# Housekeeping notes for me

Welcome – ARPA-E program dev workshop on CDR MRV.
Thanks to James, our director on T2M.
Thank you also to my fellow employees and arpa-e contractors who have organized this meeting.

A few announcements before we begin.

You probably have seen the agenda, we have four breakout sessions amongst the talks. We have tried to populate the sessions with targeted groups, please ensure you attend the correct breakout. Lists and names should have been provided to you when you checked in..

Where are the breakout sessions?

Masks: Boston is experiencing a wave of Omicron. In order to be allowed to have this workshop, we need to mandate masks except when eating and also speaking on a stage. Please follow the guidelines as the agency does not want to be responsible for a super spreader event.

# New Technologies for marine Carbon Dioxide Removal (CDR) Measurement, Reporting and Validation (MRV)

Simon Freeman

Program Director @ ARPA-E

ARPA-E Program Development Workshop
June 15-16, 2022

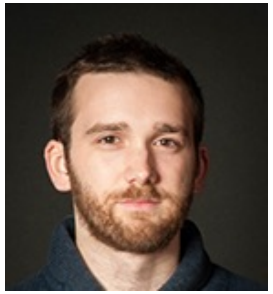
# Acknowledgements

Julia Blackburn

Katherine Slater

Dylan Temple

Calden Stimpson



Jake Russell

Elizabeth Troein

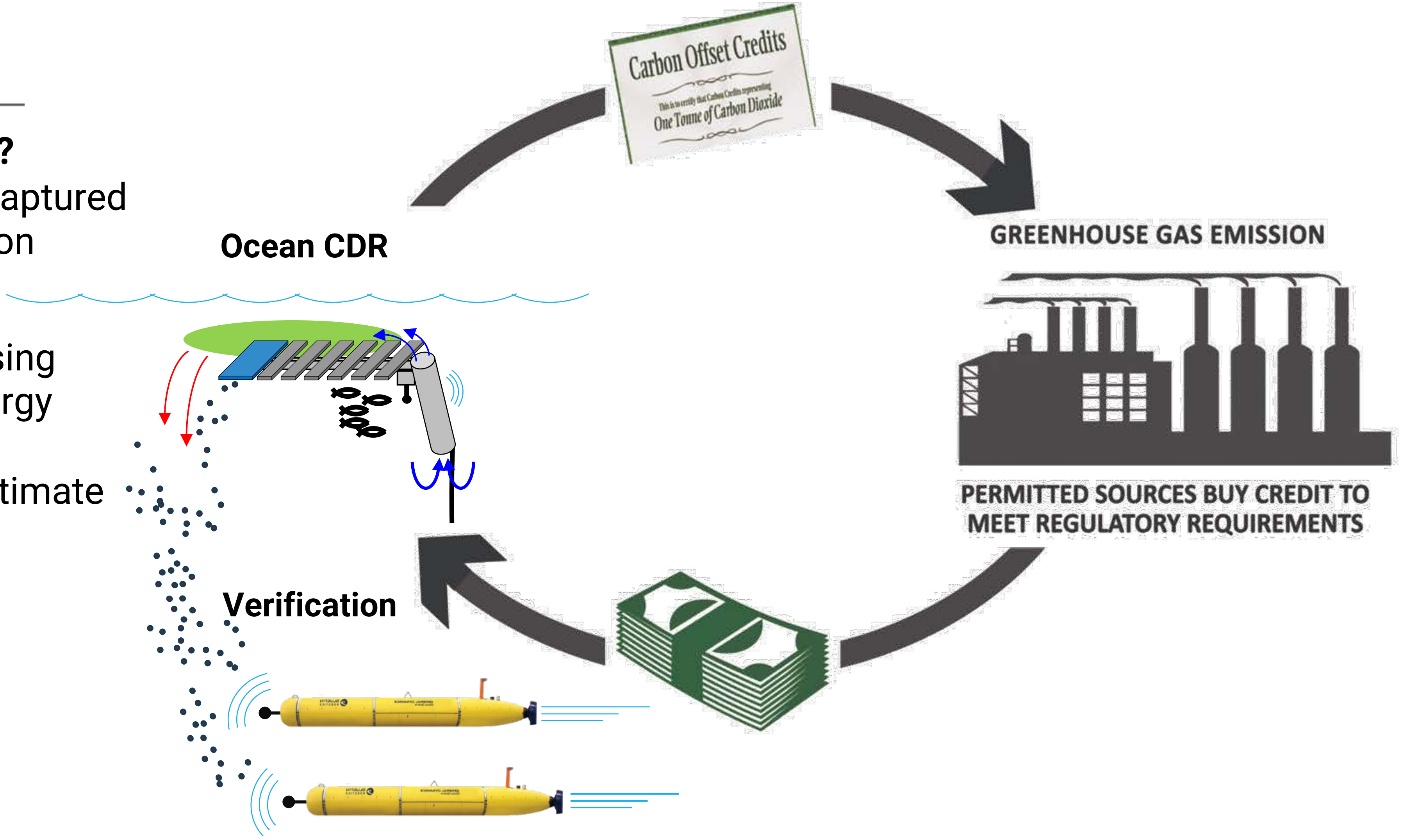
Daniel Rogers

# ARPA-E Goals

**What are we trying to do?**

Quantify the amount of carbon captured through distributed marine Carbon Dioxide Removal processes

- Develop scalable carbon sensing
- Create virtually perpetual, energy harvesting platforms
- Create effective models to estimate CDR performance




**Why does this matter?**

- Quantification gives marine CDR financial value in a carbon market
- Enables enormous scalability for solutions to *reversing our existential climate disaster*
- Avoids resource conflicts with terrestrial industries

