

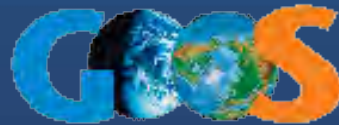


Global Ocean Acidification  
Observing Network

# Requirements-driven global ocean observing system for Ocean Acidification

*Maciej Telszewski*

*Masao Ishii, Kim Currie, Artur Palacz and Albert Fischer*

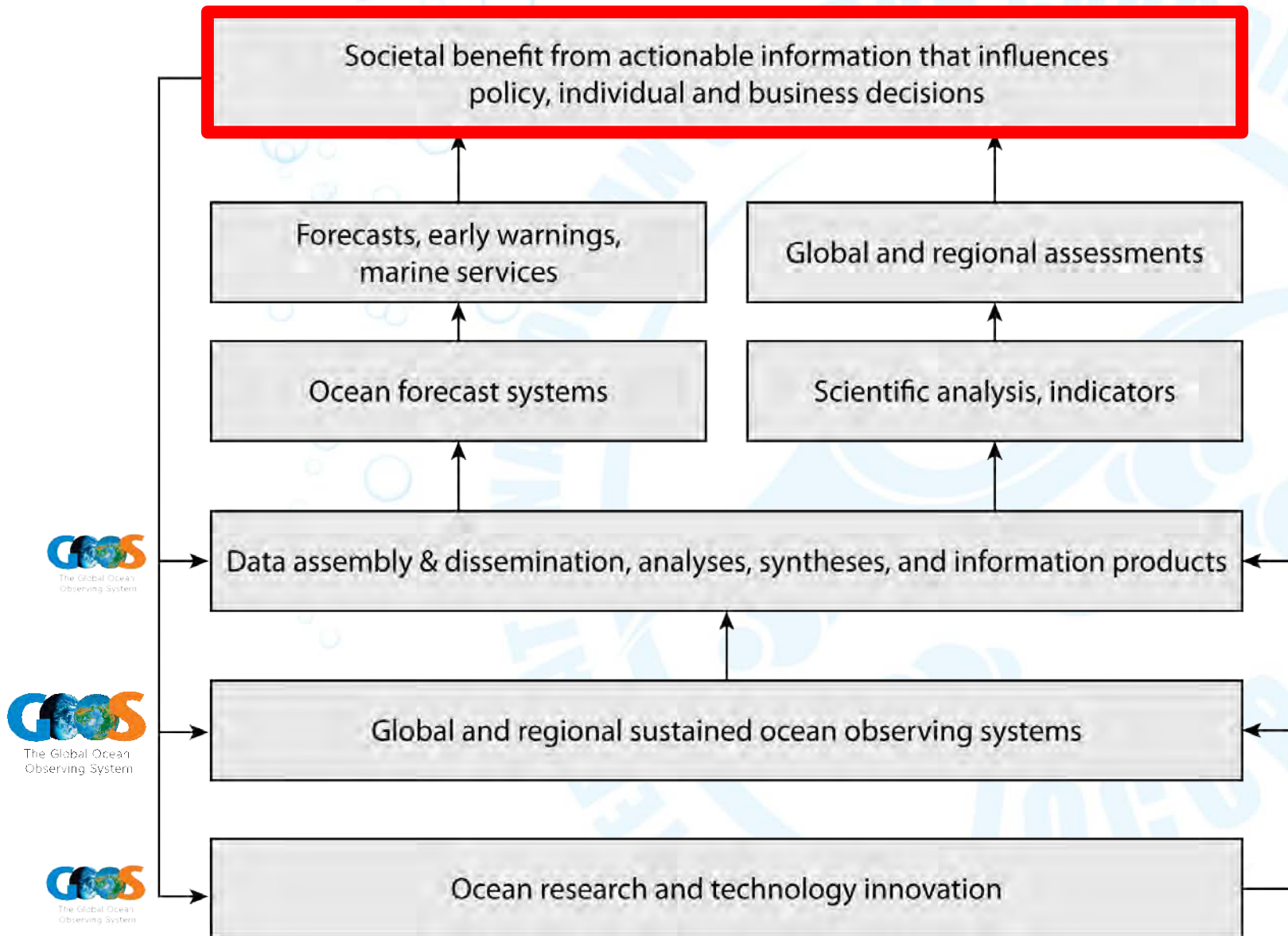


Biogeochemistry

Panel

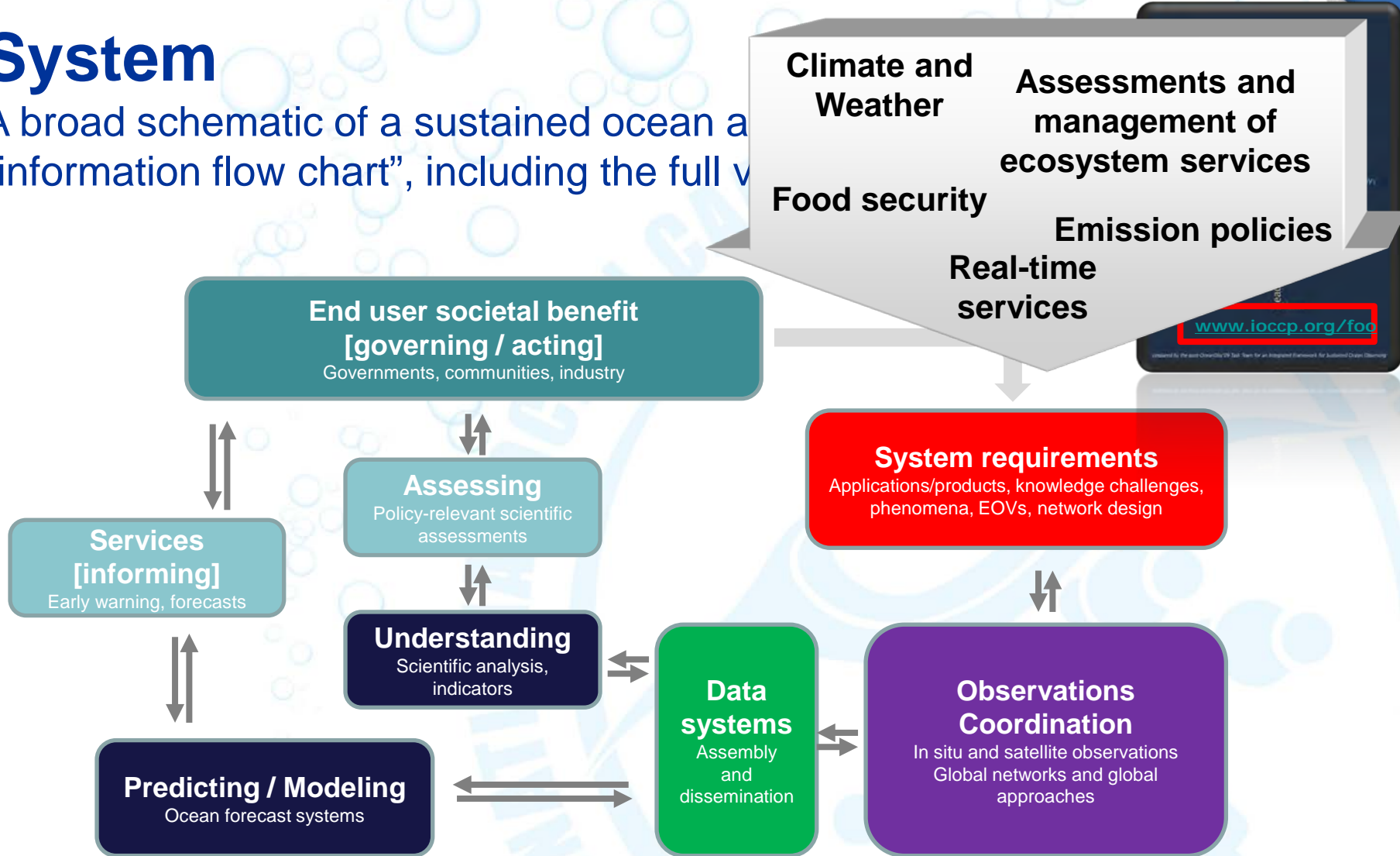
# Societal benefit value chain

Adapted from G7 Think Piece on Ocean Observations



# System

A broad schematic of a sustained ocean assessment system as an “information flow chart”, including the full value chain



# 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<sub>2</sub> 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



# 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*

EOV Specification Sheets: [www.goosocean.org/eov](http://www.goosocean.org/eov)

[www.ioccp.org/foov](http://www.ioccp.org/foov)

# GOA-ON




Global Ocean Acidification Observing Network

## Global Ocean Acidification Observing Network: Requirements and Governance Plan

Second Edition  
October 2015

J.A. Newton, R.A. Feely,  
E.B. Jewett, P. Williamson,  
J. Mathis




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Global Ocean Acidification Observing Network

## Global Ocean Acidification Observing Network: Implementation Strategy

First Edition  
2018 ?



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# The Essential Ocean Variables Specification Sheets

EOV Specification Sheets:  
[www.goosocean.org/eov](http://www.goosocean.org/eov)  
[www.ioccp.org/foo](http://www.ioccp.org/foo)

## Essential Ocean Variable (EOV): Inorganic Carbon

<b>Name of EOV</b>	Inorganic Carbon
<b>Sub-Variables</b>	<b>Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), Partial pressure of carbon dioxide (pCO<sub>2</sub>) and pH.</b> <i>[At least two of the four Sub-Variables are needed.]</i>
<b>Derived Products</b>	Saturation state (aragonite, calcite), Dissolved carbonate ion concentration, Air-sea flux of CO <sub>2</sub> , Anthropogenic carbon, Change in total carbon
