Requirements-driven Global Ocean Observing System for Biogeochemistry

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Masao Ishii, Kim Currie, Artur Palacz and Albert Fischer

with slides from Dorothee Bakker and Rik Wanninkhof

Biogeochemistry Panel

COP21: A UNIVERSAL AGREEMENT AND A FIRST FOR THE OCEAN

- After years of work and negotiations, the Paris Climate Agreement was signed on 12 December 2015, marking a historic moment for the Planet.
- For the first time, the mention of the ocean as an ecosystem vital for the climate is a symbolic victory for all involved advocates and stakeholders. Many organizations and individuals have worked for many years creating the momentum required for this recognition.
- Appearing in the preamble of the final text ***(“noting that it is important to ensure the integrity of all ecosystems, including oceans…”***) which is not however a binding part of the agreement, this reference is sign of a global awareness of the oceans’ major role in climate change. This awareness is also reflected at the level of heads of state and national delegations with the signing of the declaration ‘Because The Ocean’.

G 7 2016
ISE-SHIMA SUMMIT

The S&T Ministers of the G7 and the EU met in May 2016 to discuss science, technology and innovation aspects across global challenges such as health, energy, agriculture and the environment. They issued a Communiqué:

- Support the development of an initiative for **enhanced global sea and ocean observation** required to monitor inter alia climate change and marine biodiversity,
- Support an enhanced system of ocean assessment through the UN Regular Process to develop a consensus view on the state of the oceans and enable **sustainable management strategies** to be developed and implemented
- Promote open science and the improvement of the global data sharing infrastructure to ensure the discoverability, accessibility, and interoperability of a wide range of ocean and marine data;
- Strengthen collaborative approaches to encourage the development of **regional observing capabilities** and knowledge networks in a coordinated and coherent way, including supporting the capacity building of developing countries; and
- Promote increased G7 political cooperation by identifying additional actions needed to enhance **future routine ocean observations**.

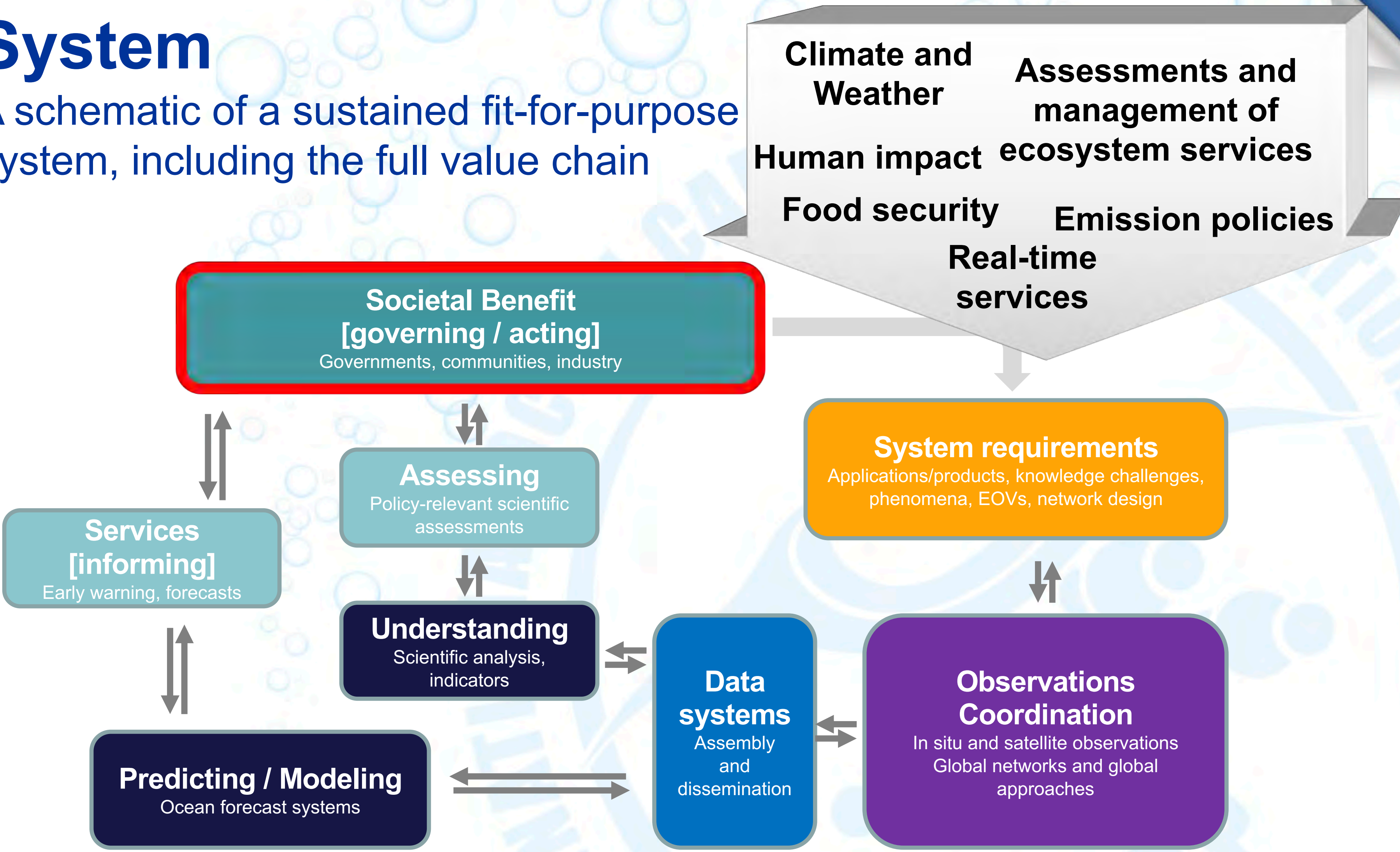
United Nations
Educational, Scientific and
Cultural Organization

Intergovernmental
Oceanographic
Commission

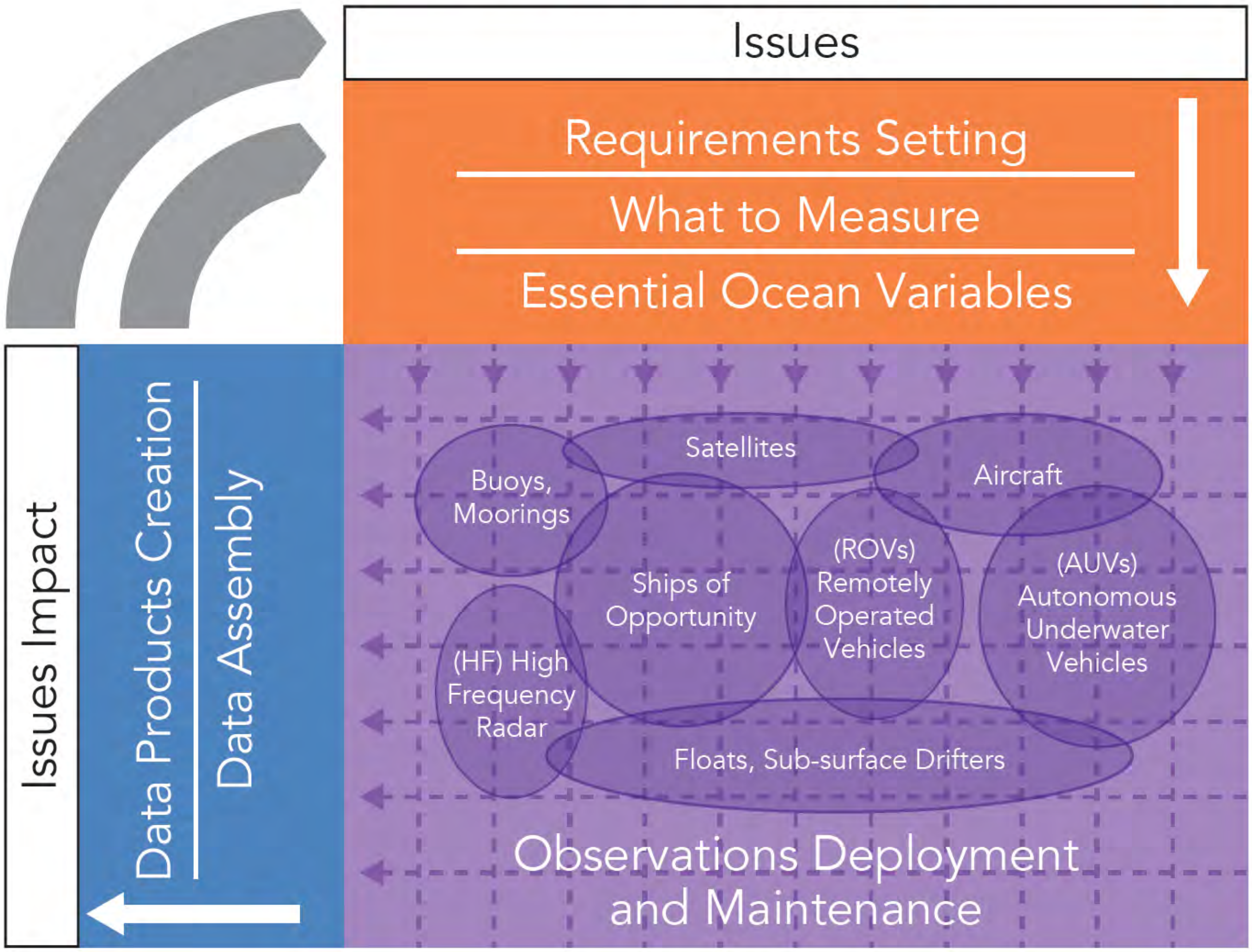
17 objectives to transform our world: Agenda 2030 (September 2015, New York)

System

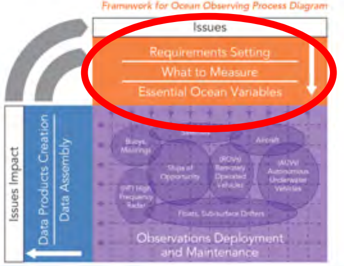
A schematic of a sustained fit-for-purpose system, including the full value chain