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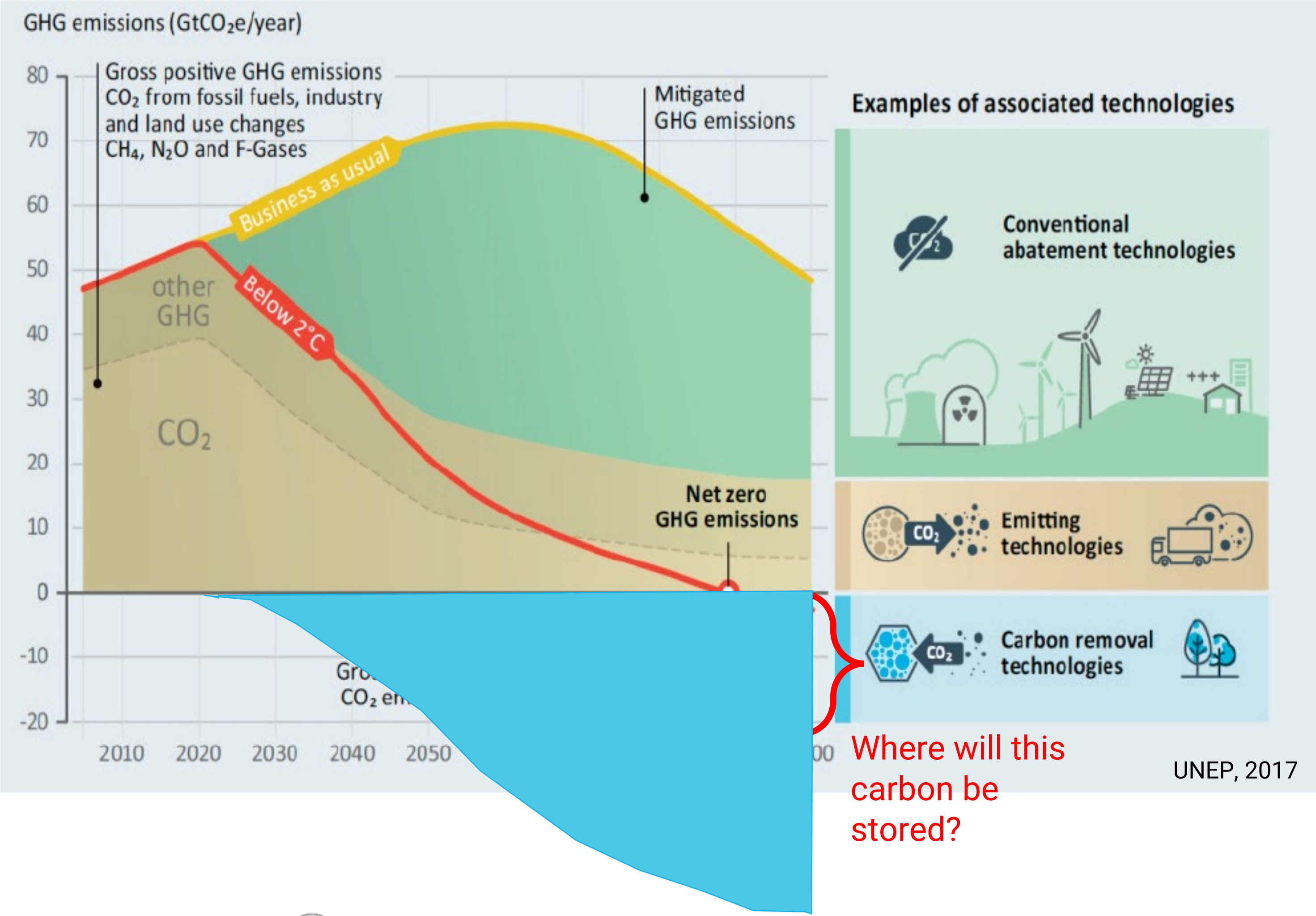
LEONARDO DiCAPRIO
JENNIFER LAWRENCE
ROB MORGAN
JONAH HILL
MARK RYLANCE
TYLER PERRY
TIMOTHÉE CHALAMET
RON PERLMAN
ARIANA GRANDE
SCOTT MESCUDI
WITH CATE BLANCHETT
AND MERYL STREEP
Don't Look UP
BASED ON TRULY POSSIBLE EVENTS
A FILM BY ADAM McKAY
DON'T LOOK UP
NETFLIX PRESENTS A HYPEROBJECT INDUSTRIES PRODUCTION A FILM BY ADAM McKAY LEONARDO DiCAPRIO JENNIFER LAWRENCE "DON'T LOOK UP" ROB MORGAN JONAH HILL MARK RYLANCE TYLER PERRY TIMOTHÉE CHALAMET RON PERLMAN ARIANA GRANDE SCOTT MESCUDI WITH CATE BLANCHETT AND MERYL STREEP CASTING BY FRANCINE MAISLER MUSIC SUPERVISOR GABE HILFER MUSIC BY NICHOLAS BRITELL COSTUME DESIGNER SUSAN MATHESON EDITED BY HANK CORWIN, ACE PRODUCTION DESIGNER CLAYTON HARTLEY DIRECTOR OF PHOTOGRAPHY LINUS SANDGREN, ASC, FSF CO-PRODUCER RON SUSKIND EXECUTIVE PRODUCER JEFF WAXMAN PRODUCED BY ADAM McKAY, p.g.a. & KEVIN MESSICK, p.g.a.
STORY BY ADAM McKAY & DAVID SIROTA SCREENPLAY BY ADAM McKAY DIRECTED BY ADAM McKAY
IN SELECT THEATERS DECEMBER AND ON
NETFLIX
NETFLIX | DECEMBER 24

# What is the Purpose Of This Workshop?

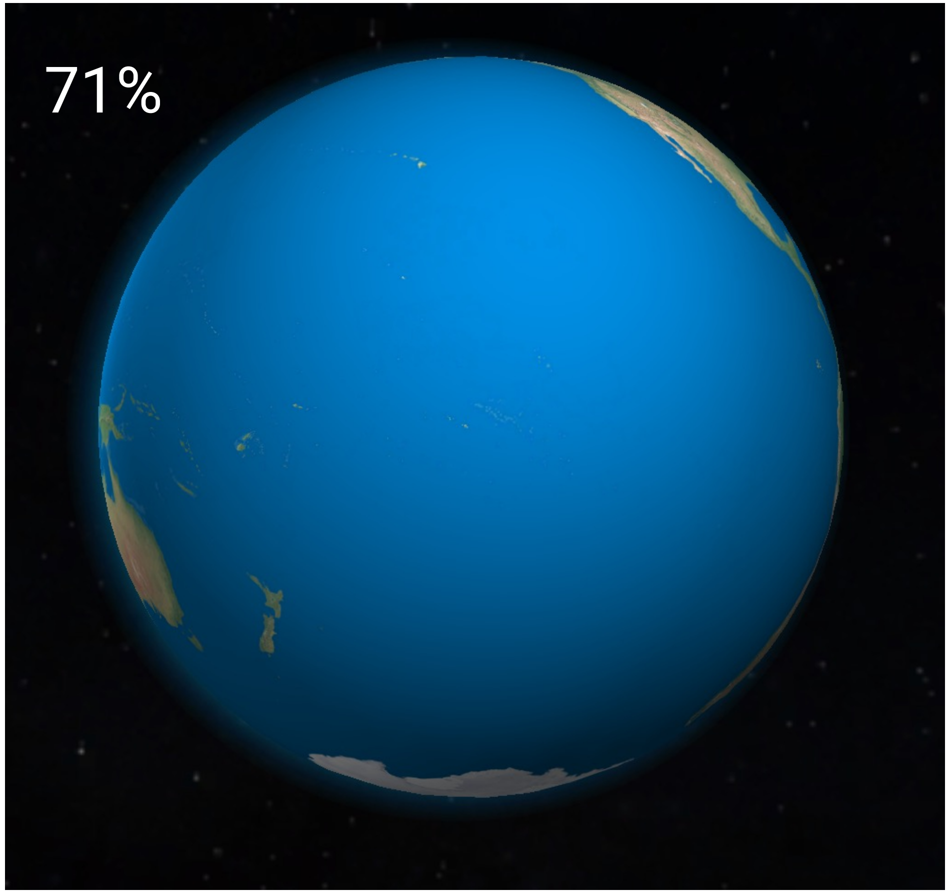
“Help us develop the justification for a \$30-\$50M program on marine CDR MRV technology development”.