<b>Supporting Variables</b>	Surface and subsurface Temperature, Surface and subsurface Salinity, Ocean vector stress (wind speed), Atmospheric column-averaged dry-air mole fraction of CO <sub>2</sub> (xCO <sub>2</sub> ), Barometric pressure, Oxygen, Calcium concentration, Transient tracers, Oxygen to argon ratio (O <sub>2</sub> /Ar)
<b>Responsible GOOS Panel</b>	GOOS Biogeochemistry Panel Contact: <a href="mailto:ioccp@ioccp.org">ioccp@ioccp.org</a>



## Table 2: Requirements Setting (Inorganic Carbon)

<b>Societal Drivers</b>	<ol style="list-style-type: none"> <li>1. The role of ocean biogeochemistry in climate</li> <li>2. Human impacts on ocean biogeochemistry</li> <li>3. Ocean ecosystem health</li> </ol>			
<b>Scientific Application(s)</b>	<p>Q 1.1. How is the ocean carbon content changing?</p> <p>Q 2.1. How large are the ocean's dead zones and how fast are they growing?</p> <p>Q 2.2. What are rates and impacts of ocean acidification?</p> <p>Q 3.1. Is the biomass of the oceans changing?</p>			
<b>Readiness Level</b> <i>[as defined in the FOO]</i>	Mature			
<b>Phenomena to Capture</b>	<b>1</b> Air-Sea Fluxes	<b>2</b> Storage / inventory	<b>3</b> Ocean Acidification	<b>4</b> Primary production
<b>Temporal Scales of the Phenomena</b>	Monthly	Annual	<u>Coastal</u> Daily <u>Open Ocean</u> Seasonal	Seasonal to decadal
<b>Spatial Scales of the Phenomena</b>	1-250 km	100-1000 km	<u>Coastal</u> 0.1-100 km <u>Open Ocean</u> 100-1000km	<u>Coastal</u> 1-100 km <u>Open Ocean</u> 100-1000 km
<b>Magnitudes/Range of the Signal to Capture</b>	$2 \text{ Pg C yr}^{-1}$	$20 \text{ Pg C decade}^{-1}$	<u>Saturation states</u> $0.1 \text{ decade}^{-1}$ pH $0.01 \text{ decade}^{-1}$	$0.5 \text{ Pg C yr}^{-1} \text{ decade}^{-1}$ (net community production)
<b>Current Uncertainty Relative to the Signal</b>				
<b>Target Uncertainty Relative to the Signal</b>	$\pm 10\%$	$\pm 10\%$	$\pm 20\%$	