Framework for Ocean Observing Process Diagram

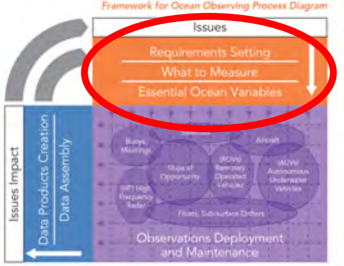


Requirements for GOOS Biogeochemistry



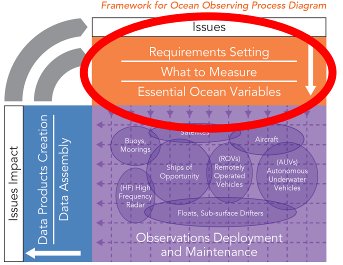
- **The role of ocean biogeochemistry in climate**
  - **Q1.1 How is the ocean carbon content changing?**
  - **Q1.2 How does the ocean influence cycles of non-CO_2 greenhouse gases?**
- **Human impacts on ocean biogeochemistry**
  - **Q2.1. How large are the ocean's "dead zones" and how fast are they changing?**
  - **Q2.2 What are rates and impacts of ocean acidification?**
- **Ocean ecosystem health**
  - **Q3.1 Is the biomass of the ocean changing?**
  - **Q3.2 How does eutrophication and pollution impact ocean productivity and water quality?**

GOOS Phenomena - Biogeochemistry



- Anthropogenic Carbon Sequestration
- Air-sea Fluxes
- Land-sea Fluxes
- Ventilation
- Ocean Acidification
- Eutrophication
- Circulation
- Deoxygenation
- Contamination /Pollution
- Primary Production
- Upwelling
- Benthic Fluxes
- Reminerali-zation
- Storage / Inventory
- Export Fluxes
- Calcification

GOOS Essential Ocean Variables



Physics & Climate

- Sea State
- Ocean Surface Stress
- Sea Ice
- Sea Surface Height
- Sea Surface Temperature
- Subsurface Temperature
- Surface Currents
- Subsurface Currents
- Sea Surface Salinity
- Subsurface Salinity
- Ocean Surface Heat Flux

Biogeochemistry

- Oxygen
- Nutrients
- Inorganic Carbon
- Transient Tracers
- Particulate Matter
- Nitrous Oxide
- Stable Carbon Isotopes
- Dissolved Organic Carbon
- Ocean Colour

Biology & Ecosystems

- Phytoplankton Biomass & Diversity
- Zooplankton Biomass & Diversity
- Fish Abundance & Distribution
- Marine Turtles, Birds, Mammals Abundance & Distribution
- Hard Coral Cover & Composition
- Seagrass Cover
- Macroalgal Canopy
- Mangrove Cover
- Microbe Biomass & Diversity
- Benthic Invertebrate Abundance & Distribution

Emerging EOVs (Microbe Biomass & Diversity; Benthic Invertebrate Abundance & Distribution)

EOV Specification Sheets:
www.goosocean.org/eov
www.ioccp.org/foo

GOOS

GLOBAL OCEAN OBSERVING SYSTEM

www.ioc-goos.org

The oceans are the basis of the life support system. GOOS measures ocean warming and provides an opportunity for the human system to respond.

IOC

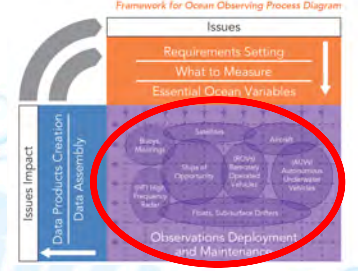
WMO

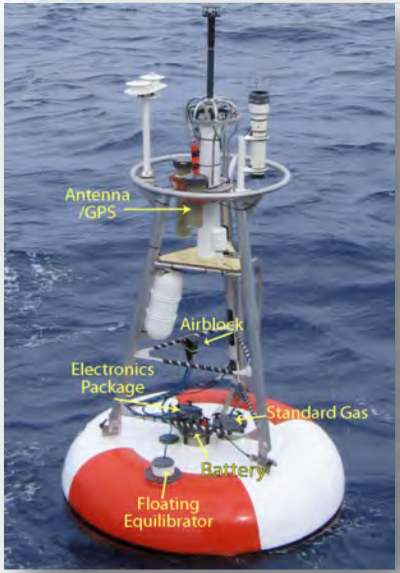
UNEP

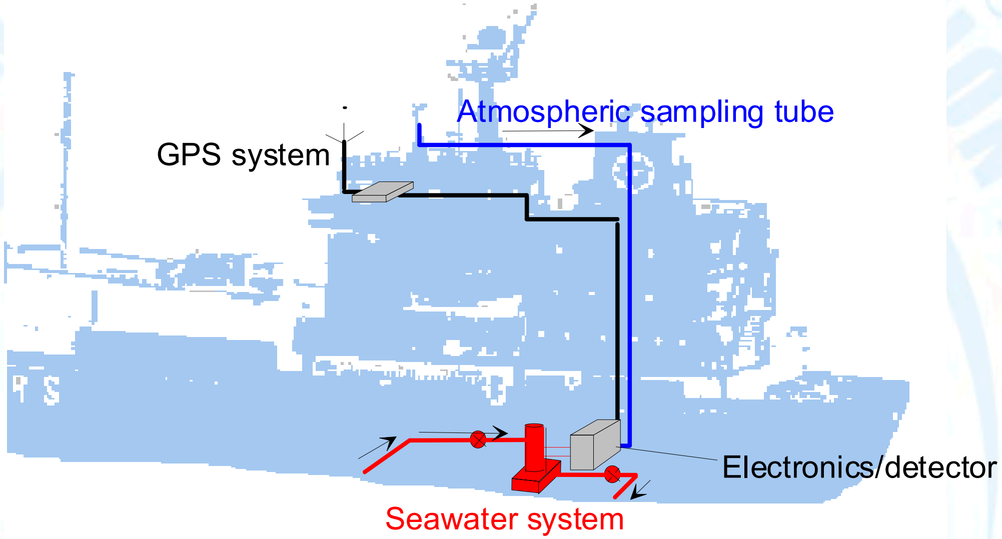
ICSU

soconet

SURFACE OCEAN CO_2 OBSERVING NETWORK



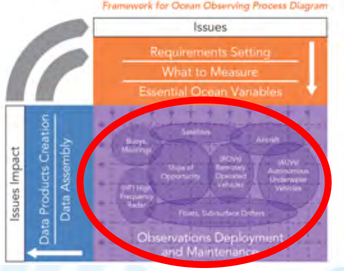




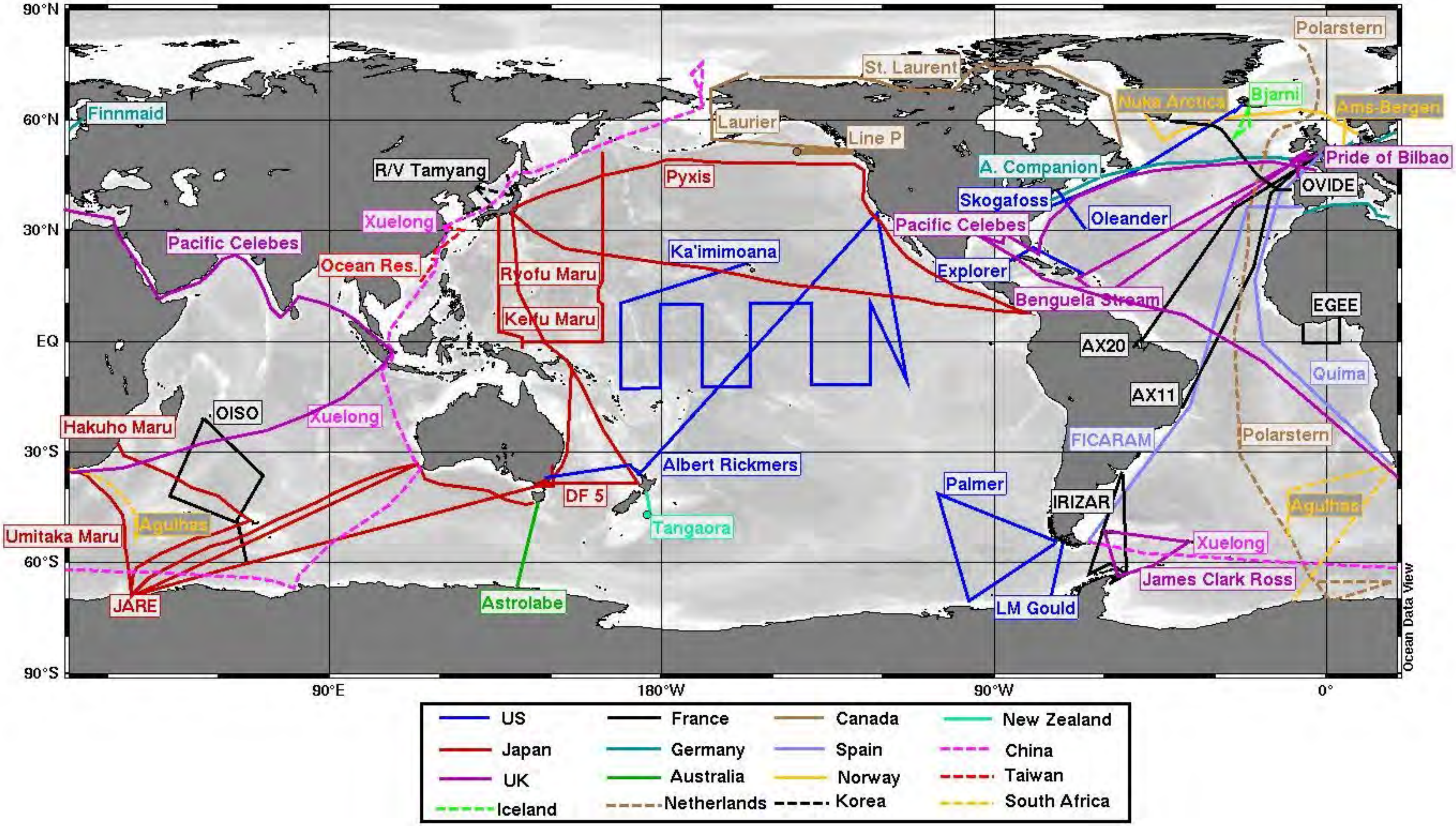
SOCONET:

- **Surface ocean CO_2 measurements** from moving and fixed platforms (With other parameters in concept and pilot phase pH, TA, DIC);
- **Atmospheric CO_2** from some data originators (discussions with GAW);
- Checked sea surface temperature and salinity as well as other BGC parameters (oxygen, nutrients)

