from floats, gliders?

Applications

www.socat.info



SOCAT is named or cited in 194 peer-reviewed articles

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

(Bakker et al., 2016)

Voluntary Commitment to the 2017 UN Ocean Conference

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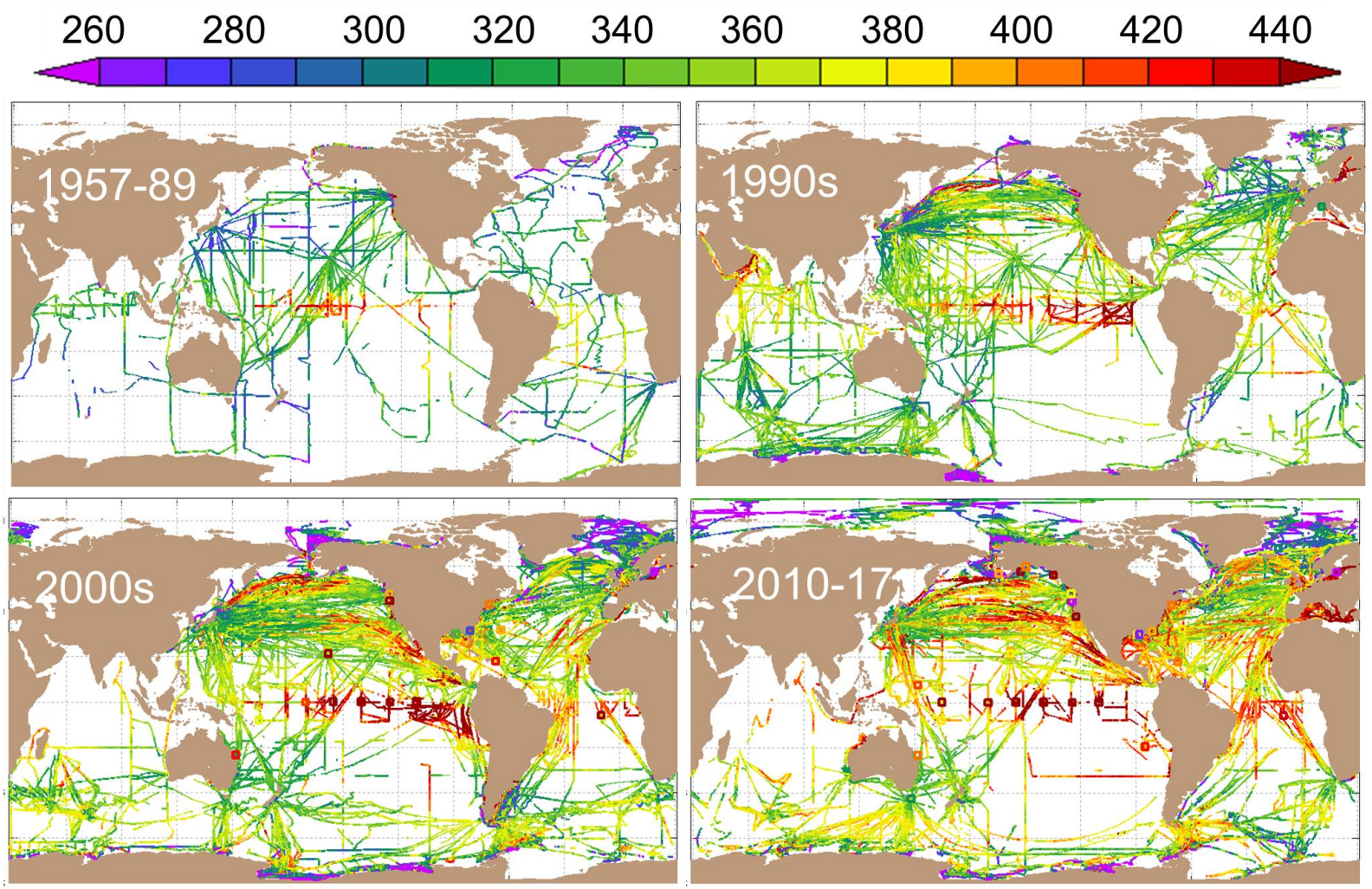
Annual, public releases of the Surface Ocean CO2 Atlas (SOCAT)

#OceanAction20464

by SOCAT scientific community (Scientific community)

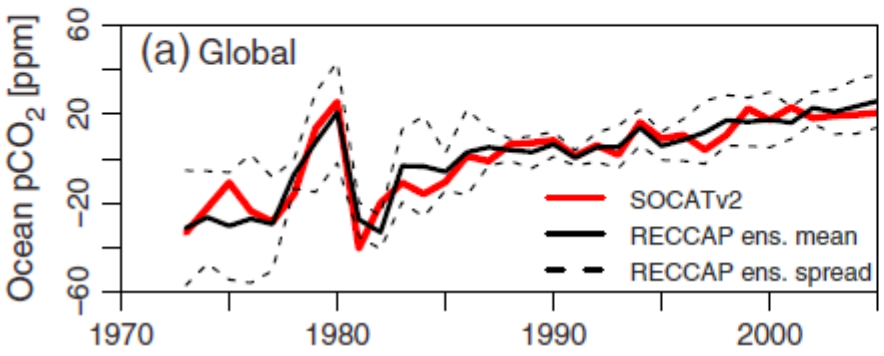
Surface ocean fCO_2 over time (V5)