- How could we bring about this new industry that is well regulated and based on accurate and predictable metrics, the fastest?
    1. Identify critical technology gaps and opportunities for advancement
    2. Think through what is required to enable the marine MRV process, and how an ARPA-E program could address these needs
    3. Consider program design and end-goals (metrics, tech-to-market strategies) that maximize the odds of technical success and follow-on industry funding

# Carbon Sequestration Magnitudes




UNEP, 2017



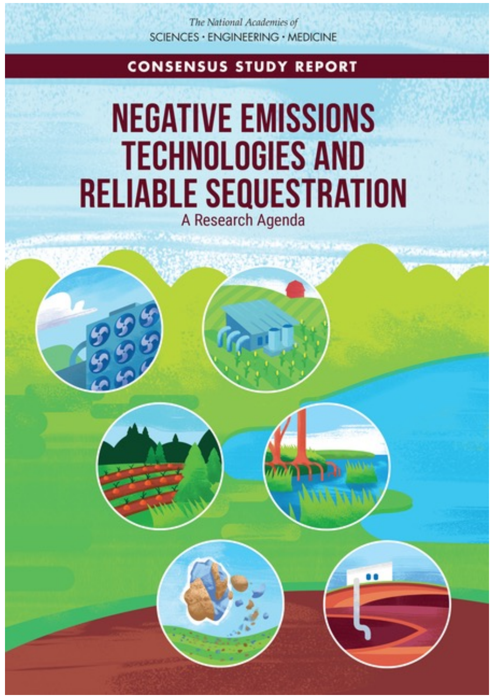
# Why Emphasize Scale?

Even if we reduce emissions to zero, we must remove *tens of Gigatons of carbon per year for ~ 50+ years,* *just to stay below 2° C of warming under a favorable emissions scenario.*

*By 2100 we need to remove at least ~20 Gt/y carbon to remain below 2°C.*

Present / Anticipated Carbon Capture Technologies *will not be enough*:

| Technology | Est. Cost ($/t CO2) | Maximum safe potential removal rate (Gt/y CO2) | Current Limiting Factors |
|---|---|---|---|
| Coastal Blue Carbon | < 20 | 0.13 | Land area, sea level rise |
| Afforestation/Reforestation | < 20 | 1 | Land area, implementation |
| Forest Management | < 20 | 1.5 | Wood demand, implementation |
| Agricultural / Soil Carbon Storage | 20-100 | 3 | Existing practices, implementation |
| BECCS | 20-100 | 3.5-5.2 | Cost, biomass availability |
| DAC | >100 - 600 | 0 | Cost, scaling |
| Mineralization | 20 - >100 | unknown | Understanding |
| **Total** | | ***9.13-10.83*** | *National Academies Press, 2019* |




…and how do we know this sequestration will be *permanent*?