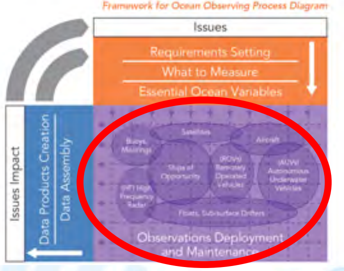
soconet
· SURFACE OCEAN CO_2 OBSERVING NETWORK ·

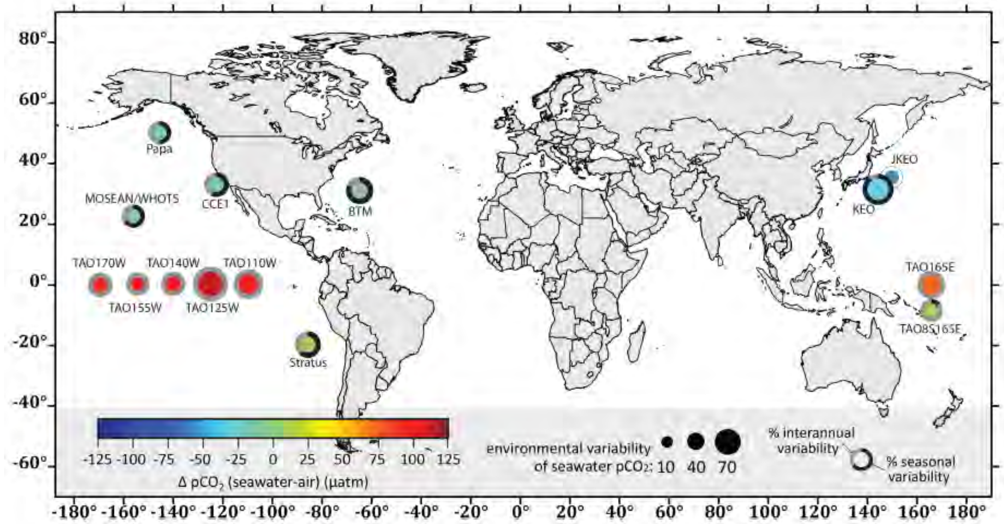


Underway CO_2 Observations



soconet
· SURFACE OCEAN CO_2 OBSERVING NETWORK ·

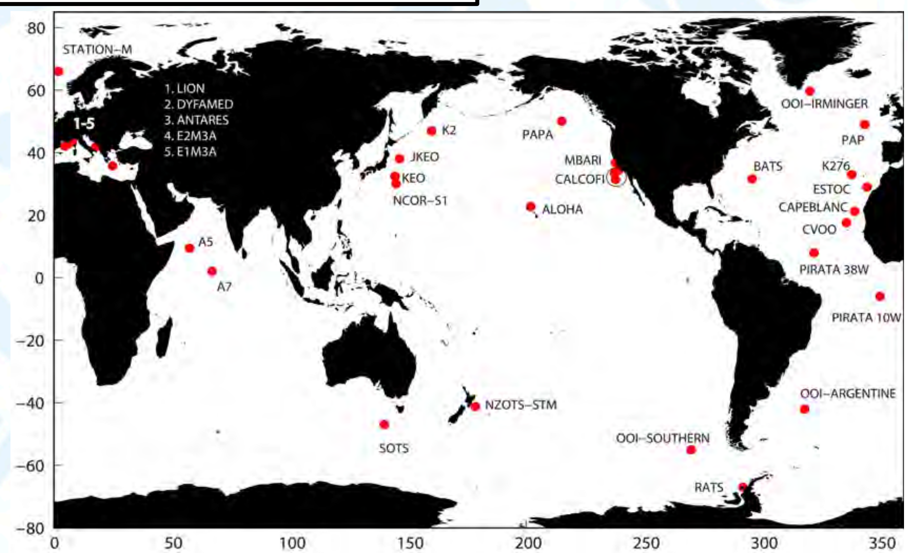




MapCO$_2$ sites (Sutton et al. 2014)

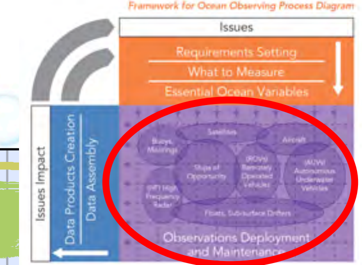
Biogeochemical Time Series

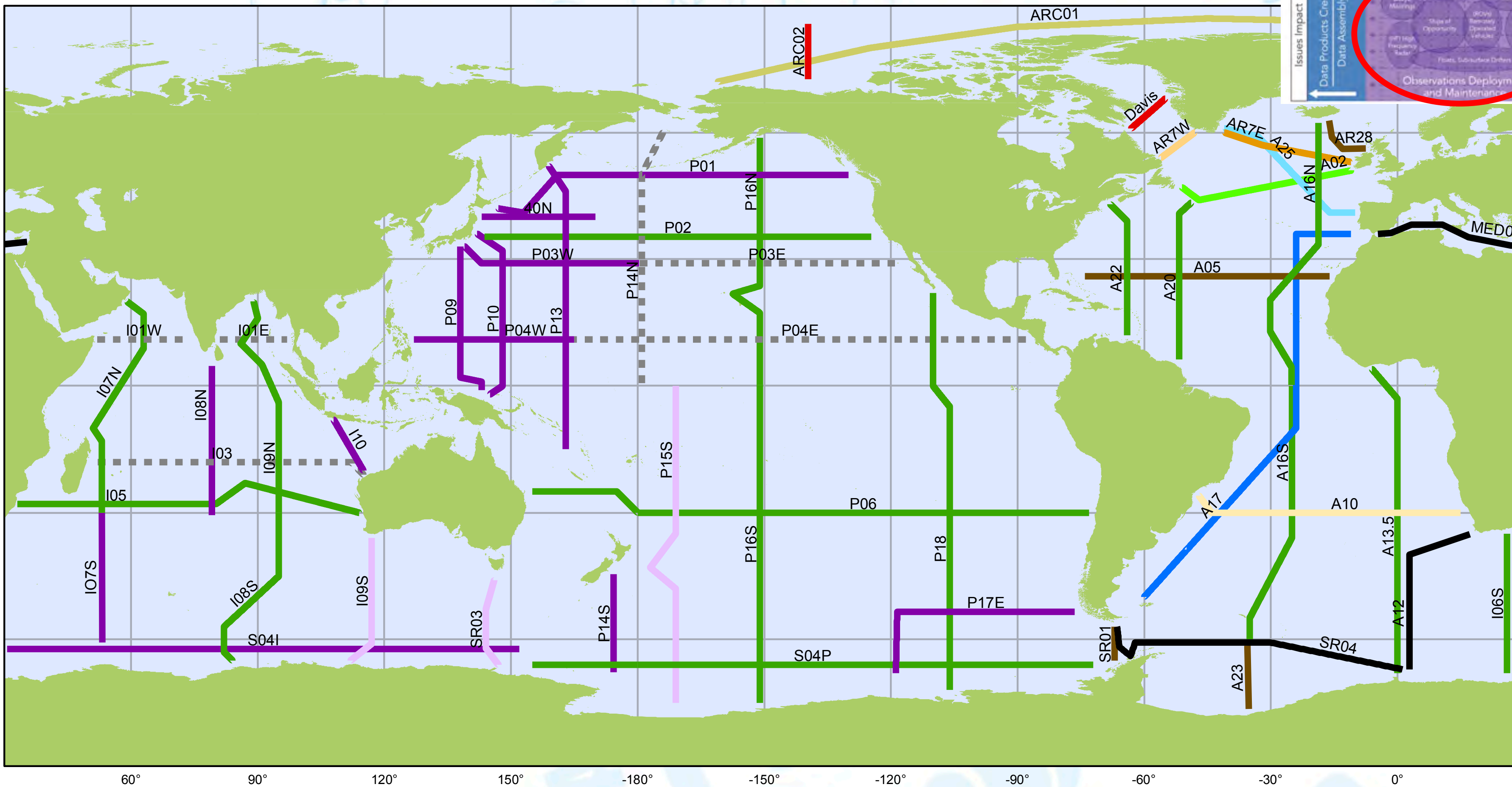
BGC OceanSITES (Henson et al. (2016))



Interior Ocean Observations

(GO-SHIP, The Global Ocean Ship-based Hydrographic Investigations Program)



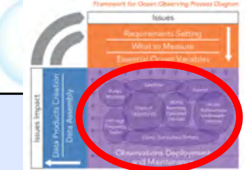


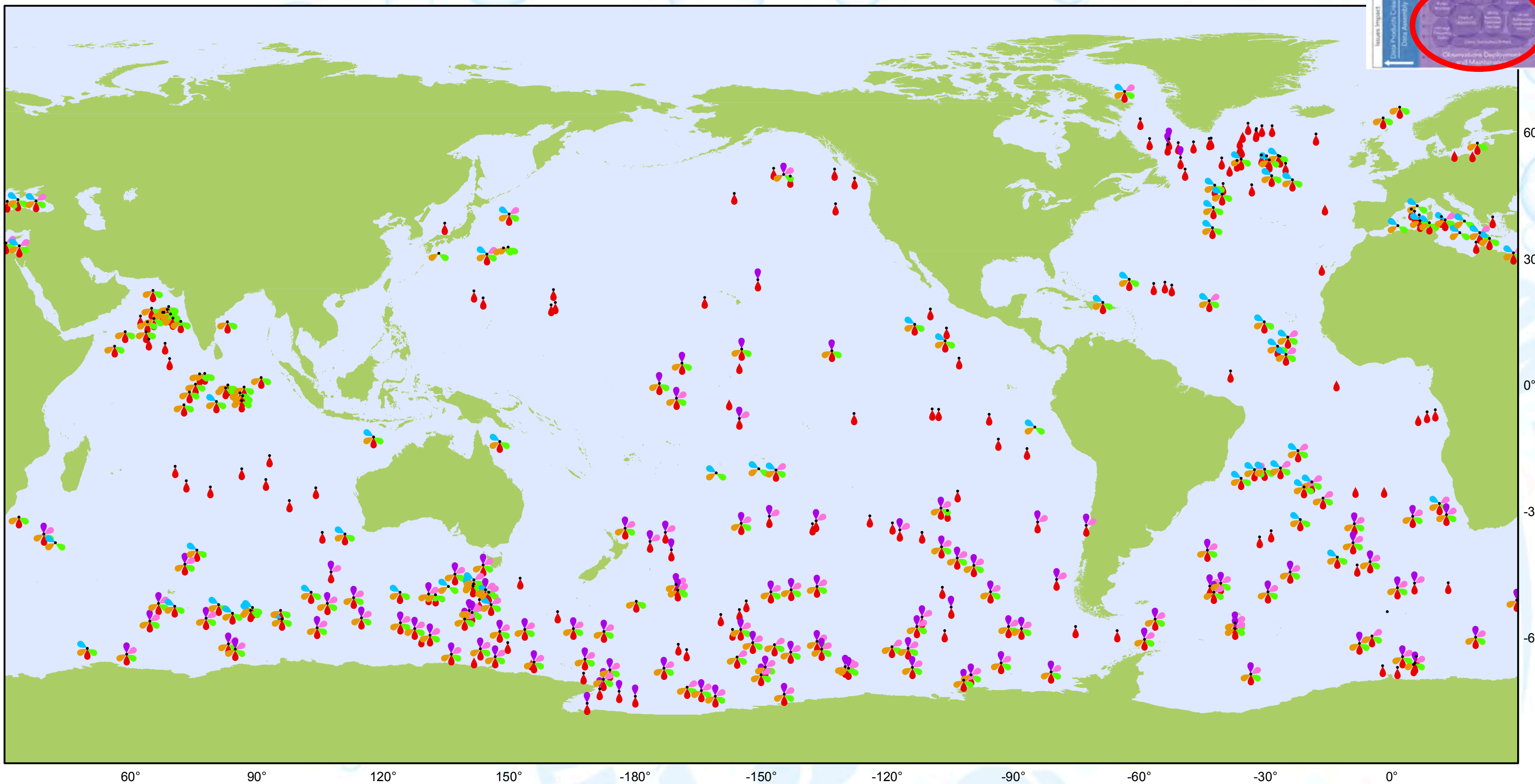
2012-2023 Survey (55 Core Lines): Lines by Nation