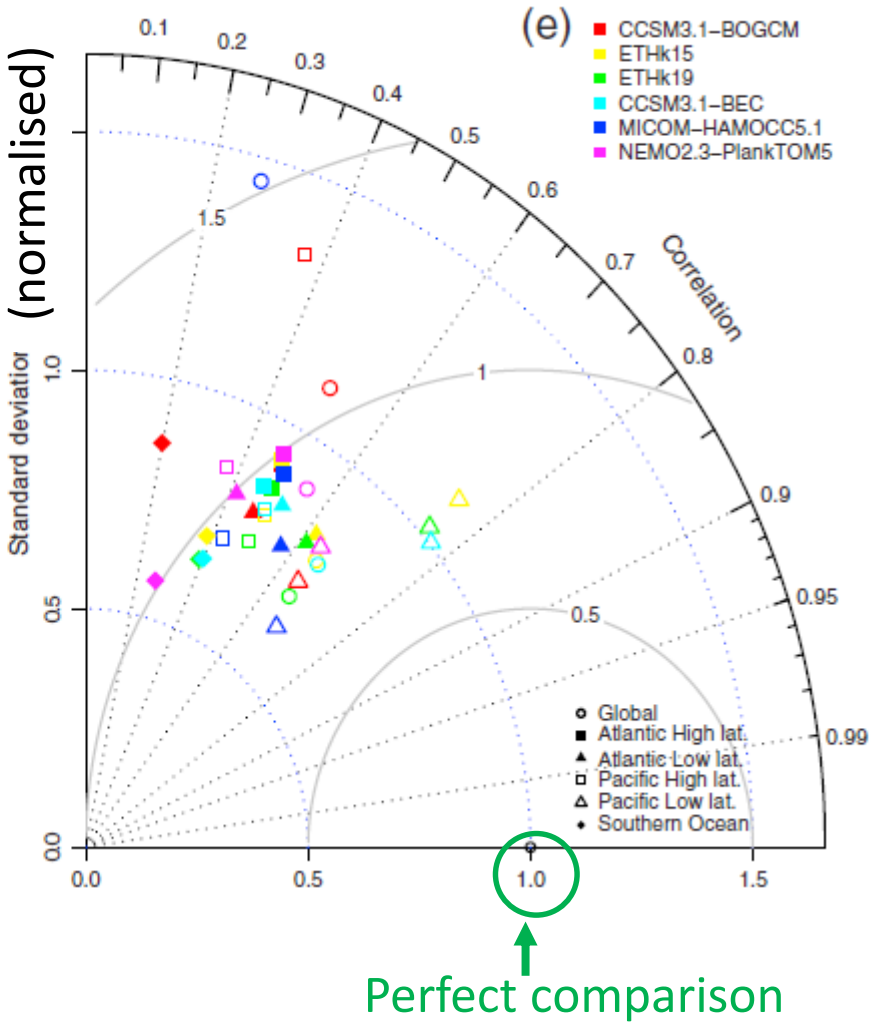


- Equilibrium with atmospheric fCO_2 takes up to 1 year,
- Large open ocean and coastal regions not sampled.

(after Bakker et al., 2016 ESSD)