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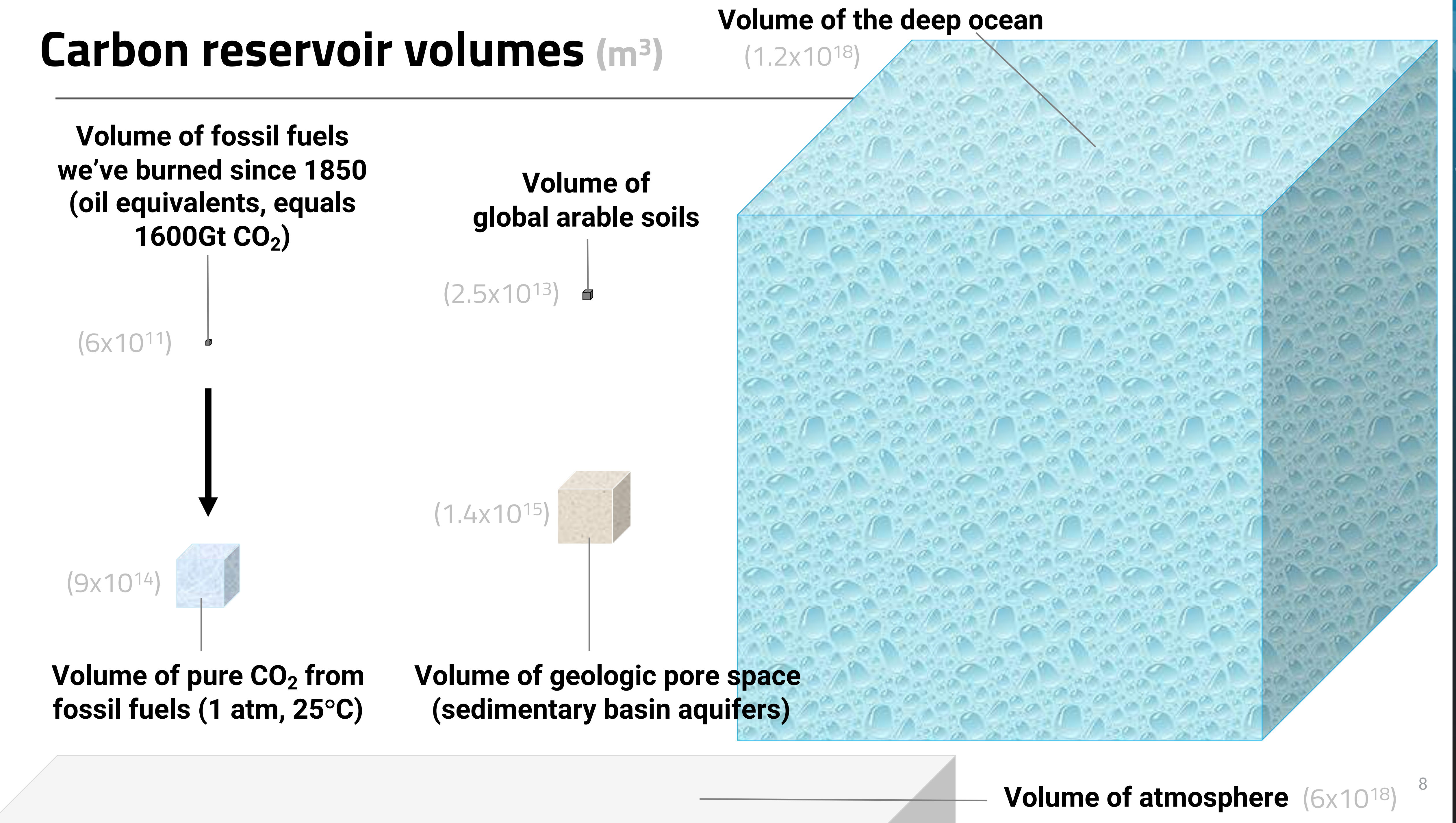
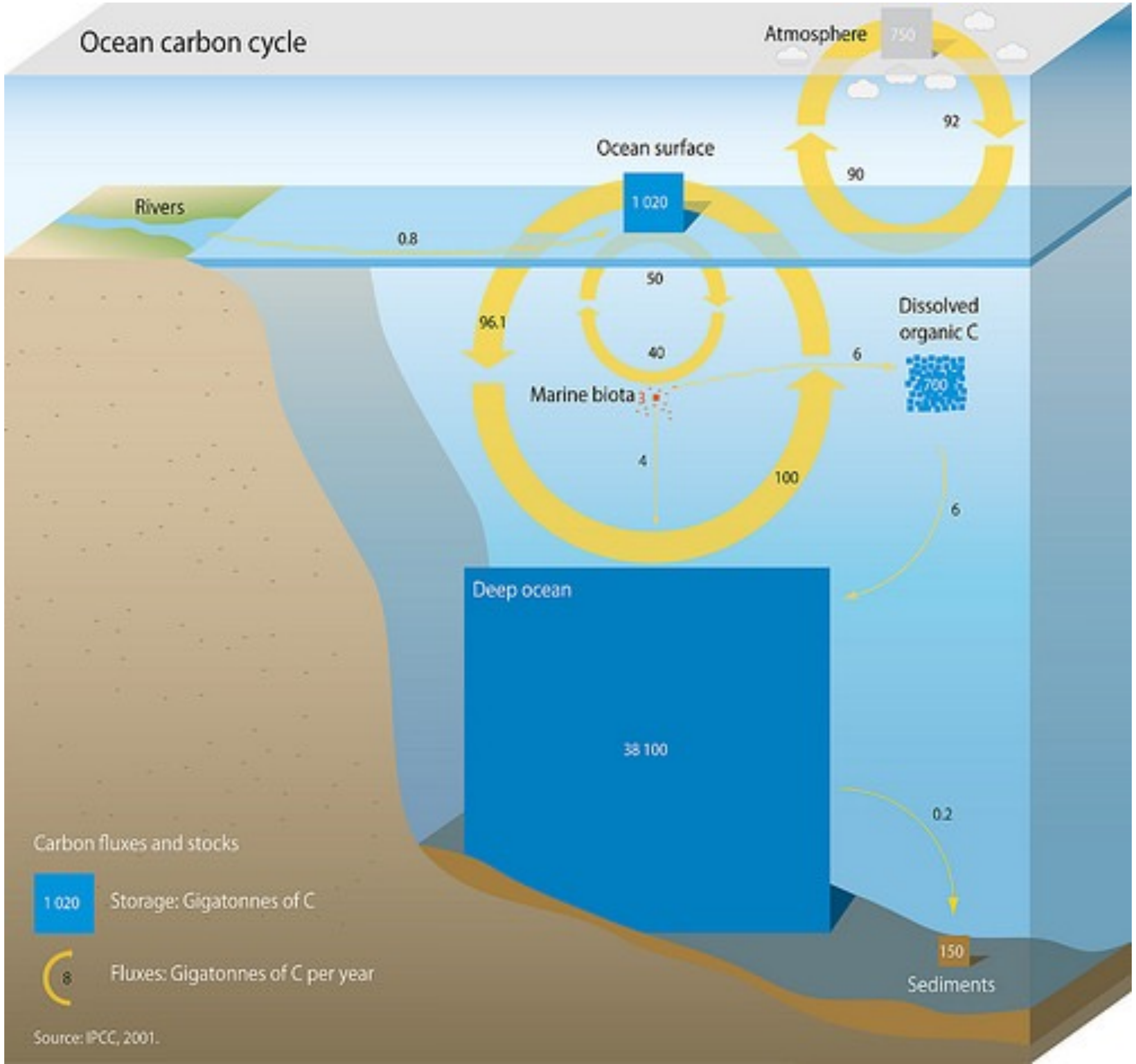
# Carbon reservoir volumes ($m^3$)