October 2018

AUS
CAN-USA
CAN-UK
ESP
FRA-ESP
GER
IRE
JAP
NOR
NOR-UK
UK
USA
USA-GER
USA-UK-GER
nil

Generated by www.jcommops.org, 16-Oct-18





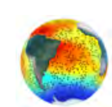
biogeochemical Argo

Sensor Types

Latest location of operational floats (data distributed within the last 30 days)

September 2018

- Operational Floats (329)
- Suspended particles (208)
- Downwelling irradiance (70)
- pH (117)
- Nitrate (131)
- Chlorophyll a (208)
- Oxygen (333)



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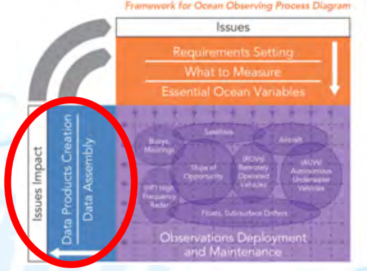
Biogeochemistry Data Management



NOAA National Centers for Environmental Information
Ocean CO2 CDIAC
CCHDO
Bjerknes Centre for Climate Research
BCDC Bjerknes Climate Data Centre
BCO-DMO Biological & Chemical Oceanography Data Management Office

International Ocean Carbon Coordination Project IOCCP
GOA-ON Global Ocean Acidification Observing Network
IMBeR
solas

ICOS Ocean Thematic Centre
IOOS Integrated Ocean Observing System
FixO3 Fixed-Point Open Ocean Observatories

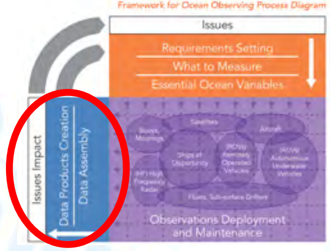
The Global Ocean Observing System GOOS
UNESCO United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission
WMO
jcommops

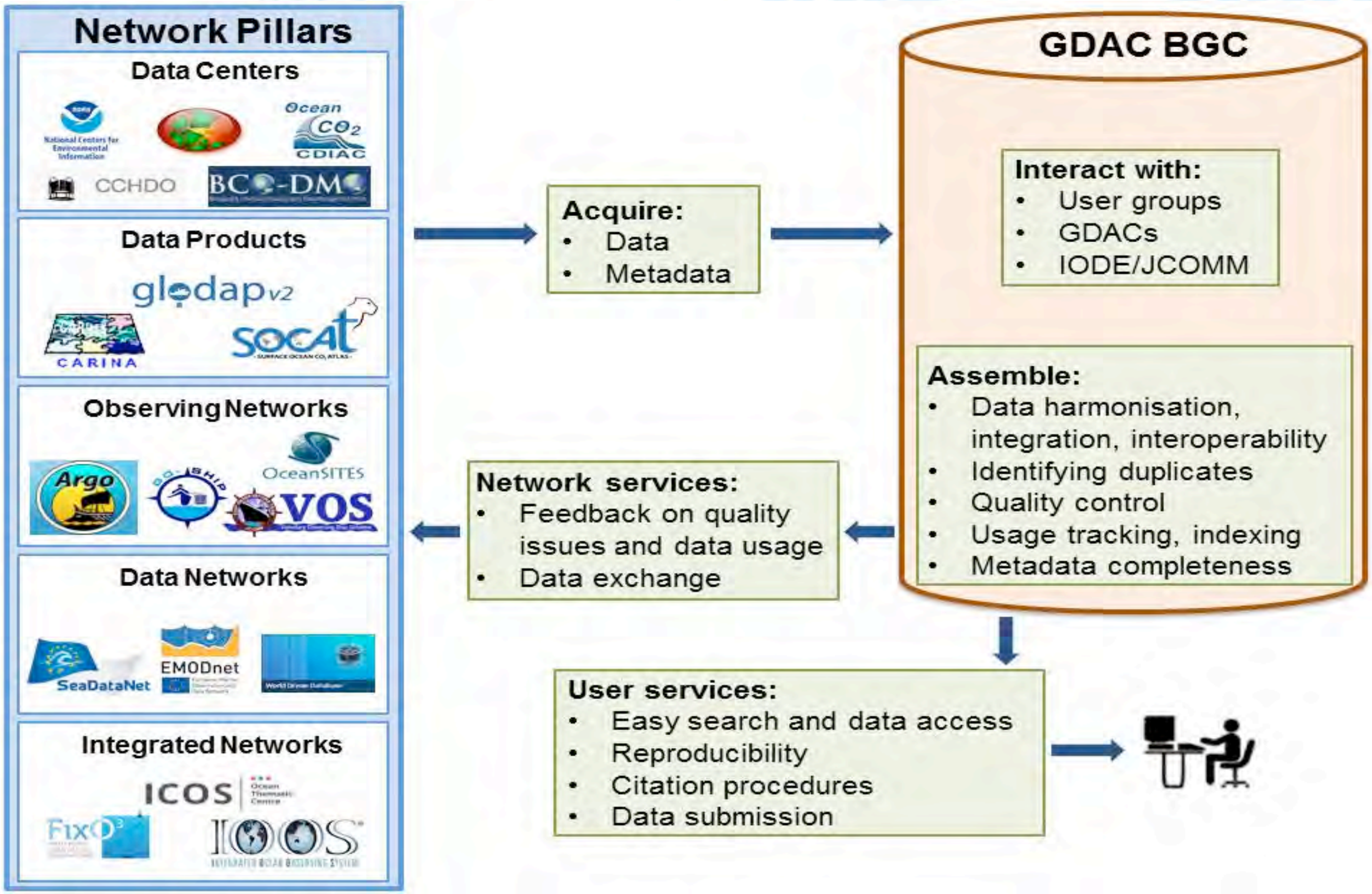
GO-SHIP
OceanSITES
Argo
VOS Voluntary Observing Ship Scheme
Ship Observations Team JCOMM

SeaDataNet
EMODnet European Marine Observation and Data Network
World Ocean Database
GEO

SOCAT Surface Ocean CO_2 Atlas
glodap v2

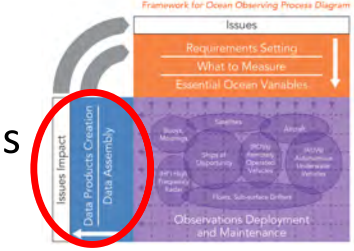
Global Data Assembly Centre for Marine Biogeochemistry

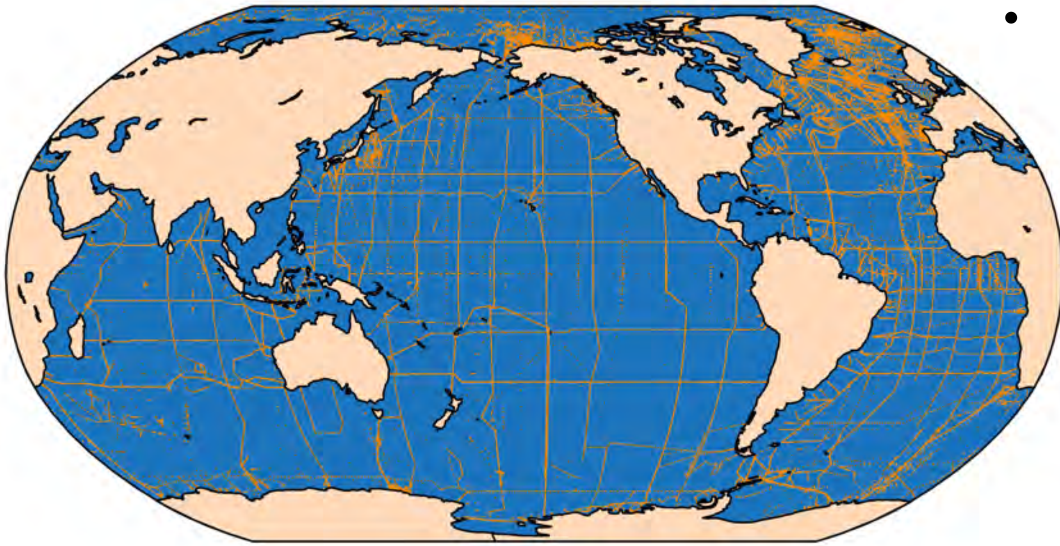




glodap v2

- A global collection of CO_2 relevant data from 724 cruises
- 45 306 stations
- 999 488 sampling depths
- 1972 -2013 GEOSECS-TTO-WOCE-CLIVAR
- Corrected for biases
- Extensively documented





Earth Syst. Sci. Data, 8, 297–323, 2016
www.earth-syst-sci-data.net/8/297/2016/
doi:10.5194/essd-8-297-2016

Open Access Earth System Science Data

The Global Ocean Data Analysis Project version 2 (GLODAPv2) – an internally consistent data product for the world ocean