Model evaluation



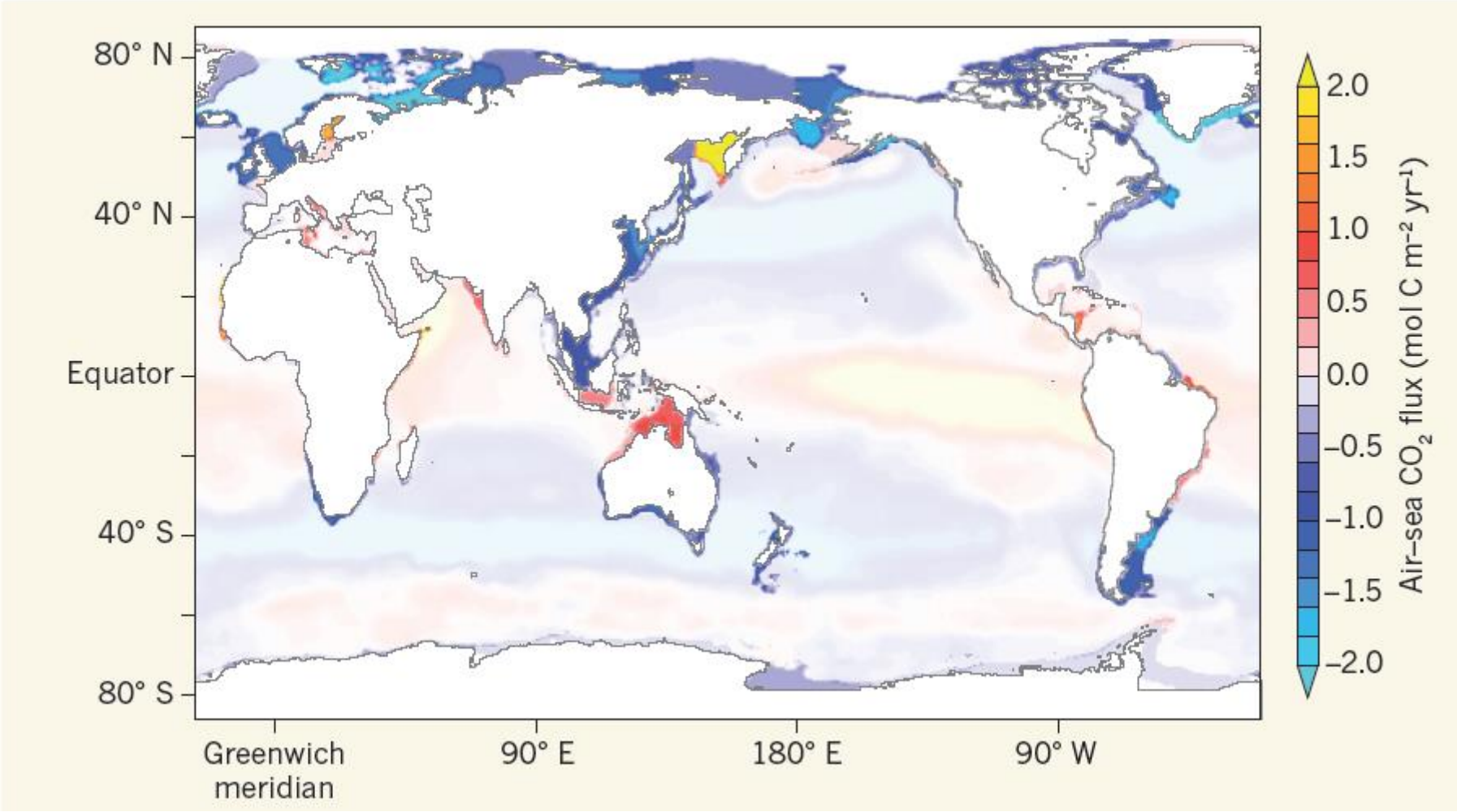


- Subsampling of 6 ocean-only CMIP5 models to SOCAT v2 fCO_2 values;
- Comparison of annual mean anomalies;
- **Models underestimate the variation in surface ocean pCO_2.**

- SOCAT in Obs4MIP and ESMVal for IPCC.

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

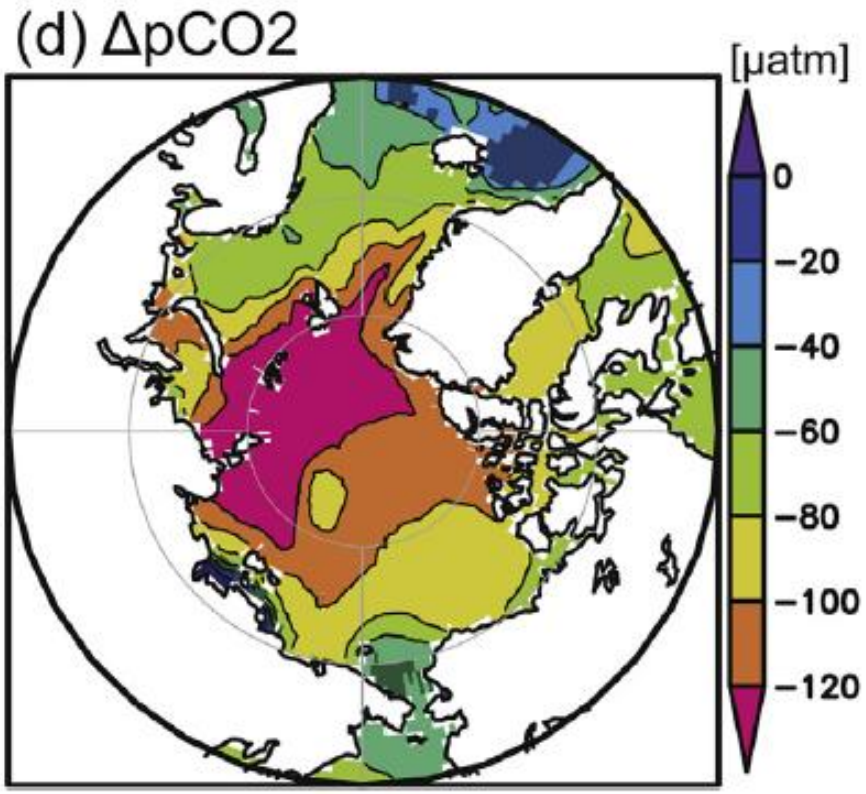
Coastal ocean carbon sink

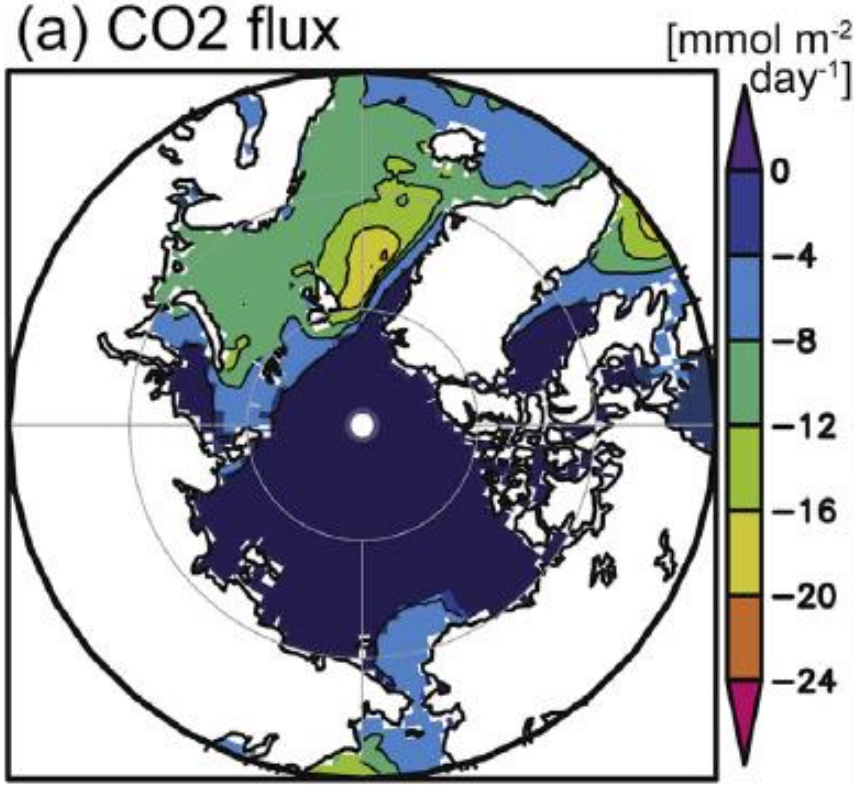


Coastal ocean carbon sink (C_{net}) of 0.2 to 0.4 Pg C yr^{-1}

(Chen et al., 2013; Laruelle et al., 2014; Gruber, 2015)