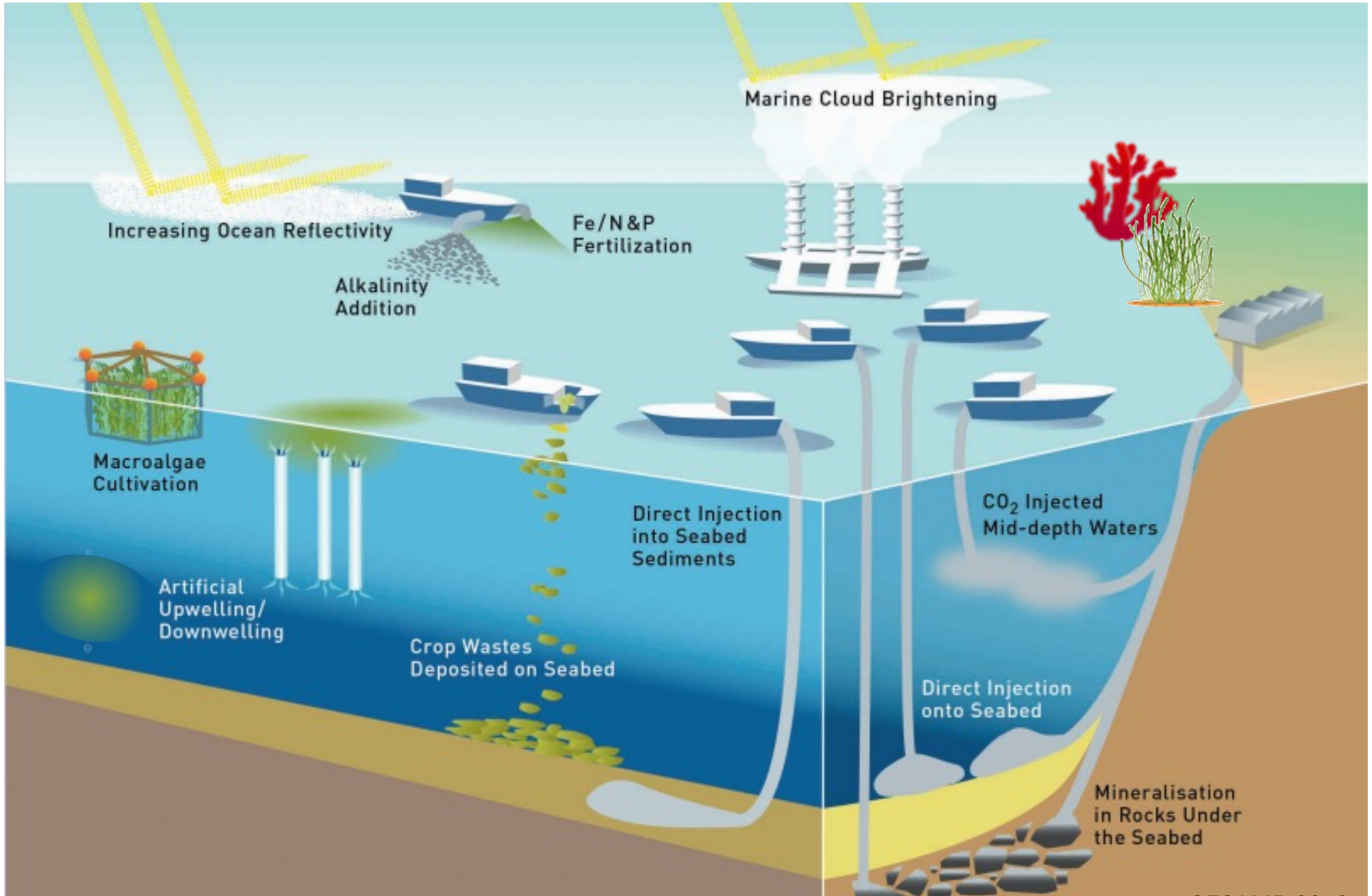


# The Ocean Carbon Cycle

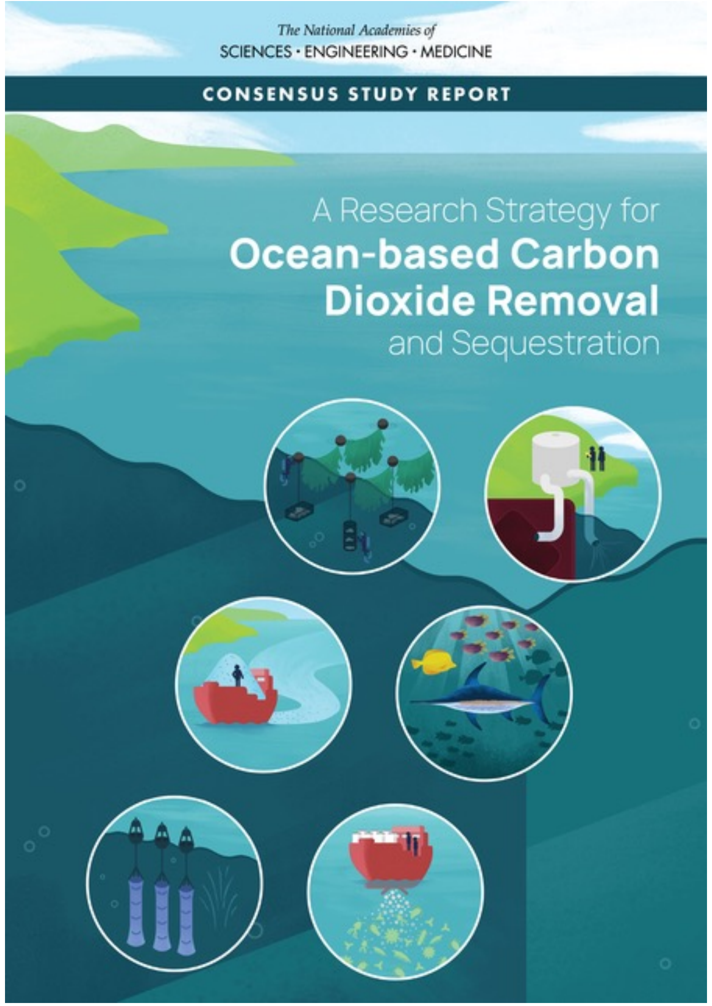
- 50 Gigaton Carbon (GtC) captured by biological processes per year
- 10 GtC biologically transported into the deep ocean
- 0.2 GtC entrained in deep sea sediment today



# Proposed marine Carbon Dioxide Removal (mCDR) Approaches




GESAMP 2019



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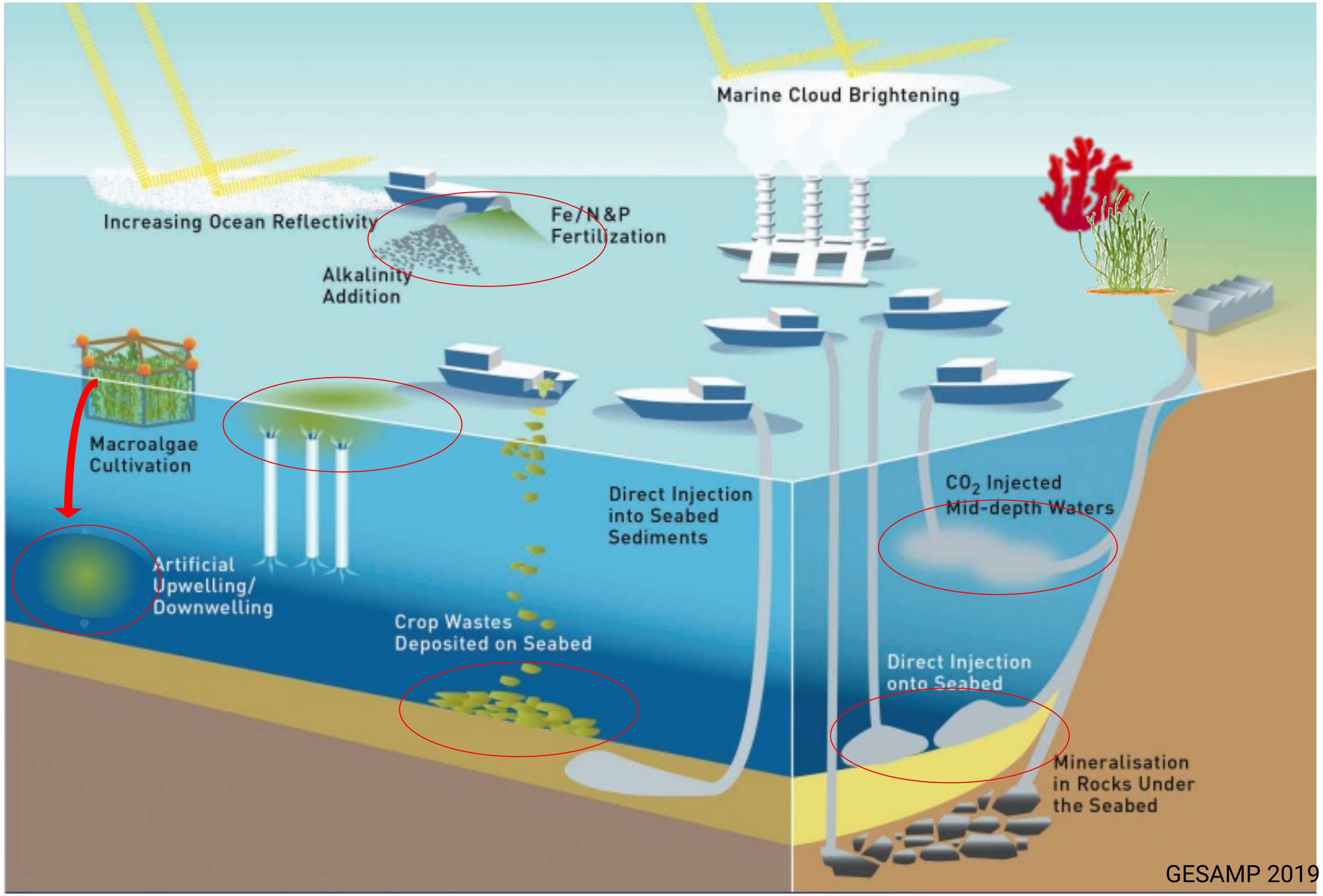