# Table 3: Current Observing Networks (Inorganic Carbon)

Observing Approach	Ship-based Underway Observations	Ship-based Repeat Hydrography	Moored Fixed-Point Observatories	Drifters	Ship-based Fixed-Point Observatories	Profiling floats
Readiness Level of the Observing Approach for this EOV	Mature	Mature	Mature	Mature	Mature	pH: Pilot pCO <sub>2</sub> : Concept DIC: Concept TA: Concept
Leading Obs. Network	SOOP-CO <sub>2</sub>	<a href="#">GO-SHIP</a>	<a href="#">OceanSITES</a>			<a href="#">Biogeochemical Argo</a>
Network Readiness Level	Concept	Mature	Pilot			Pilot
Phenomena Addressed	1,3	2,3	1,3,4	1,3	1,3,4,5	2,3,4,5
Spatial Scales Currently Captured by the Observing Network	Horizontal coverage: global, every 10°, denser in the coastal domain Vertical coverage: surface	Horizontal coverage: global, every 20° Vertical coverage: full depth	Horizontal coverage: Vertical coverage:	Horizontal coverage: Vertical coverage:	Horizontal coverage: Vertical coverage:	Horizontal coverage: every 10°, denser in the coastal domain Vertical coverage:
Typical Obs. Frequency	Weekly to decadal	Decadal	Sub-daily to seasonal and annual	Hourly to annual	Weekly to decadal	Weekly to annual
Supporting Variables Measured	Atmospheric / ocean pCO <sub>2</sub> , Surface temperature and salinity		Surface and subsurface temperature and salinity, Wind speed, Atmospheric CO <sub>2</sub>	Surface and subsurface temperature	Wind speed, Atmospheric and ocean pCO <sub>2</sub>	
Sensor(s)/Technique	Equilibrator, Permeable membrane, IR, CRDS	Benchtop instruments	Equilibrator, Permeable membrane	Spectro-photometric	Titration, equilibrator	Spectro-photometry; variety of sensors are being developed
Accuracy/Uncertainty Estimate (units)	pCO <sub>2</sub> : ±2 µatm	TA/DIC: ±2 µmol kg <sup>-1</sup> pH: ±0.005 pCO <sub>2</sub> : ±2 µatm	pCO <sub>2</sub> ±5 µatm	pCO <sub>2</sub> : ±5 µatm pH: ±0.005	TA/DIC: ±2 µmol kg <sup>-1</sup> pH: ±0.005 pCO <sub>2</sub> : ±2 µatm	pCO <sub>2</sub> : ±5 µatm pH: ±0.005
Reporting Mechanisms(s)	Individual Networks Annual Reports; IOCCP Annual Report					

# Table 4: Future Observing Capacity (Inorganic Carbon)

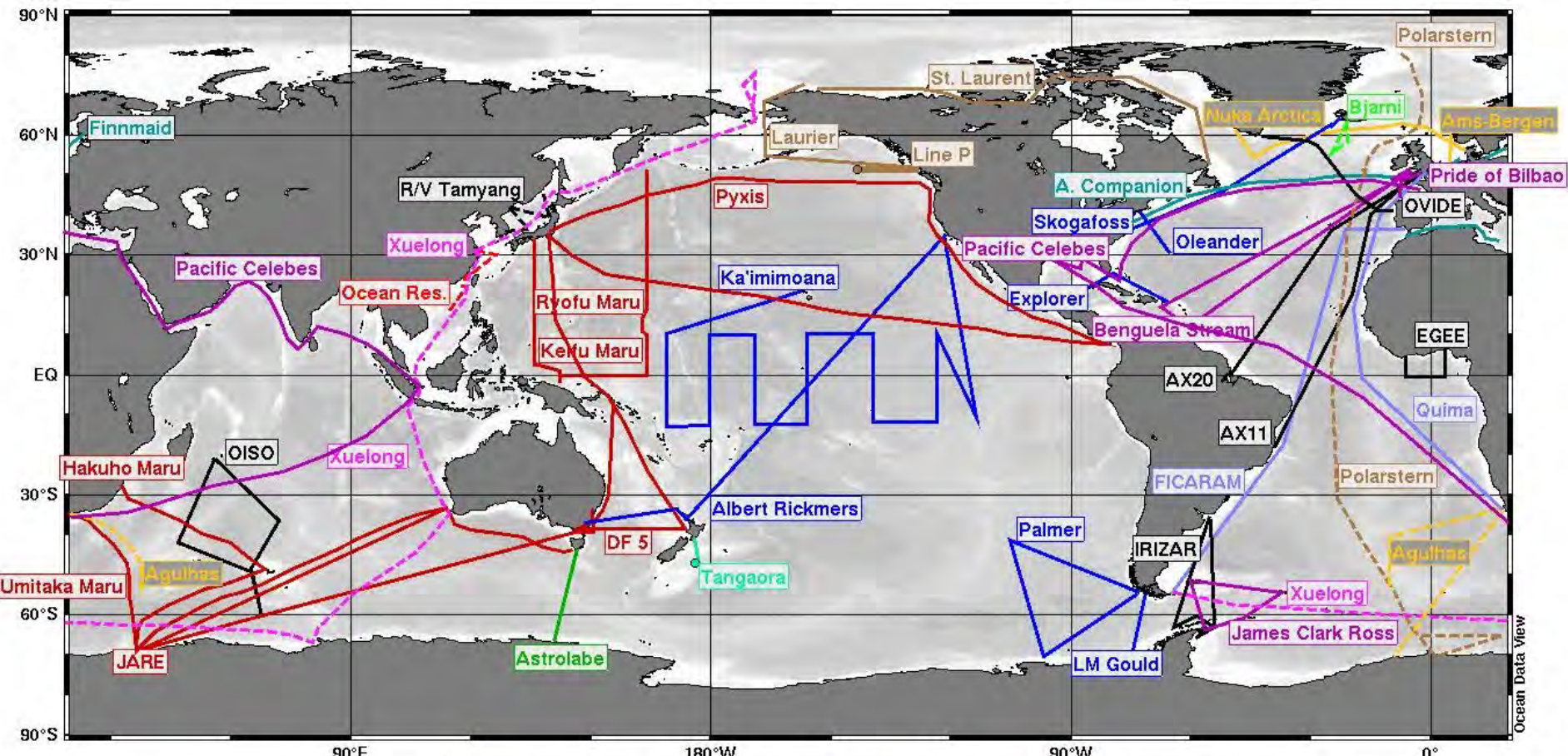
Observing Approach	Surface Autonomous Vehicles	Moored Fixed-point Observatories	Autonomous Underwater Vehicles	Ship-based Underway Observations
<b>Novel aspect of the observing approach</b>	Novel observing approach and network ( <a href="#">OceanGliders</a> ) for pH and pCO <sub>2</sub> .	Resolving full water column measurement of pH and pCO <sub>2</sub> .	Novel observing approach resolving water column measurements of pH and pCO <sub>2</sub> .	New sub-variables measured (DIC/TA) using new sensors/techniques.
<b>How does this novel aspect impact our observing capacity?</b>				
<b>Readiness Level of the Observing Network</b>	pH: Pilot pCO <sub>2</sub> : Concept DIC: Concept TA: Concept	pCO <sub>2</sub> (surface) Mature pCO <sub>2</sub> (interior): Concept pH: Concept	Concept	underway pCO <sub>2</sub> : Mature underway DIC/TA: underway pH:
<b>Spatial Scales Captured by the Observing Network</b>	20°, surface	1 km	10-1000 km, full depth	Every 10°, Denser in the coastal domain, Surface
<b>Typical Observing Frequency</b>	Daily to monthly	Sub-daily to seasonal and annual	Daily to monthly	Weekly to annual
<b>Time-Scale Until Part of Observing System</b>				
<b>Supporting Variables Measured</b>				
<b>Sensor(s)/Technique</b>	Spectro-photometry & Equilibrator  Very dynamic field, variety of sensors are being developed	Permeable membrane  Very dynamic field, variety of sensors are being developed	Spectro-photometry  Very dynamic field, variety of sensors are being developed	DIC: NDIR (?CRDS)  pCO <sub>2</sub> : Equilibrator pH: Permeable membrane  TA: Titration
<b>Accuracy/Uncertainty Estimate (units)</b>	pCO <sub>2</sub> : ±5 µatm  pH: ±0.005	pCO <sub>2</sub> : ±10 µatm  pH: ±0.005	pCO <sub>2</sub> : ±5 µatm  pH: ±0.005	pH: ±0.005  TA: ±2 µatm  DIC: ±4 µatm