Arctic ocean carbon sink

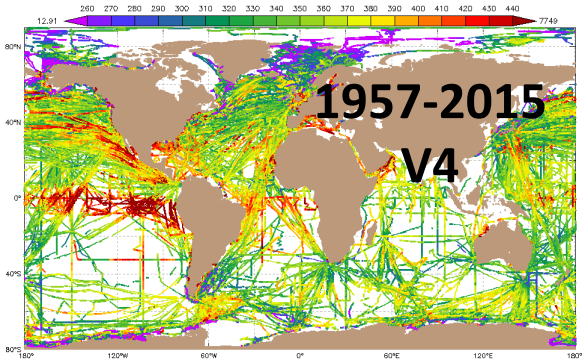




Arctic Ocean carbon sink (C_{net}) of 0.18 Pg C yr^{-1}

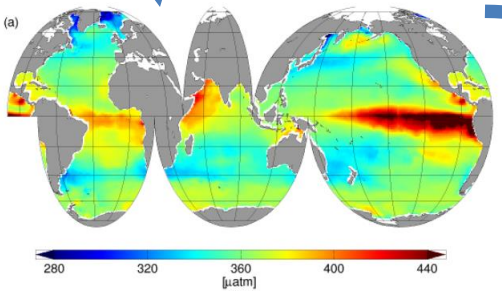
(Yasunaka et al., 2016 Polar Biology)

Ocean carbon sink from surface ocean pCO_2



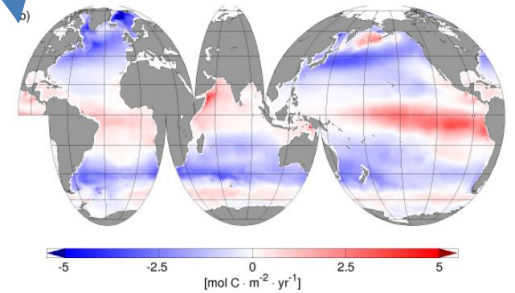
A synthesis product
(here SOCAT v4)

Mapping



Surface water pCO_2
(here 1998-2011)

Flux = k K_0 ΔpCO_2(w-a)
gas transfer parameterisation,
wind speed product



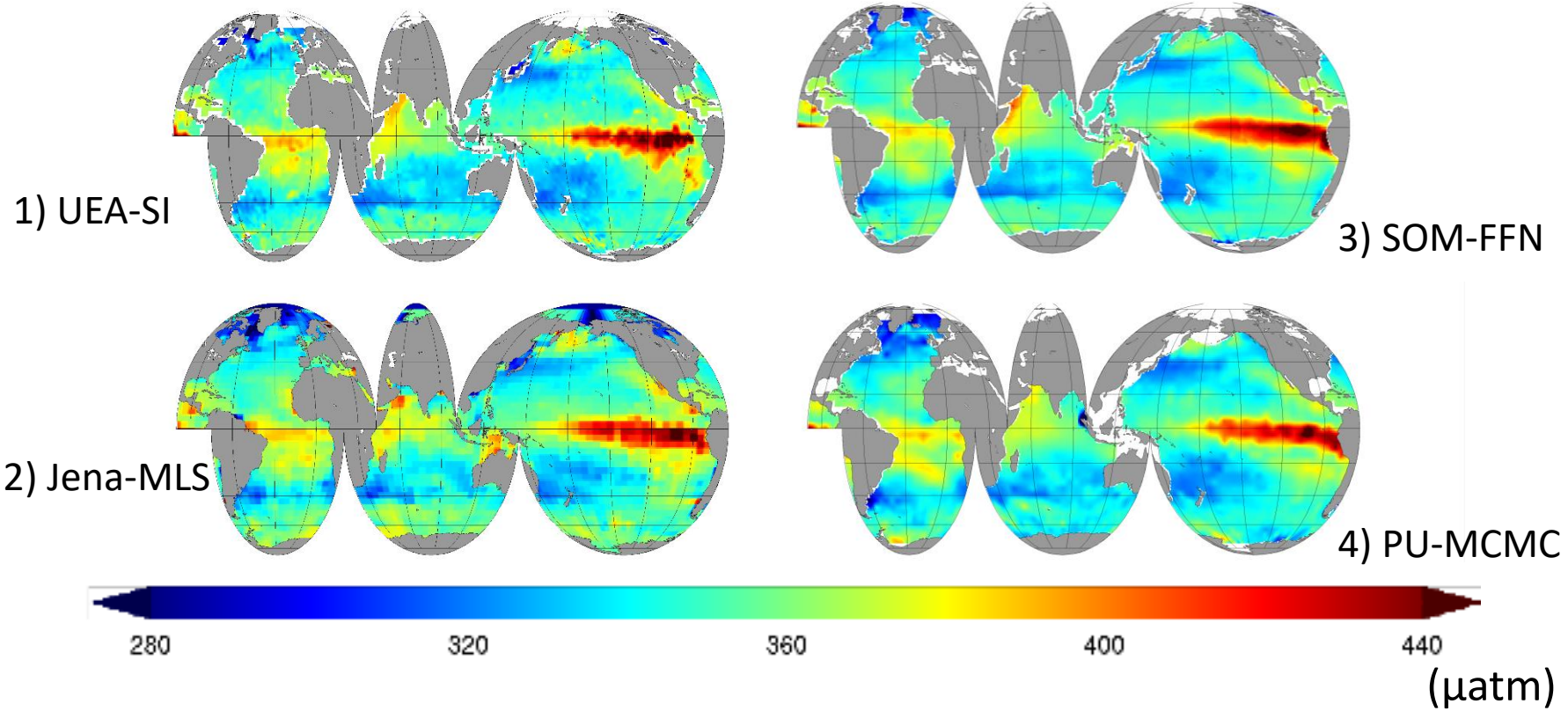
Air-sea CO_2 flux (C_{net})
(here 1998-2011)