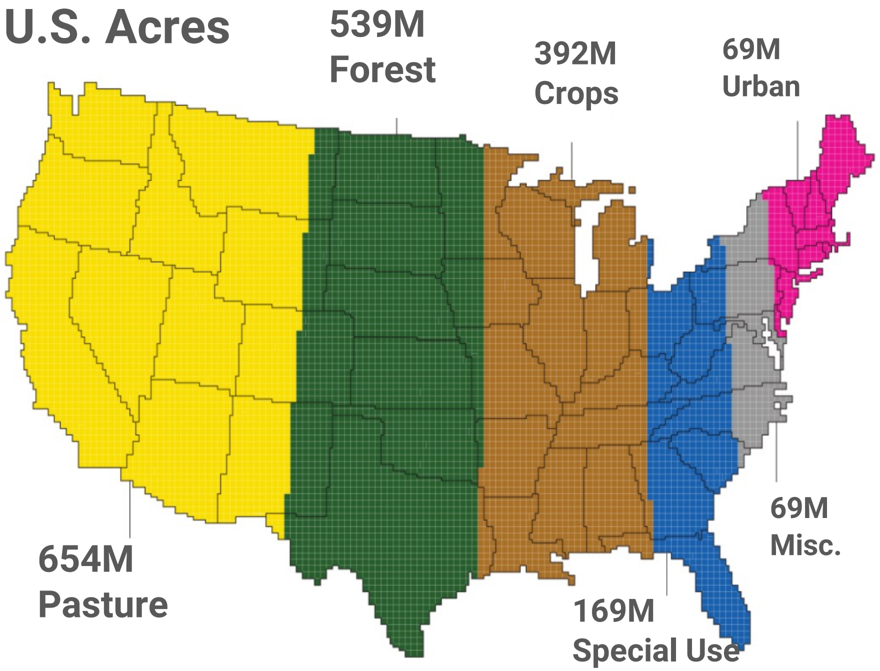

*Distributed Carbon Sinking Processes:*

- *Most scalable*
- *Requires least infrastructure*
- *Many are Biologically based*
- *Most challenging MRV?*

# Why Ocean CDR?

**Land use needs to be optimized to deliver energy, CDR, food, and ecosystem services**

- No land use conflicts
- Potential for greater economies of scale
- Positive environmental impacts (some)




## Other Considerations

- Climate impacts likely positive for MCDR, while negative for terrestrial bio-CDR

| **Today** | | **2050*** |
|---|---|---|
| ~50M, Biofuels<br>~7M, Renewables | ➡ | +70M, E- B+<br>+250M, E+ RE+ |

*Princeton Net-Zero America
E- B+ = High Biomass
E+ RE+ High Electrification, 100% Renewable

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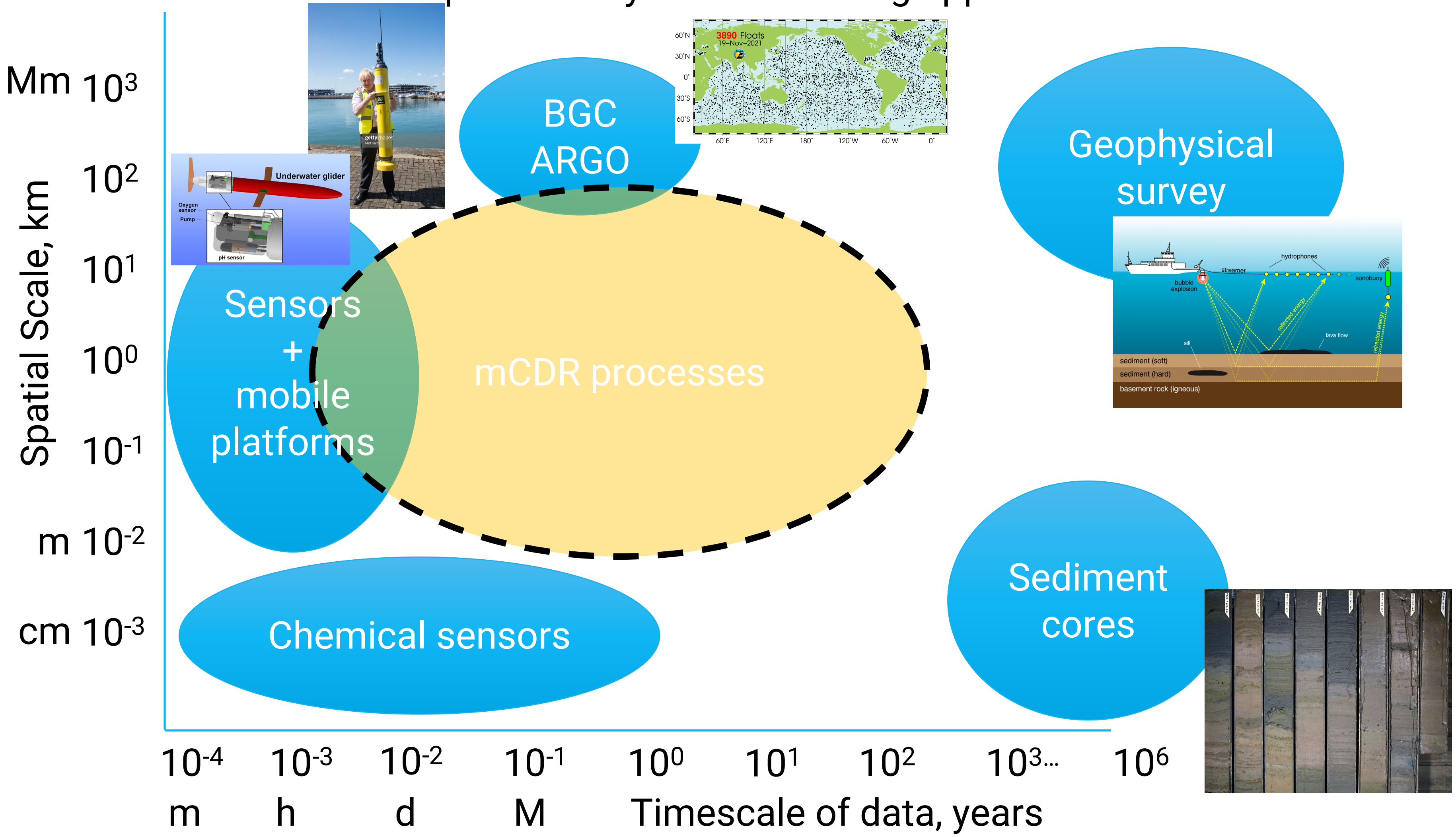
# Ocean CDR Measurement Challenges: Time and Distance