Are Olsen[1], Robert M. Key[2], Steven van Heuven[3], Siv K. Lauvset[1,4], Anton Velo[5], Xiaohua Lin[2], Carsten Schirnick[6], Alex Kozyr[7], Toste Tanhua[6], Mario Hoppema[8], Sara Jutterström[9], Reiner Steinfeldt[10], Emil Jeansson[4], Masao Ishii[11], Fiz F. Pérez[5], and Toru Suzuki[12]

Earth Syst. Sci. Data, 8, 325–340, 2016
www.earth-syst-sci-data.net/8/325/2016/
doi:10.5194/essd-8-325-2016

Open Access Earth System Science Data

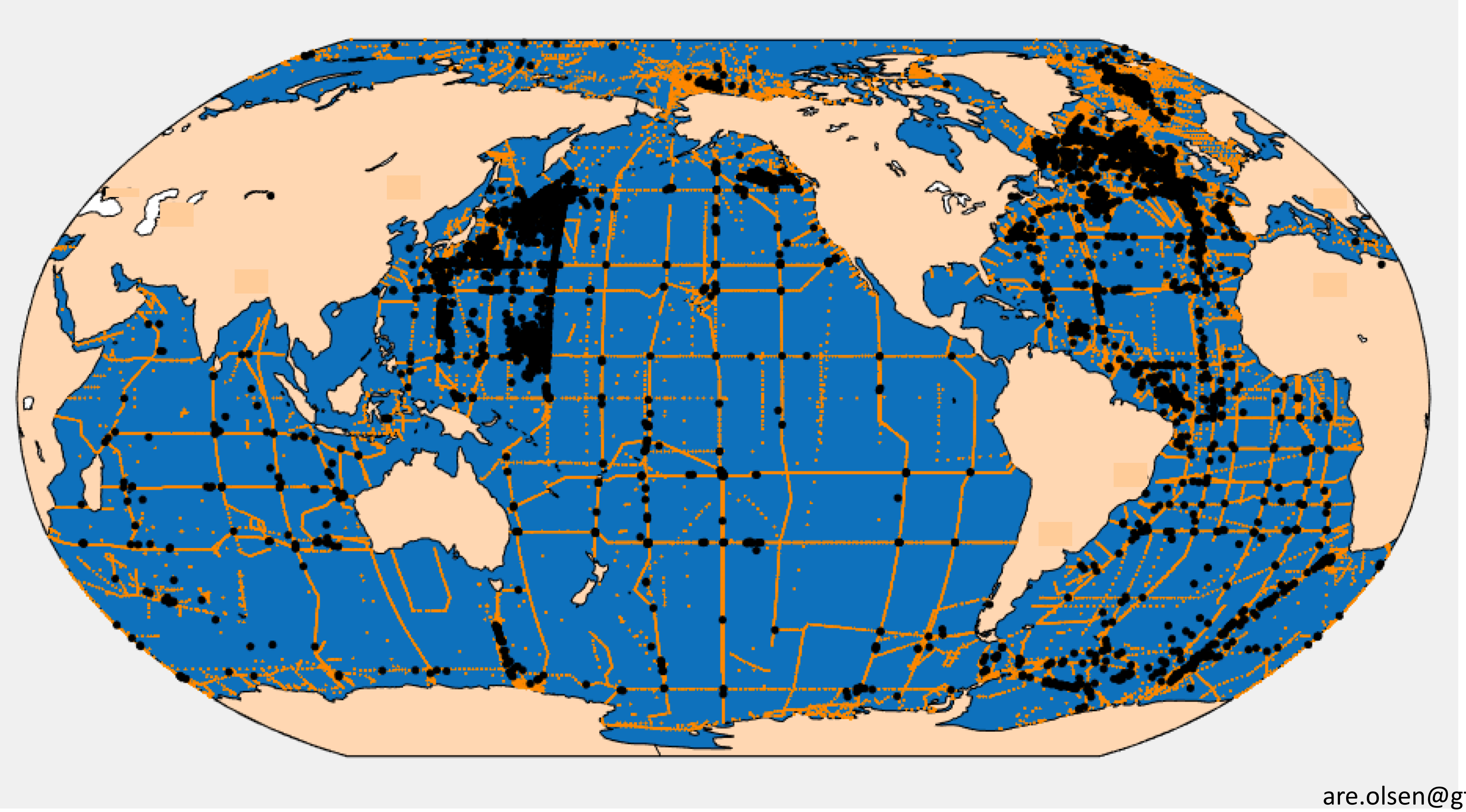
A new global interior ocean mapped climatology: the 1° × 1° GLODAP version 2

Siv K. Lauvset[1,2], Robert M. Key[3], Are Olsen[1,2], Steven van Heuven[4], Anton Velo[5], Xiaohua Lin[3], Carsten Schirnick[6], Alex Kozyr[7], Toste Tanhua[6], Mario Hoppema[8], Sara Jutterström[9], Reiner Steinfeldt[10], Emil Jeansson[2], Masao Ishii[11], Fiz F. Perez[5], Toru Suzuki[12], and Sylvain Watelet[13]

glodap v2

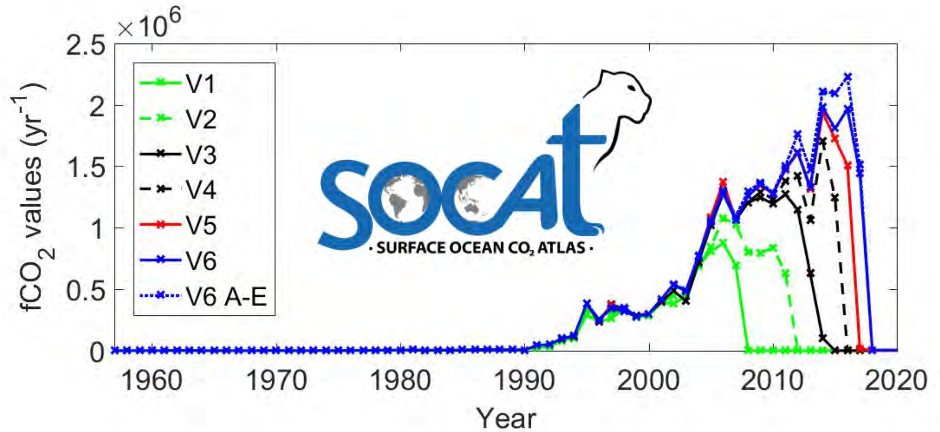
1. Assembled original data from GLODAPv1, CARINA and PACIFICA and data from 168 new cruises at a single access point.

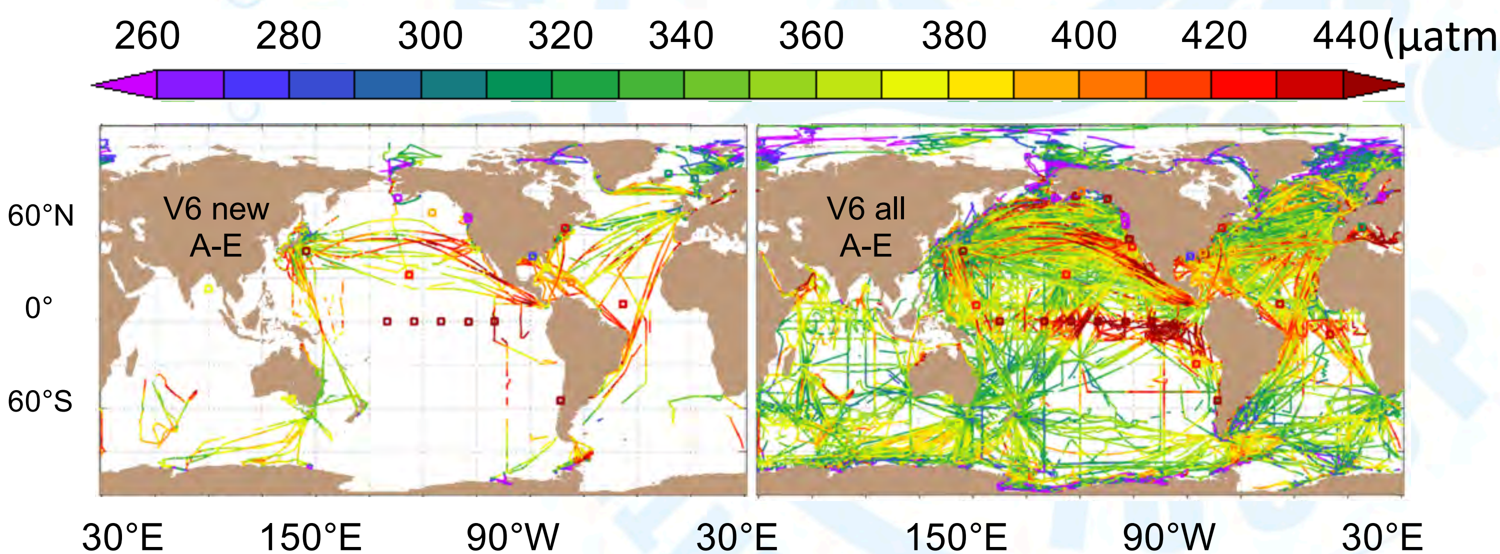
2. Analyse consistency (of S, O_2, Nitr, Si, Phos, DIC, Talk, pH) by comparing data from different cruises using crossover and inversion approach and applied corrections generating a globally consistent data product.