# soconet

• SURFACE OCEAN CO<sub>2</sub> OBSERVING NETWORK •

N COORDIN



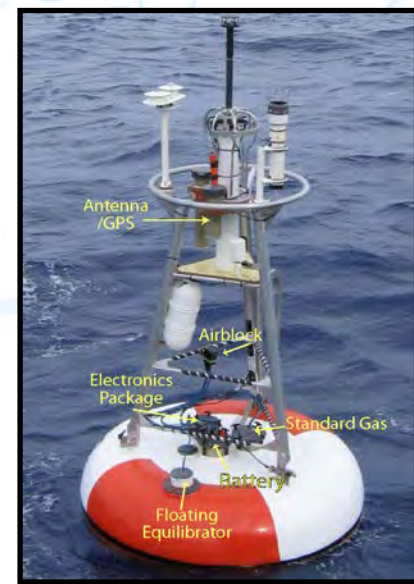
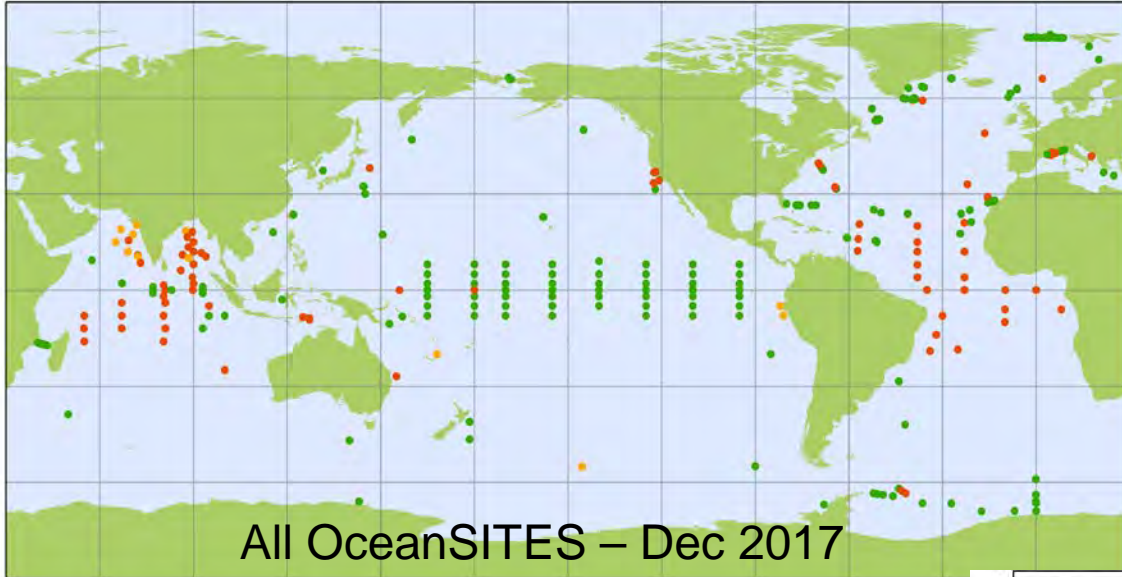
— US	— France	— Canada	— New Zealand
— Japan	— Germany	— Spain	— China
— UK	— Australia	— Norway	— Taiwan
— Iceland	— Netherlands	— Korea	— South Africa