Riverine carbon outgassing
0.45 ± 0.18 Pg C yr^{-1}

Anthropogenic ocean
carbon sink (C_{ant})

(Jacobson et al., 2007; Bakker et al., 2016; Landschützer et al., 2014; Rödenbeck et al., 2015)

Mean surface ocean pCO_2 (2000-2009)

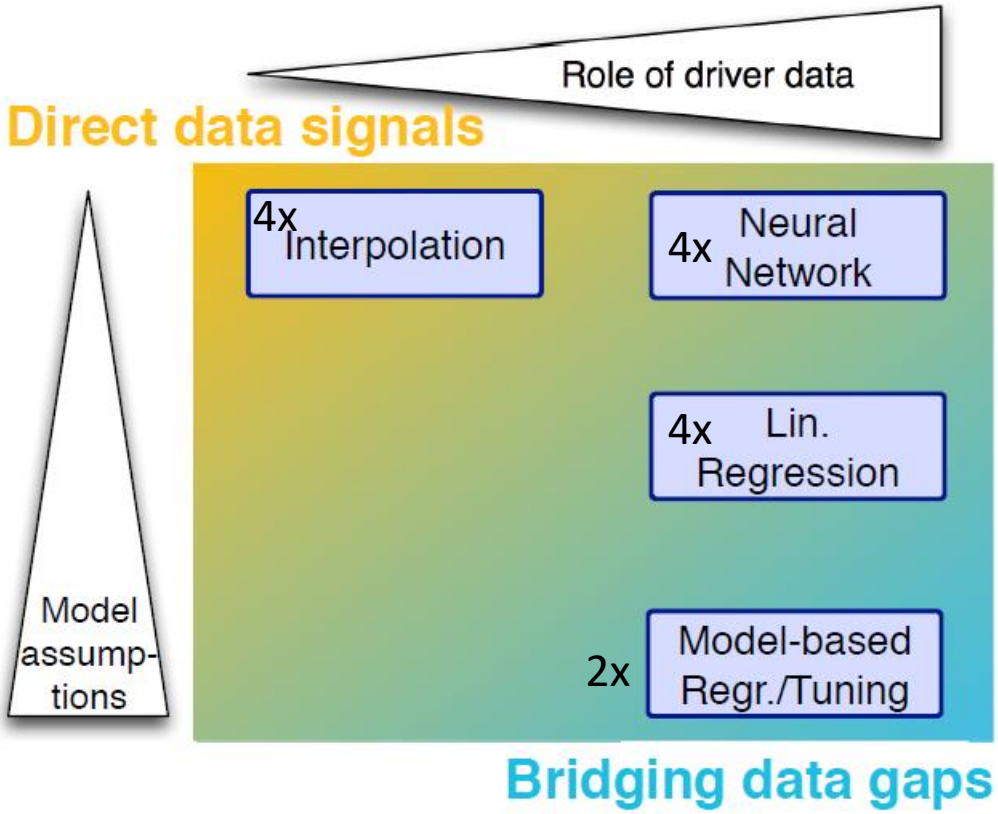


Uncertainties:

- Differences between methods,
- Methods often exclude the **Arctic Ocean** and **coastal seas** or treat coastal seas as open ocean.

(Rödenbeck et al., 2015 BG)