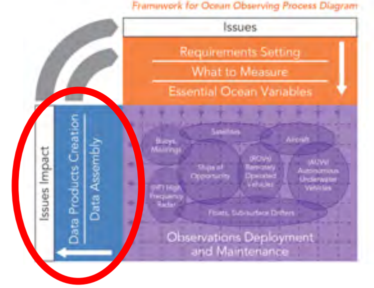
are.olsen@gfi.uib.no

Surface Ocean CO_2 Atlas version 6
23 million in situ surface ocean CO_2 observations





www.socat.info

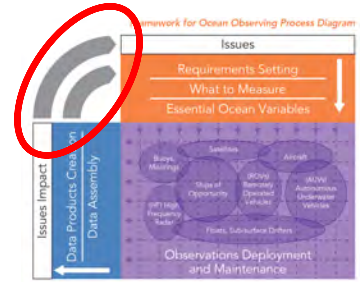


Global synthesis and gridded products of surface ocean fCO_2

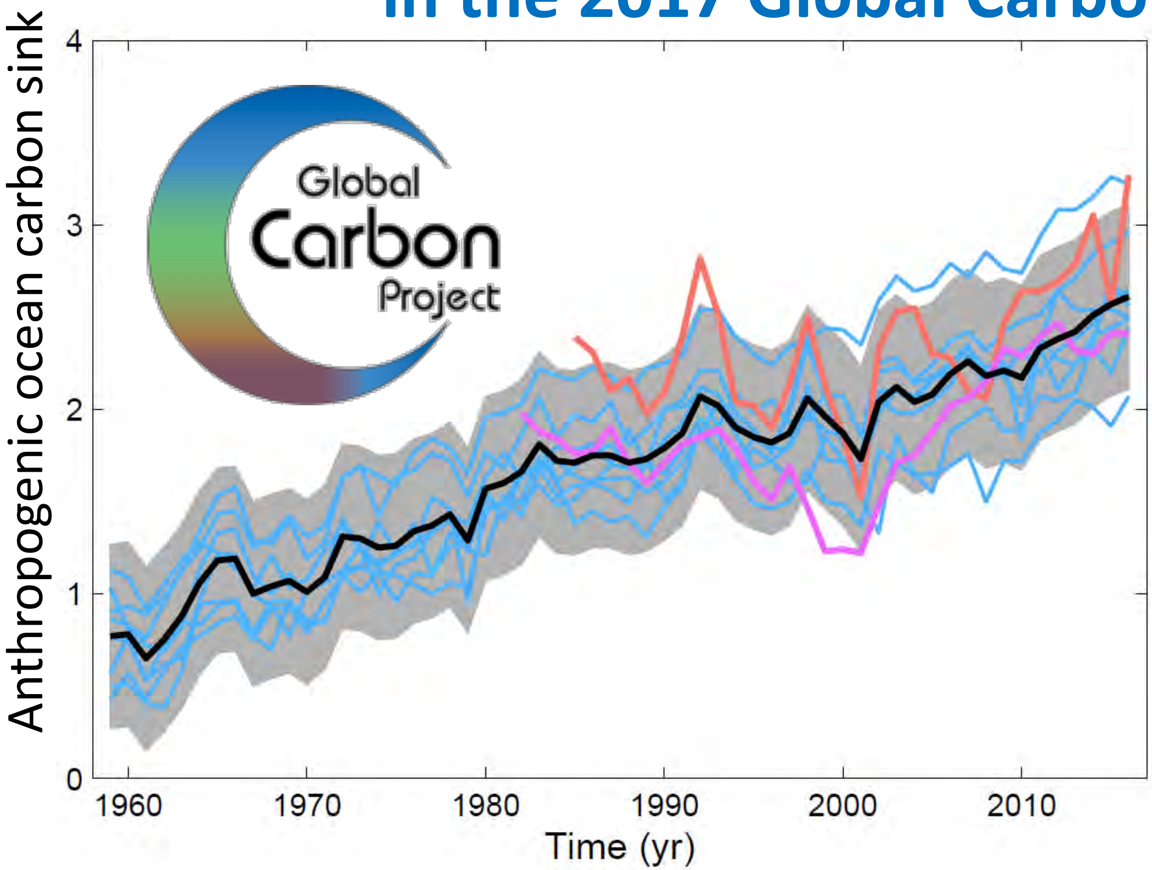
- (fugacity of CO_2) in uniform format with quality control;
- No gap filling; Annual public releases;
- V6: 23.4 million fCO_2 values from 1957-2017, accuracy < 5 µatm (flags A-D);
- Plus 1.2 million calibrated sensor data (< 10 µatm, flag E);
- Access via online viewers and data dowload (text, NetCDF, ODV)
- Consistent and documented quality control;
- Documented in ESSD articles;
- Fair Data Use Statement;
- Community activity with >100 contributors worldwide.

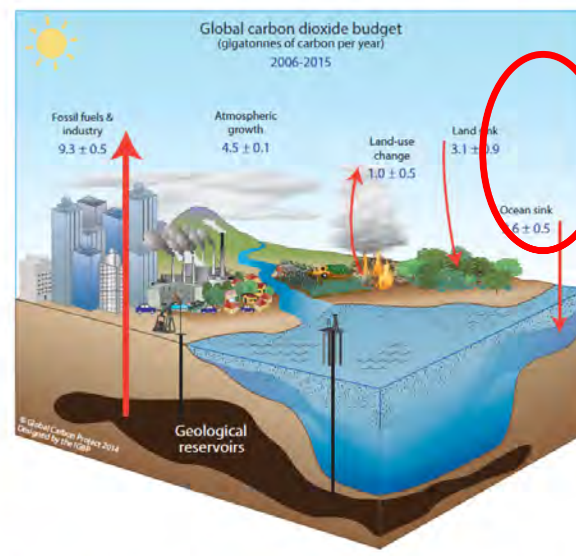
(**Pfeil et al., 2013; Sabine et al., 2013; Bakker et al., 2014, 2016, all in ESSD**)

Applications



Global ocean carbon sink (C_{ant}) in the 2017 Global Carbon Budget

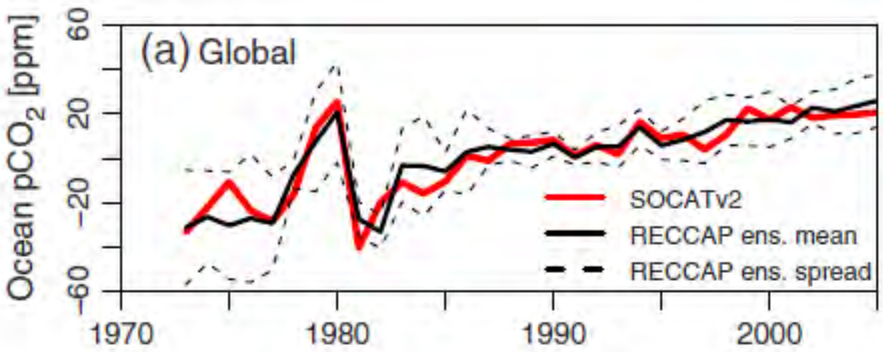


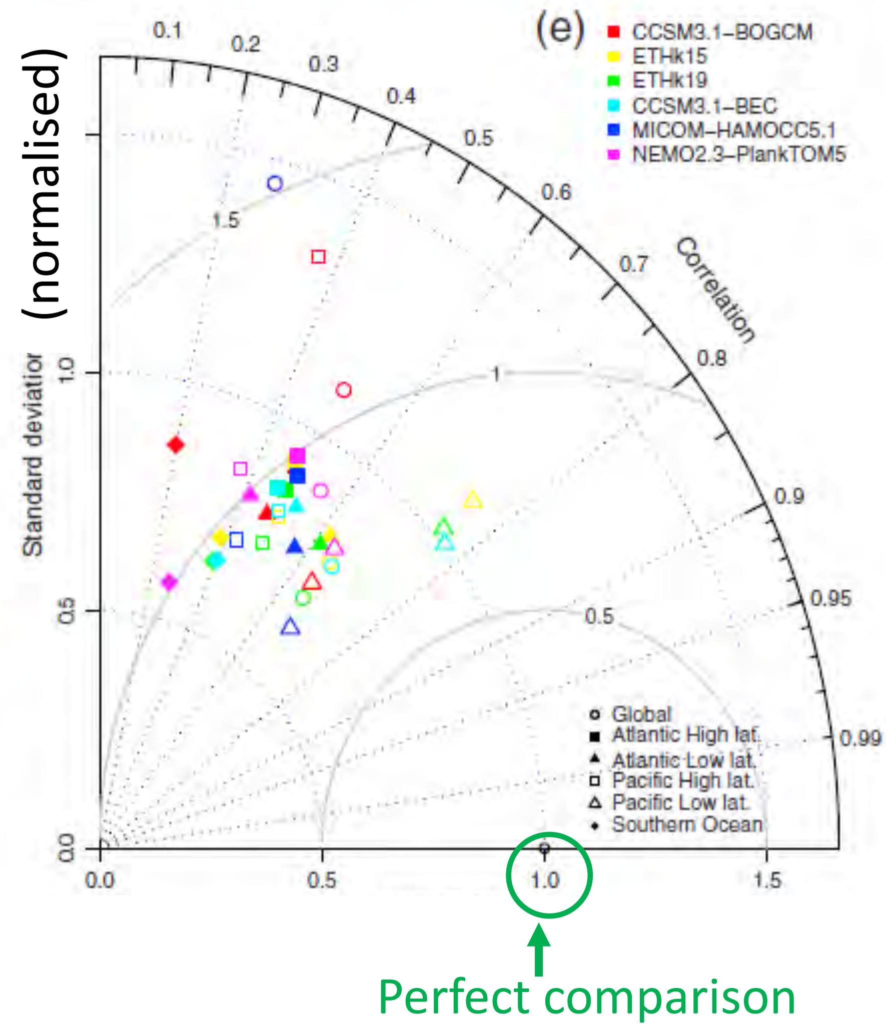


Anthropogenic ocean carbon uptake in the 2017 Global Carbon Budget. Shown are SOCAT-based mapping results (pink[b], orange[g] lines), model results (blue lines), the model ensemble mean (black) and model uncertainty (grey shading).

Figure from Le Quéré et al., 2018.