Ocean Data View



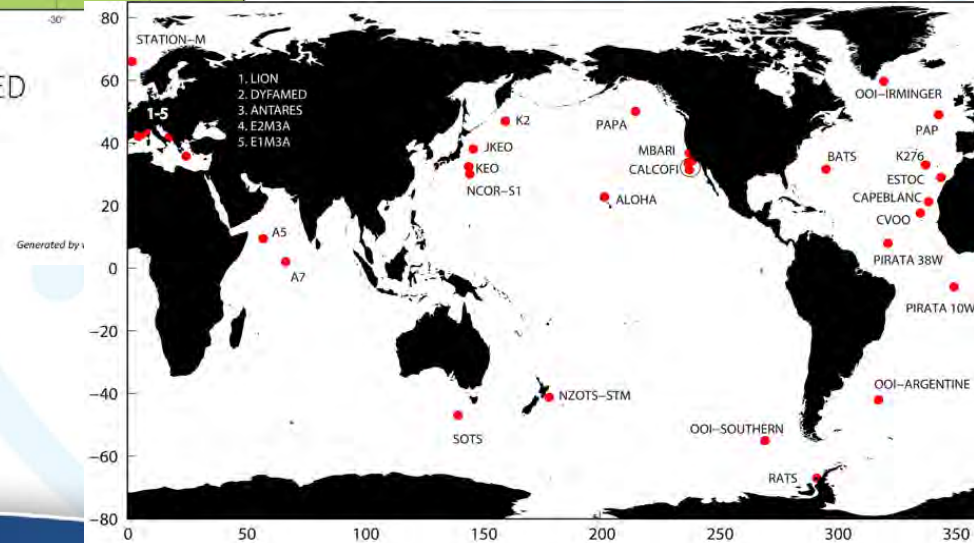
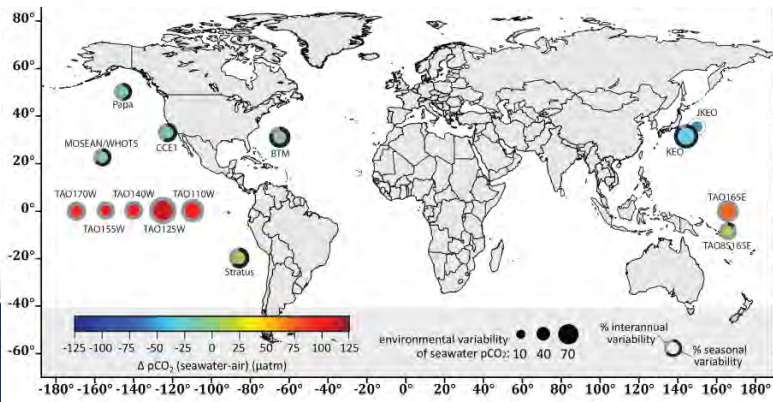


# Biogeochemical Time Series



BGC OceanSITES  
(Henson et al. (2016))

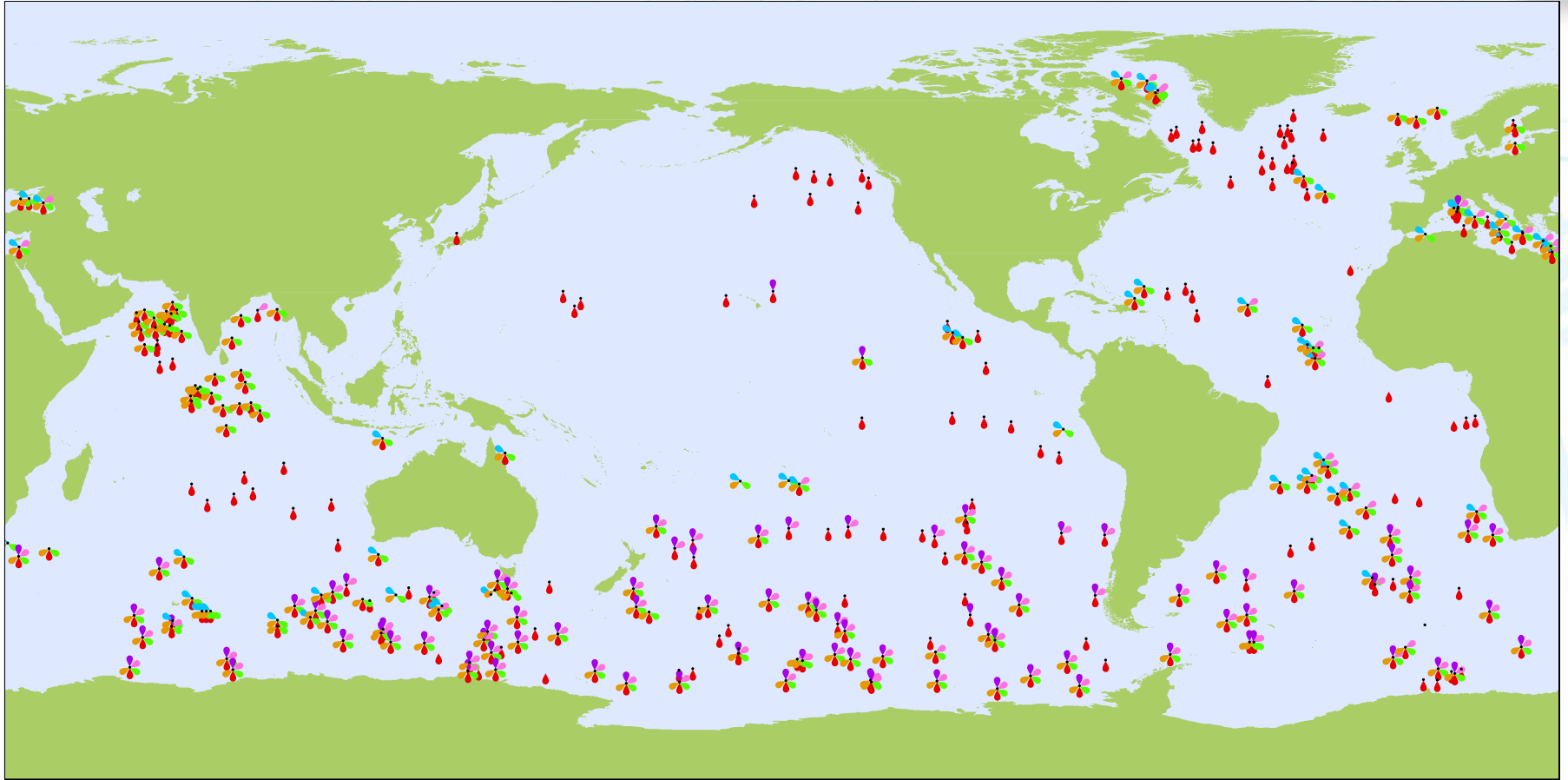
● REGISTERED   
 ● OPERATIONAL   
 ● INACTIVE   
 ● CLOSED