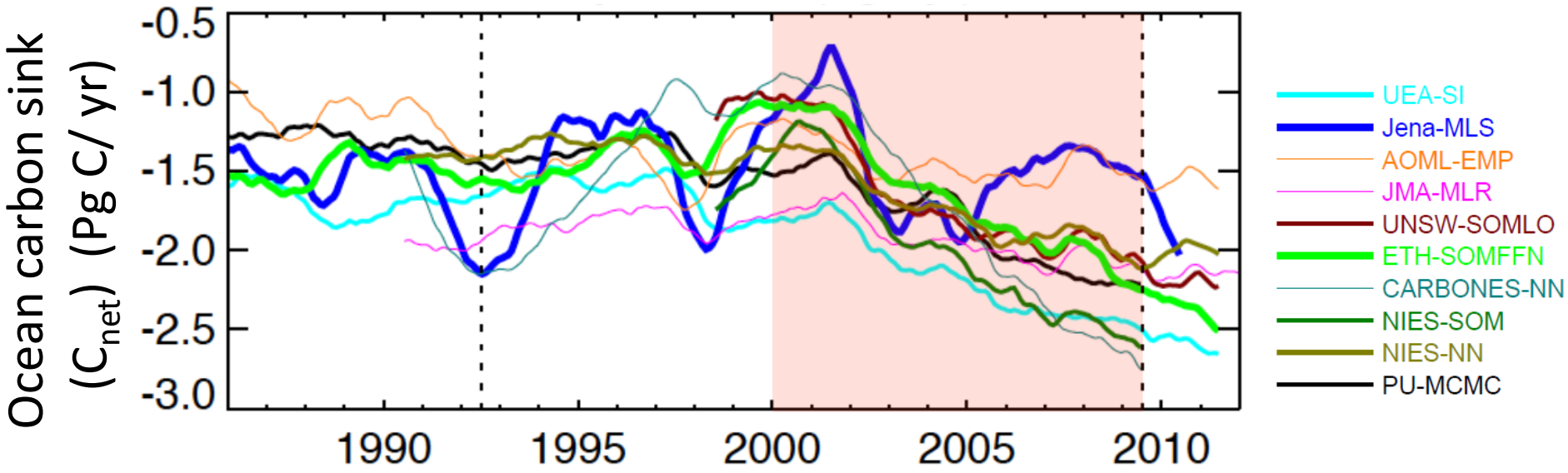
Surface Ocean pCO_2 Mapping intercomparison



- 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)

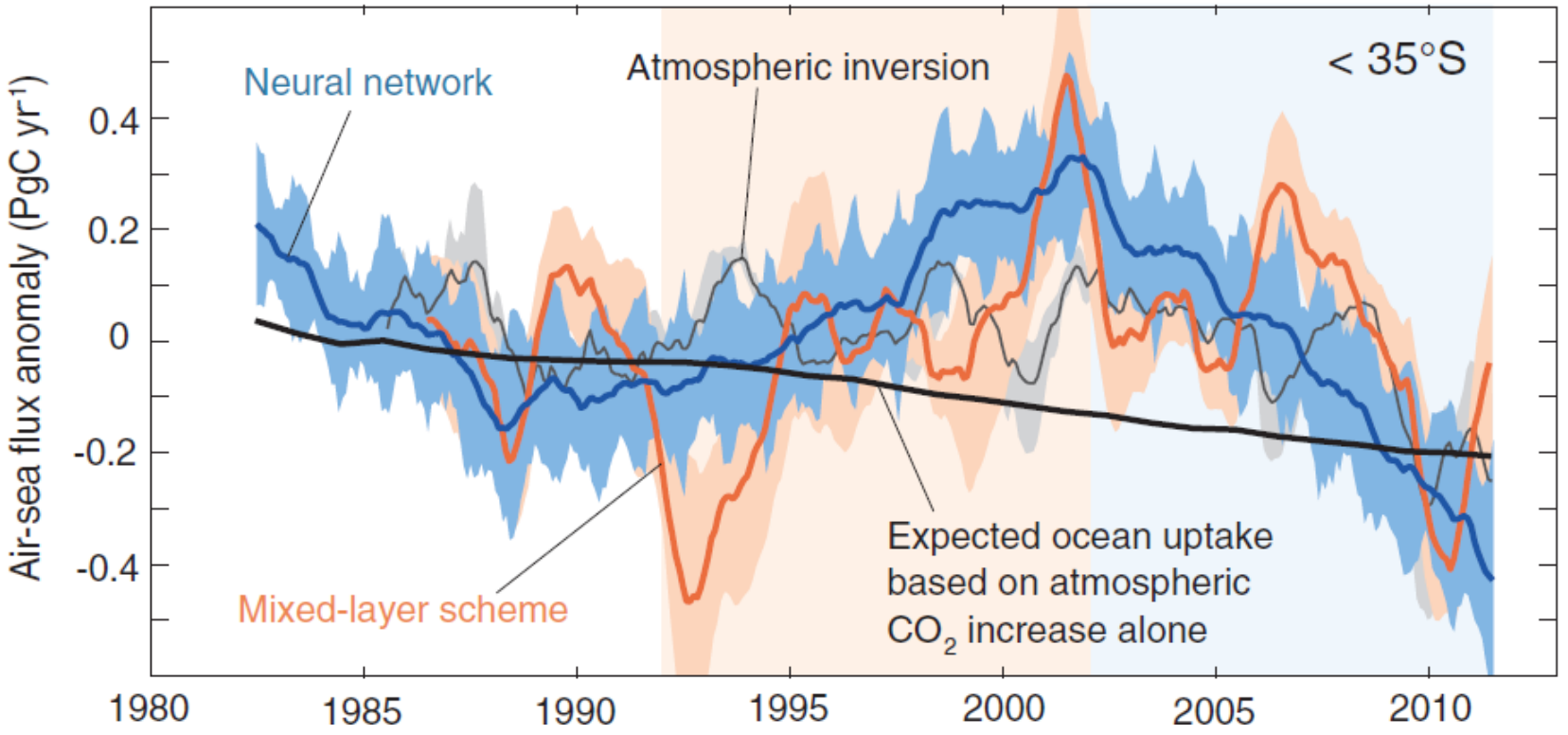
Global air-sea CO_2 fluxes (C_{net}) in 10 mapping methods



- Year-to-year and decadal variation in ocean carbon sink;
- Models underestimate this variation;
- Low decadal change before 2000, increasing sink after 2000;
- Ocean carbon sink estimates provide **priors for atmospheric inversion, thus aiding quantification of the land carbon sink.**

(Rödenbeck et al., 2015 BG)