Model evaluation



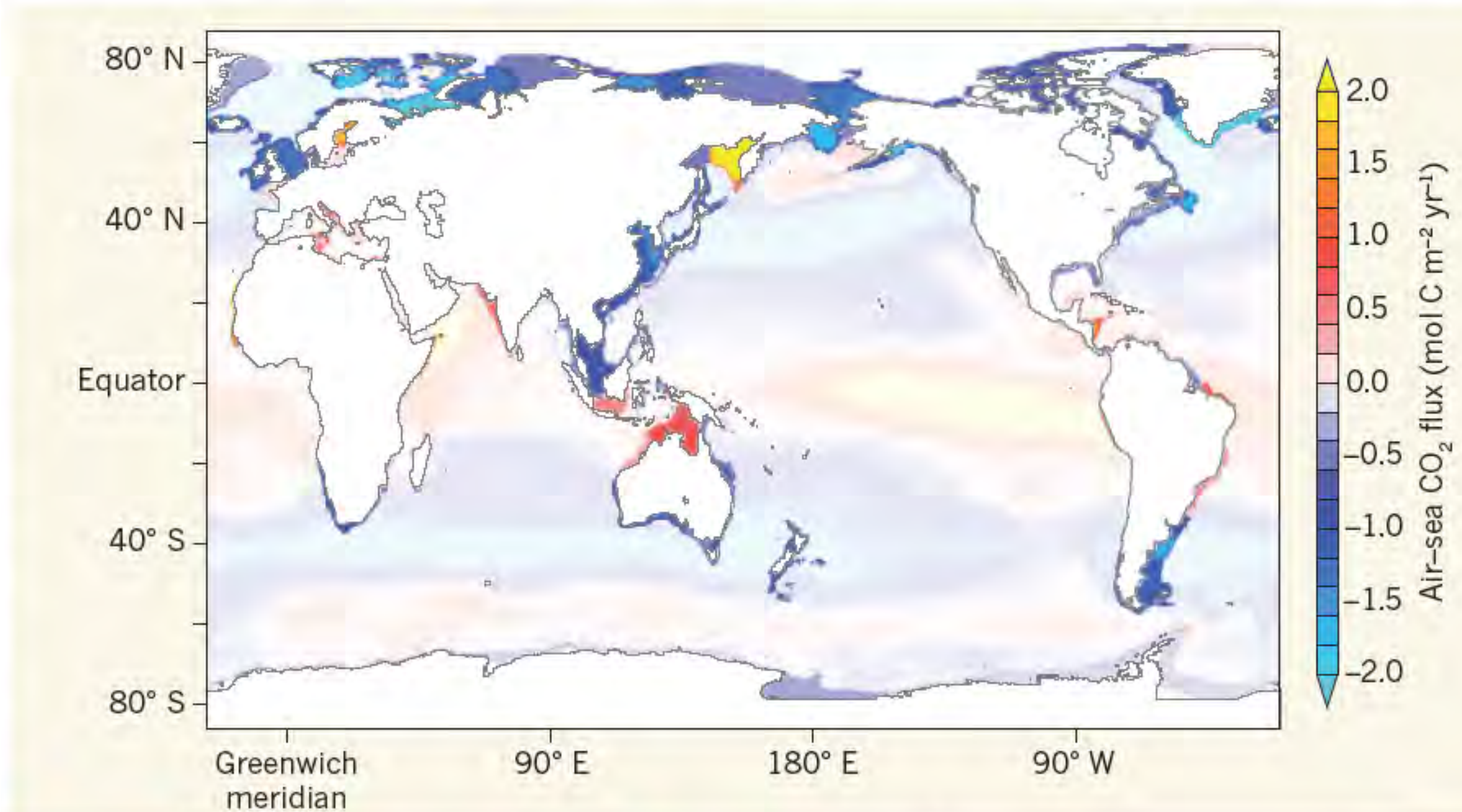


- Subsampling of 6 ocean-only CMIP5 models to SOCAT v2 fCO_2 values;
- Comparison of annual mean anomalies;
- **Models underestimate the variation in surface ocean pCO_2.**

- SOCAT in Obs4MIP and ESMVal for IPCC.

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

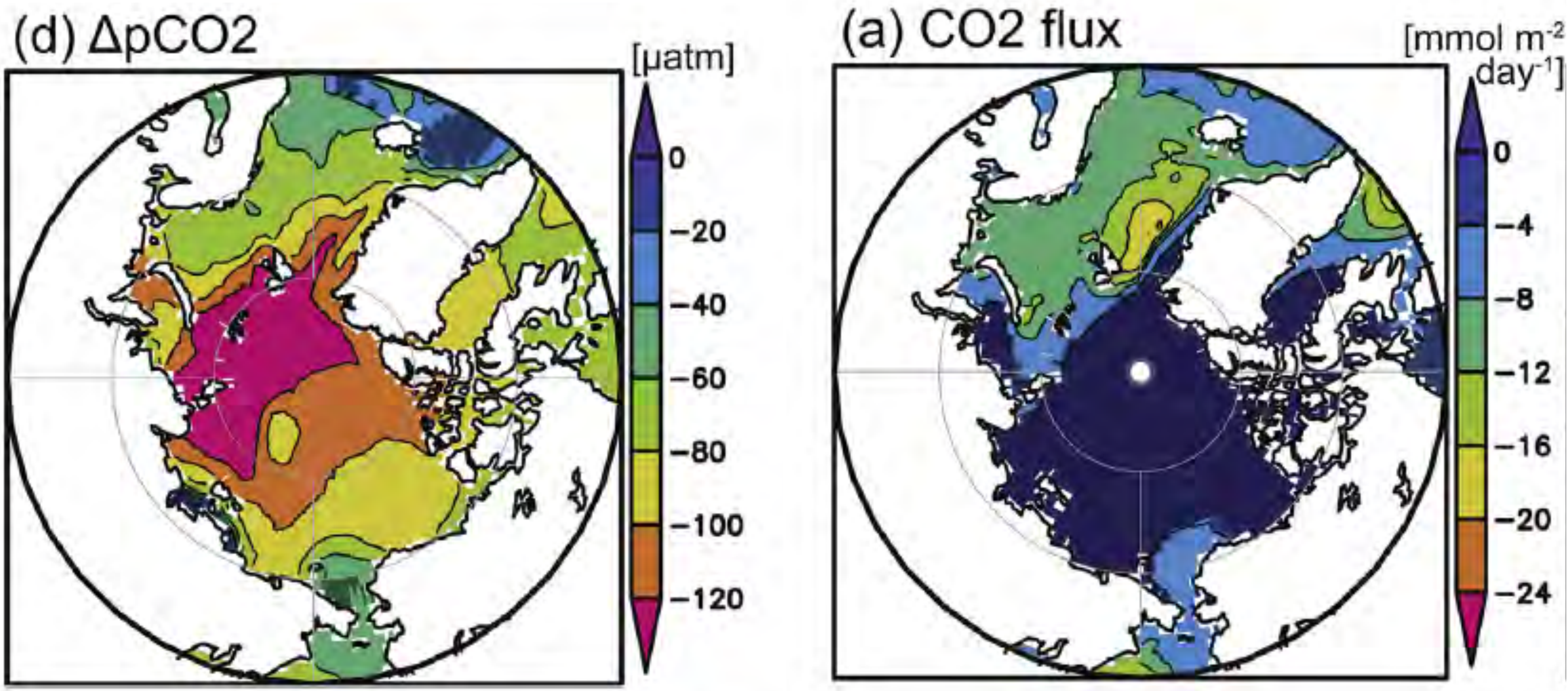
Coastal ocean carbon sink



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)

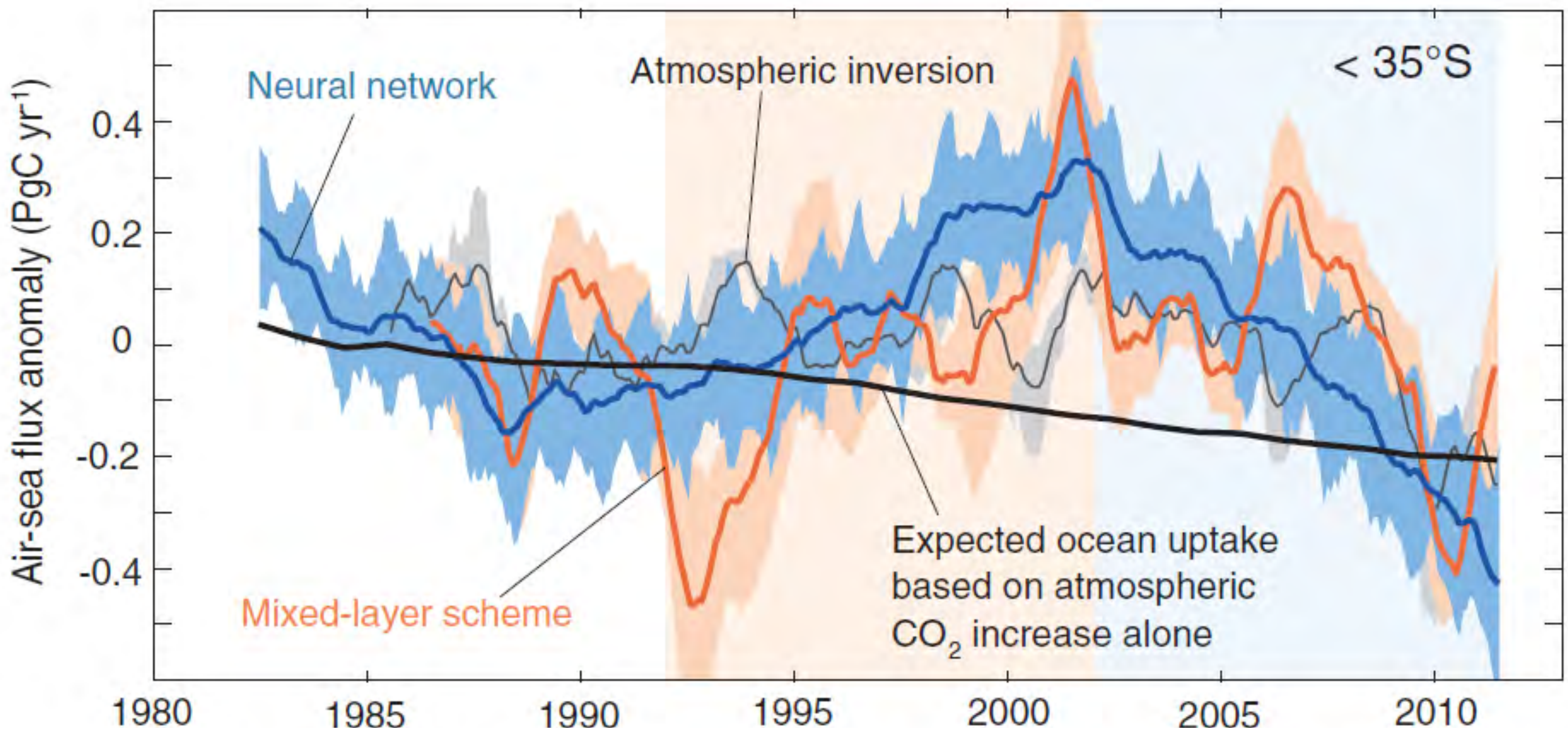
Arctic ocean carbon sink



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

(Yasunaka et al., 2016 Polar Biology)