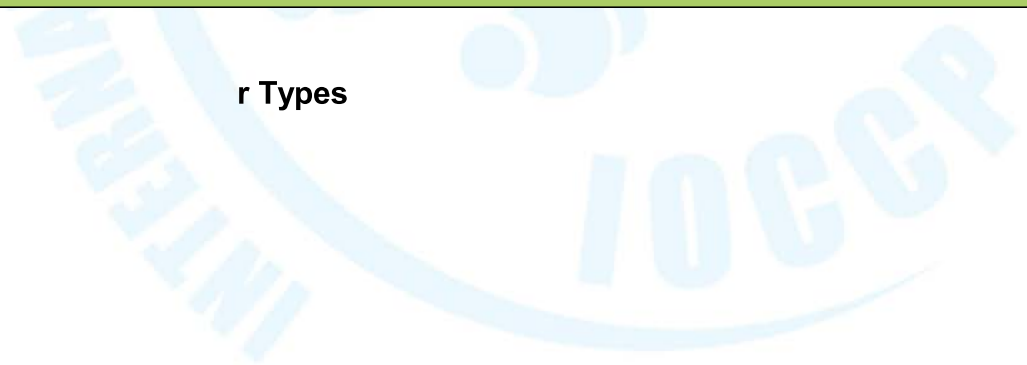
MapCO<sub>2</sub> sites (Sutton et al. 2014)



# Biogeochemical Argo



r Types



# Carbon Data Management

NOAA National Centers for Environmental Information

Ocean CO<sub>2</sub> CDIAC

CCHDO

Bjerknes Centre for Climate Research

BCDC Bjerknes Climate Data Centre

BC<sub>2</sub>-DM

INTERNATIONAL OCEAN CARBON COORDINATION PROJECT IOCCP

GOA-ON Global Ocean Acidification Observing Network

IMBeR solas 2019

The Global Ocean Observing System

GOOS

UNESCO United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

WMO

jcommops

ICOS Ocean Thematic Centre

IOOS INTEGRATED OCEAN OBSERVING SYSTEM

FixO<sup>3</sup> FIXED-POINT OPEN OCEAN OBSERVATORIES

GO-SHIP

OceanSITES

Argo

VOS Voluntary Observing Ship Scheme

SeaDataNet

EMODnet European Marine Observation and Data Network

World Ocean Database

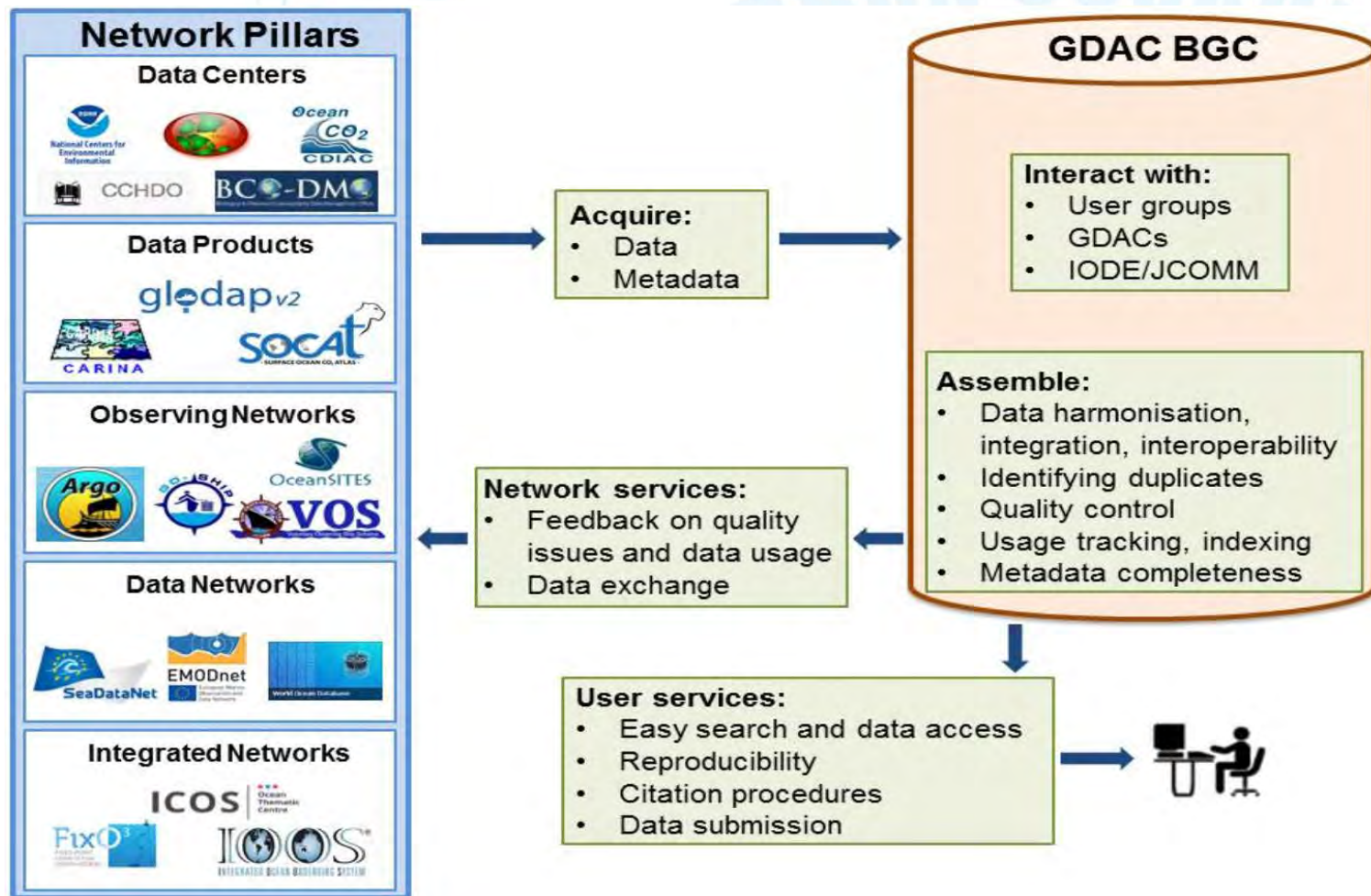
GEO

SOCAT SURFACE OCEAN CO<sub>2</sub> ATLAS

glodap v2



# Global Data Assembly Centre for Marine Biogeochemistry





# The GOA-ON interactive data portal

Featuring global OA data, asset inventory, metadata, data synthesis products, etc.