Reinvigoration of the Southern Ocean carbon sink



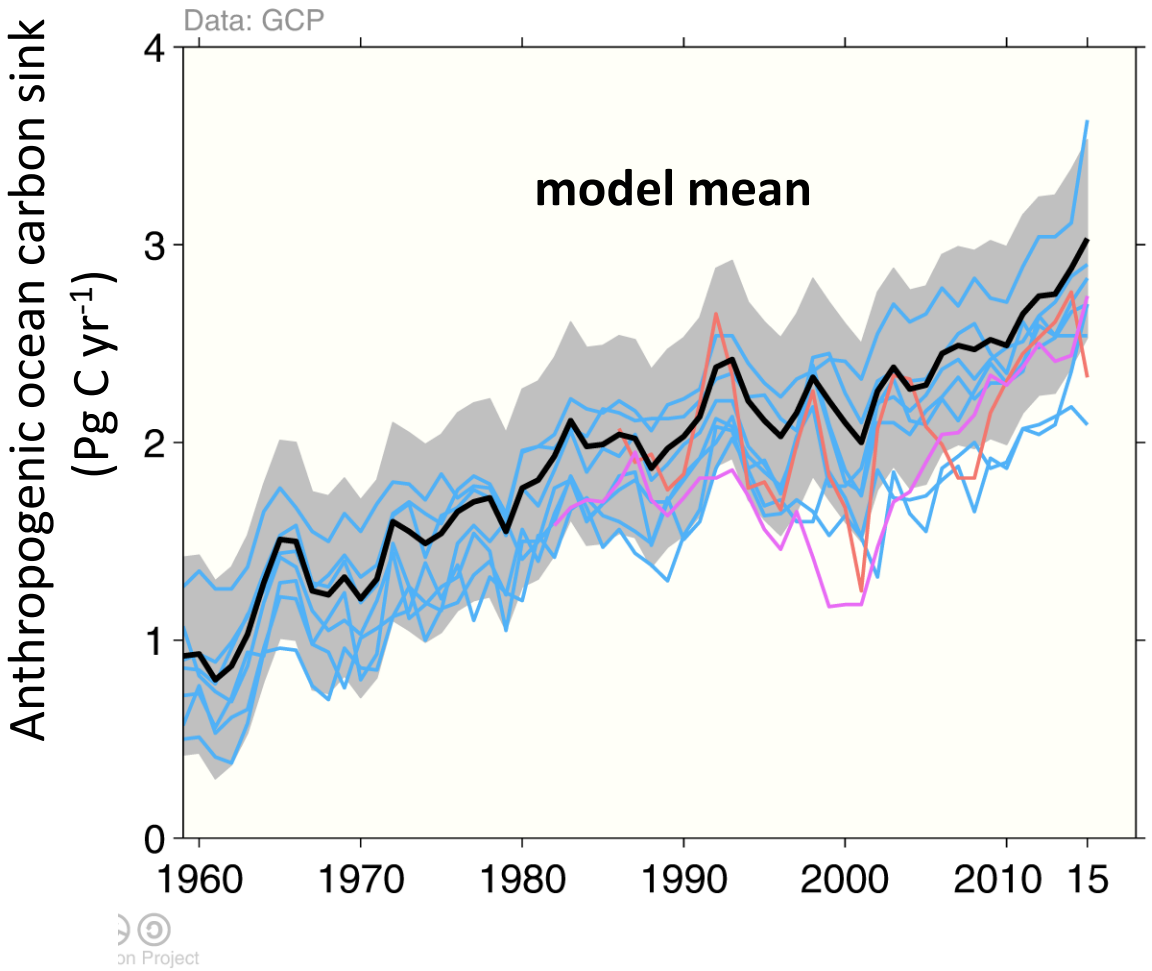
2 methods using SOCATv2 (NN, ML);

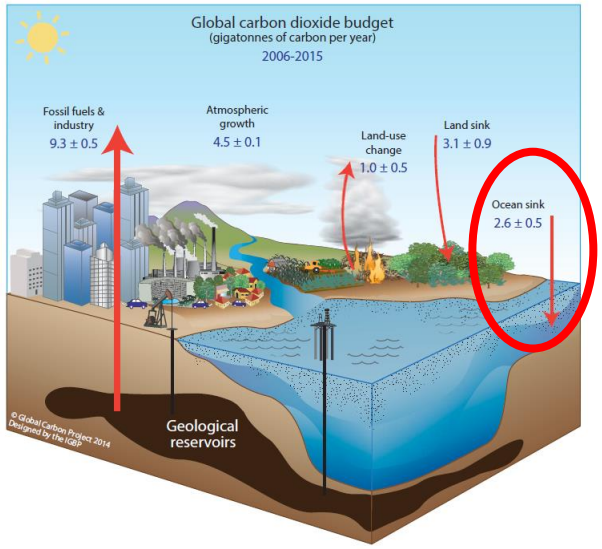
ΔpCO_2 trends dominate the sink variability;

ΔpCO_2 trends promote a sink increase of >0.5 PgC yr^{-1}.