Reinvigoration of the Southern Ocean carbon sink



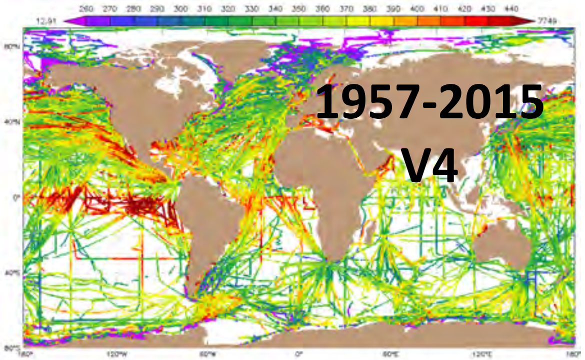
2 methods using SOCATv2 (NN, ML);

ΔpCO_2 trends dominate the sink variability;

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

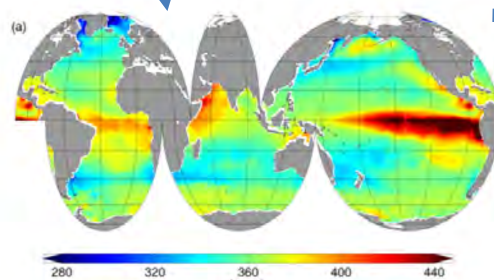
(Landschützer et al., 2015, Science)

Global mapping and fluxes



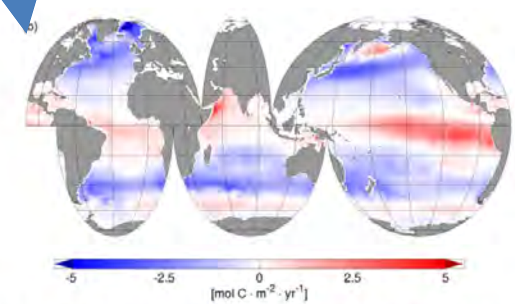
A synthesis product
(here SOCAT v4)

Mapping

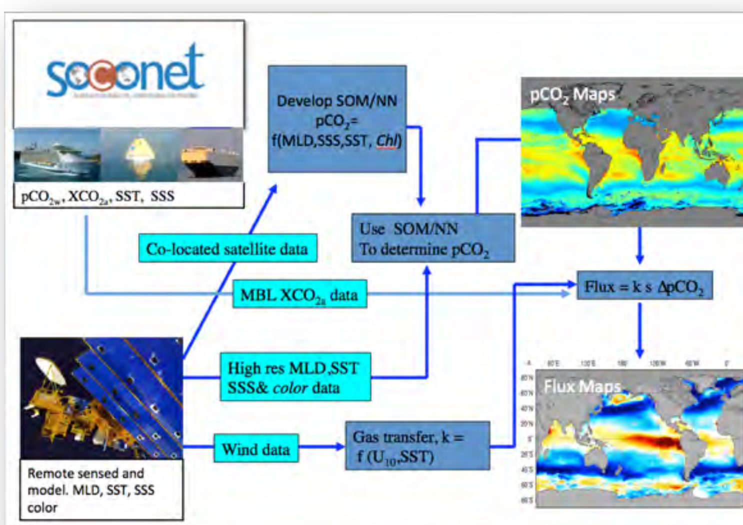


Surface water pCO_2
(here 1998-2011)

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



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

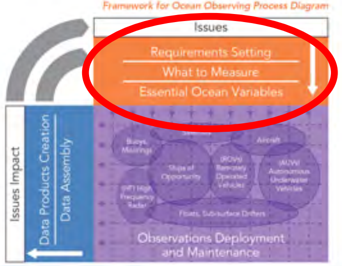


Riverine carbon outgassing
0.45 ± 0.18 Pg C yr^{-1}

Anthropogenic ocean
carbon sink (C_{ant})

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

Requirements for GOOS Biogeochemistry



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  - **Q1.1 How is the ocean carbon content changing?**
  - **Q1.2 How does the ocean influence cycles of non-CO_2 greenhouse gases?**
- **Human impacts on ocean biogeochemistry**
  - **Q2.1. How large are the ocean's "dead zones" and how fast are they changing?**
  - **Q2.2 What are rates and impacts of ocean acidification?**
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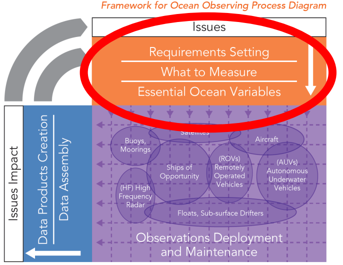


GOOS Essential Ocean Variables

Physics & Climate

- Sea State
- Ocean Surface Stress
- Sea Ice
- Sea Surface Height
- Sea Surface Temperature
- Subsurface Temperature
- Surface Currents
- Subsurface Currents
- Sea Surface Salinity
- Subsurface Salinity
- Ocean Surface Heat Flux

Biogeochemistry

- Oxygen
- Nutrients
- Inorganic Carbon
- Transient Tracers
- Particulate Matter
- Nitrous Oxide
- Stable Carbon Isotopes
- Dissolved Organic Carbon
- Ocean Colour

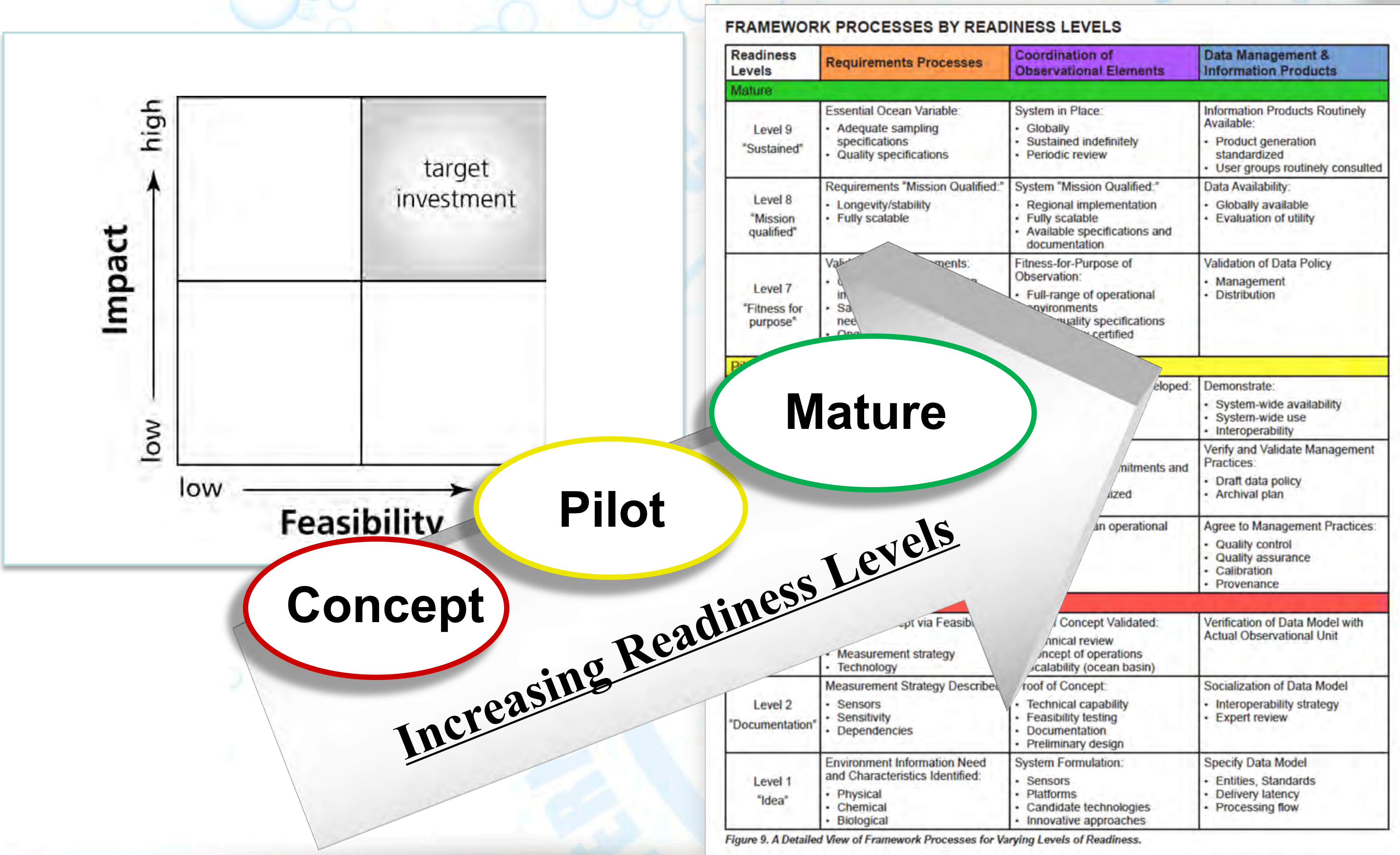
Biology & Ecosystems

- Phytoplankton Biomass & Diversity
- Zooplankton Biomass & Diversity
- Fish Abundance & Distribution
- Marine Turtles, Birds, Mammals Abundance & Distribution
- Hard Coral Cover & Composition
- Seagrass Cover
- Macroalgal Canopy
- Mangrove Cover
- Microbe Biomass & Diversity
- Benthic Invertebrate Abundance & Distribution

Emerging EOVs (Microbe Biomass & Diversity; Benthic Invertebrate Abundance & Distribution)

EOV Specification Sheets:
www.goosocean.org/eov
www.ioccp.org/foo

Increasing readiness of the sustained system



Reccomendations from the GOOS Biogeochemistry Community White Paper:

- To actively guide the **co-design of the observing system** by engaging expert WGs and observing networks to determine **phenomena-based observing targets** and jointly agree on implementation plans for all EOVs for the period 2025-2030.

- To increase the observing capacity by **adding routine biogeochemistry (and biology?) EOV measurements on existing observing networks**, in particular GO-SHIP and OceanSITES.

- To create **new data synthesis products** based on multi-EOV and multi-platform observations needed to fulfil the end user product requirements for various applications globally (e.g. SDG indicators, Global (Carbon) Budget(s), IPCC and World Ocean Assessment) and regionally (e.g. harmful algal bloom forecasts, regional (carbon) budgets, integrated ecosystem assessments).

- To increase the availability, discoverability and interoperability of marine biogeochemistry data and to enable product development by end users. To this end we recommend creating and maintaining a **Global Data Assembly Centre for Biogeochemistry EOVs**, and where relevant (e.g. Particulate Matter EOV) designing **new data repositories** capable of integrating EOV data from many heterogeneous sources.

INTERNATIONAL OCEAN CARBON COORDINATION PROJECT

IOCCP

GOOS

Biogeochemistry Panel

A coordination and communication service for marine biogeochemistry

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