Scale limits of present-day carbon sensing approaches

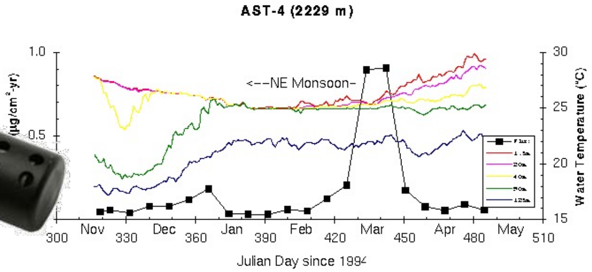


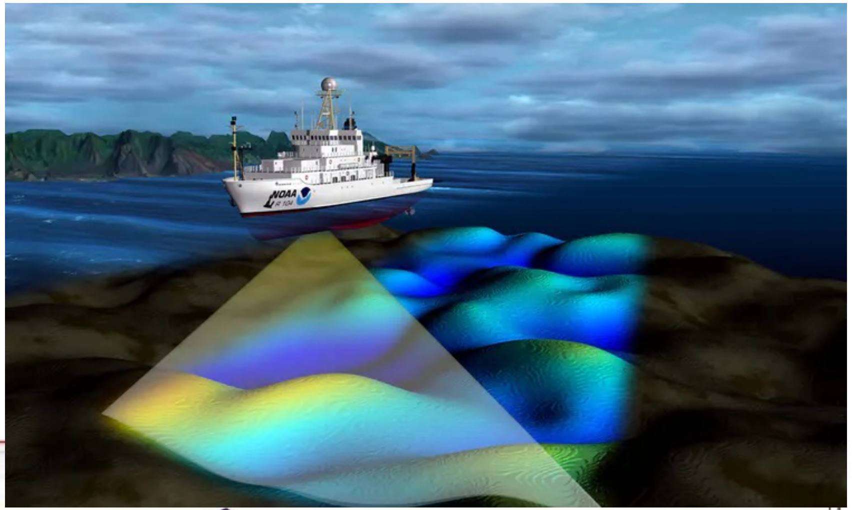
# Transformative Carbon Sensing Approaches

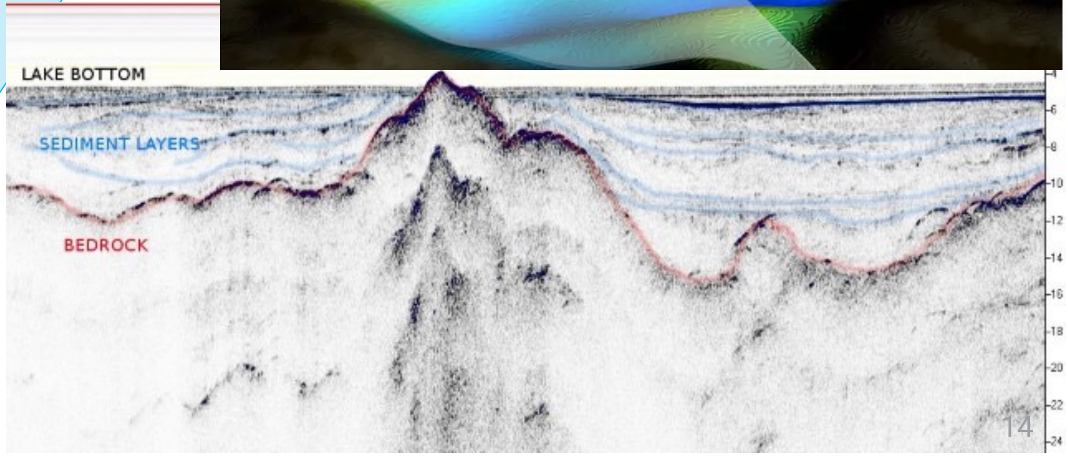
Emphasis on ‘remote’ sensing - where the water sample is not co-located with the sensor.

Physics-based (vice electrochemistry based) inferential techniques – do not drift as chemical sensors may do.

The goal: ‘Point’ to ‘swath’ sensing for transformational area vs. time capability.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# Transformative Carbon Sensing Approaches

Carbon contributions to ocean chemistry

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H+ + CO_3^{2-}$$

Carboxylic Acid

Bicarbonate

Carbonate

Ties the reaction to pH

Dissolved Inorganic Carbon (DIC)

\+ Dissolved Organic Carbon (DOC)
\+ Particulate Organic Carbon (POC)

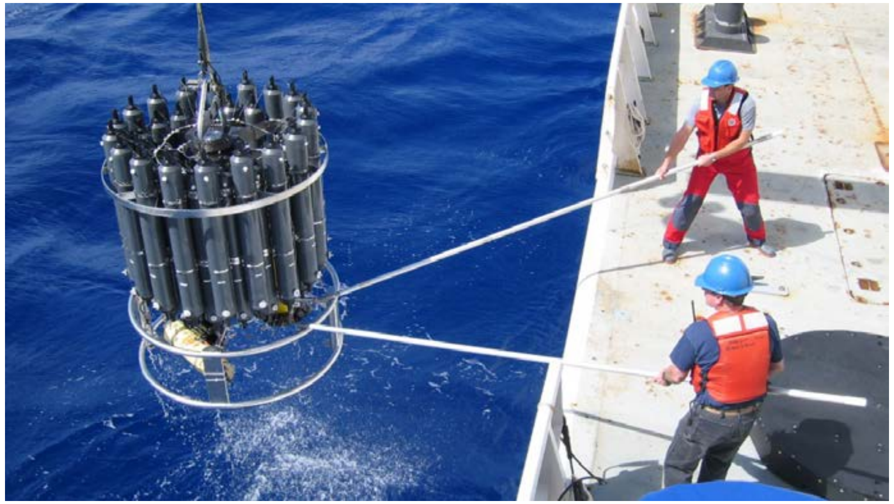
# Example: Seawater Ocean Carbon Measurement Techniques Today