(Landschützer et al., 2015, Science)

Global ocean carbon sink (C_{ant}) in the 2016 Global Carbon Budget

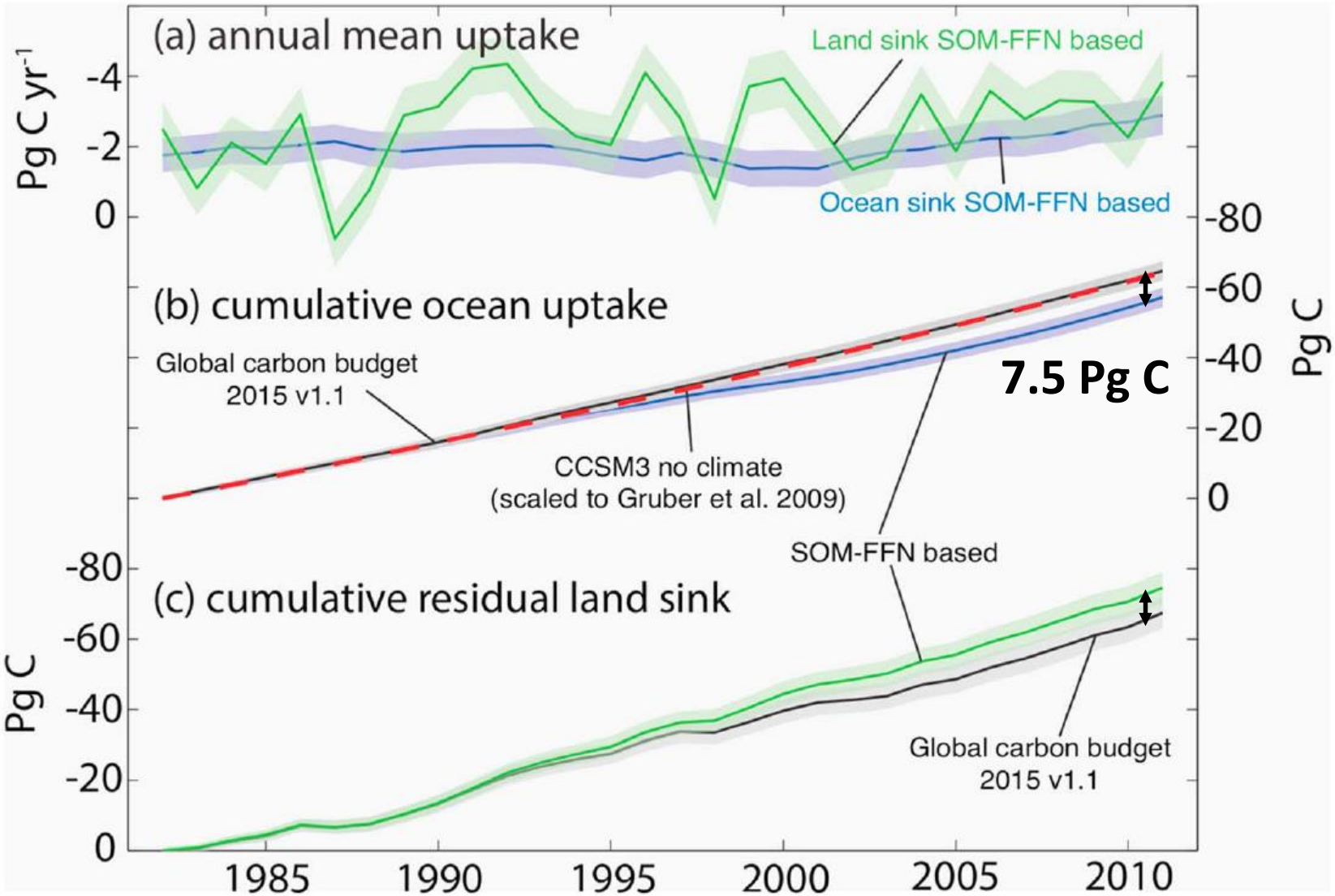




- 7 models anchored on an ocean carbon sink of 2.2 ± 0.4 PgC/yr (1990-1999);
- 2 data-based mapping methods (ML, NN) using SOCAT.

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

Ocean carbon sink (C_{ant}) informs on the land carbon sink



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

Surface ocean carbon observations

For:

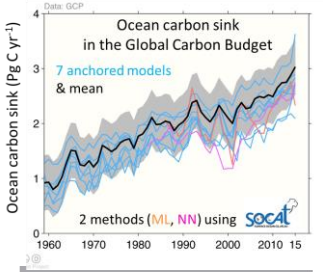
- **Quantification of the ocean carbon sink,** (variation, trends, **processes**),
- **Quantification of the land carbon sink,**
- **Evaluation of ocean carbon models** (Obs4MIP & ESMVal for IPCC),

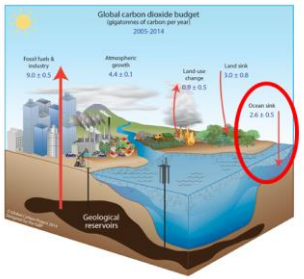
Findings:

- Year-to-year and decadal **variation** in the ocean carbon sink,
- Models underestimate this variation,

Challenges:

- Short data records,
- Data sparse regions,
- Mapping uncertainty,
- Riverine carbon outgassing (0.45 ± 0.18 Pg C yr^{-1}),
- Coastal ocean carbon sink (0.2 - 0.4 Pg C yr^{-1}),
- Arctic Ocean carbon sink (0.18 Pg C yr^{-1}),
- Role of sea ice (0.03 Pg C yr^{-1}),
- Gas transfer parameterisation, wind speed product (~6% flux, Schuster et al., poster 102)





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SOCAT at 10!
Version 5

SOCAT has >> 100 contributors and numerous funding agencies. Contribute to and/or use these products. Acknowledge the **contribution of the data providers**, e.g. by invitation to co-authorship, notably in **regional studies,** and by citation of relevant scientific publications.

User feedback essential.
Sustained funding for data collection and synthesis is key.
SOCAT discussion today at 13:00-14:00 – **All welcome**.

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SOCAT at 10!
Version 5

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