Home Explorer Settings GLOBAL OCEAN ACIDIFICATION OBSERVING NETWORK EXPLORER

Map Asset List Asset History Help

Lat: 0.0000 Lon: -113.5547 Terrain

Regions Filters Fixed Platforms Mobile Platforms Remote Sensing Legend

**Chuuk K1 Lagoon Mooring**

Observations Details Credits

Data Updated: 13 Sep 2016 17:17 PDT Provider: PMEL-CO2

ATMOSPHERIC	
CO2 Air (1 m)	395.2 ppm

HYDROGRAPHIC	
CO2 Water (-0.8 m)	465.4 ppm
pH (-0.8 m)	7.4
Salinity (-0.8 m)	34.1 PSU
Water Temperature (-0.8 m)	30.6 °C

Link

27 December 2012 12:00 am PST

2012 2013 2014 2015 2016 2017

Aragonite Saturation

CO2 Water

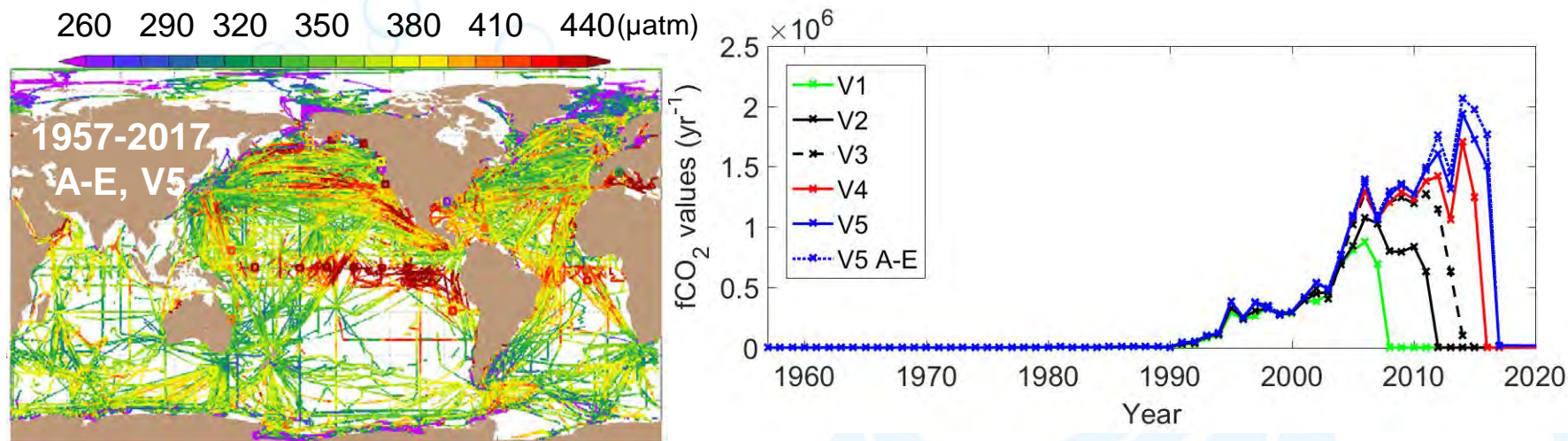
PMELCO2 chuukk1 - CO2 Water

CO2 Water ppm



# Data synthesis products

## Surface Ocean CO<sub>2</sub> Atlas



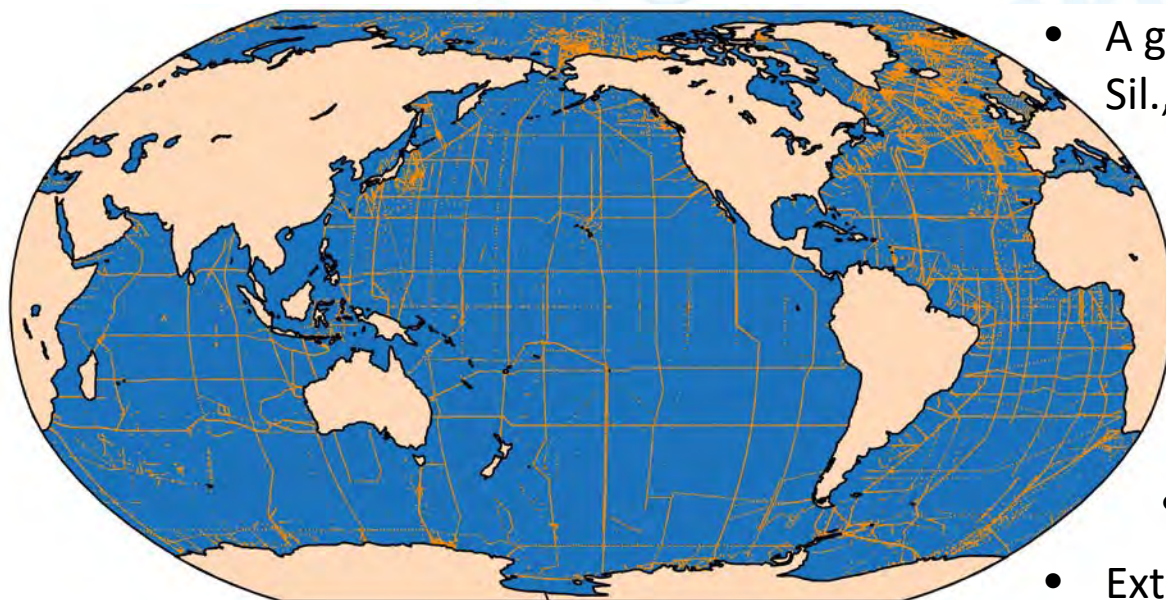
### Global synthesis and gridded products of surface ocean fCO<sub>2</sub>

- in uniform format with quality control;
- V5: 21.5 million fCO<sub>2</sub> values from 1957-2017, accuracy < 5 μatm (flags A-D);
- Plus calibrated sensor data (< 10 μatm, flag of E);
- Interactive online viewers;
- Online viewers, downloadable (text, NetCDF, ODV, Matlab);
- Documented in ESSD articles;
- Community activity with >100 contributors worldwide.

# Data synthesis products

## Global Ocean Data Analysis Project v2

glodap v2



- A global collection of Sal., O<sub>2</sub>, Nitr., Sil., Phos., DIC, Talk, pH data
- 45 306 stations (724 cruises)
- 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  
© Author(s) 2016. CC Attribution 3.0 License.

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<sup>1</sup>, Robert M. Key<sup>2</sup>, Steven van Heuven<sup>3</sup>, Siv K. Lauvset<sup>1,4</sup>, Anton Velo<sup>5</sup>, Xiaohua Lin<sup>2</sup>,  
Carsten Schirnick<sup>6</sup>, Alex Kozyr<sup>7</sup>, Toste Tanhua<sup>6</sup>, Mario Hoppema<sup>8</sup>, Sara Jutterström<sup>9</sup>,

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

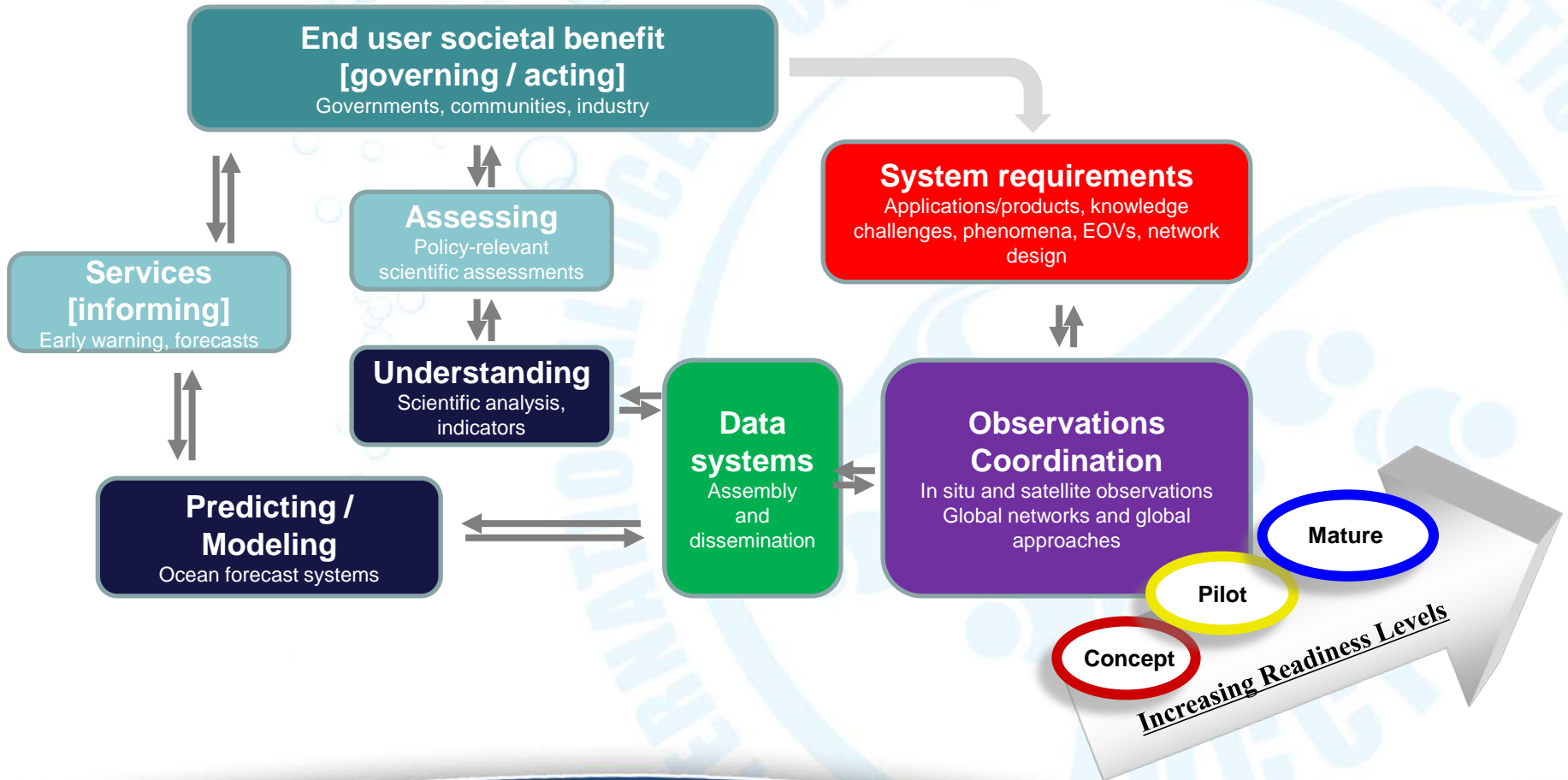
A new global interior ocean mapped climatology:  
the 1° × 1° GLODAP version 2

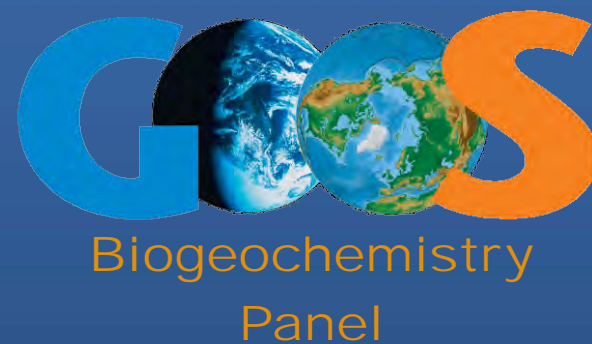
Siv K. Lauvset<sup>1,2</sup>, Robert M. Key<sup>3</sup>, Are Olsen<sup>1,2</sup>, Steven van Heuven<sup>4</sup>, Anton Velo<sup>5</sup>, Xiaohua Lin<sup>3</sup>,  
Carsten Schirnick<sup>6</sup>, Alex Kozyr<sup>7</sup>, Toste Tanhua<sup>6</sup>, Mario Hoppema<sup>8</sup>, Sara Jutterström<sup>9</sup>,



# System

A broad schematic of a sustained ocean acidification “information flow chart”, including the full value chain





***A communication and coordination service for marine biogeochemistry***