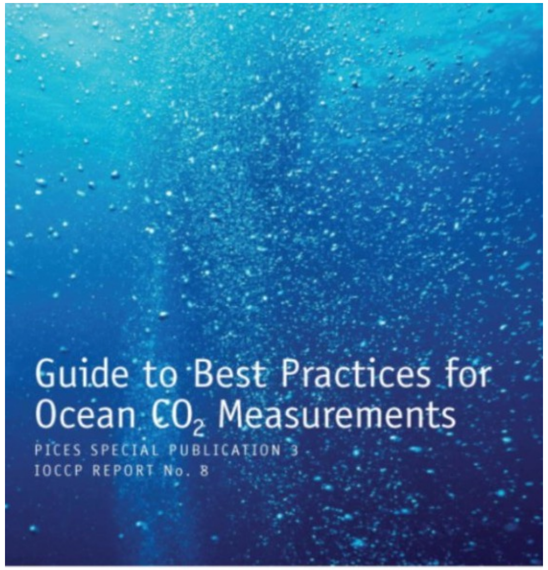
- Point measurements, direct sampling and laboratory titrations.
- Some optical (IR absorption) techniques in closed-volume systems
- Emphasis on accuracy and calibration

What are the grand challenges?
1. Paradigm shift in ocean chemical sensing
2. Inexpensive, scalable, deep-water access

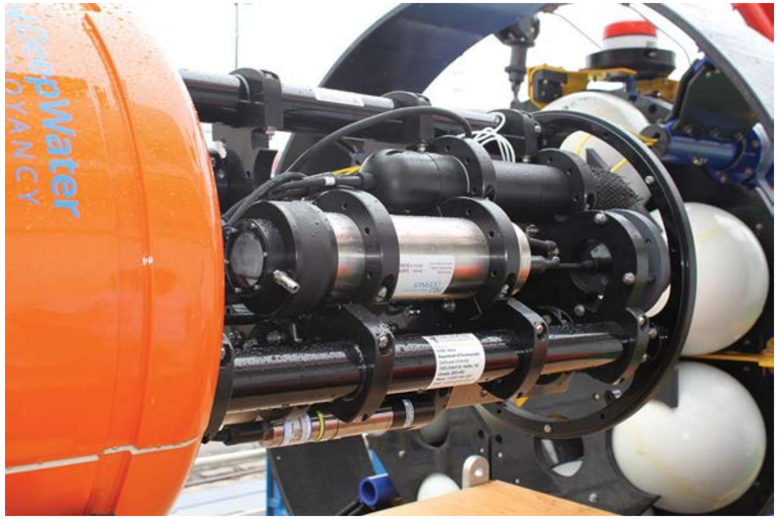

pCO2 sensing via IR sample: 2.5 min per sample

Niskin bottle full wet-chemistry assay: ~4h for 6000 m



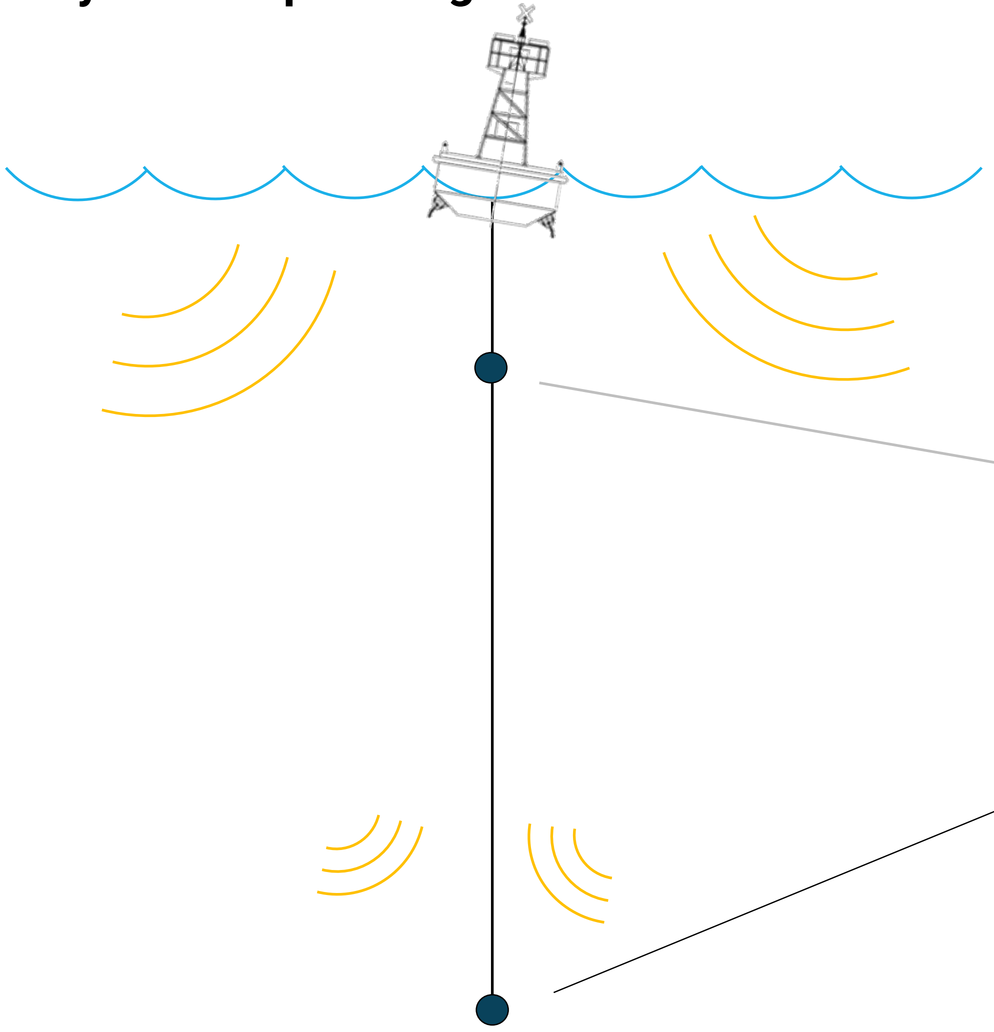


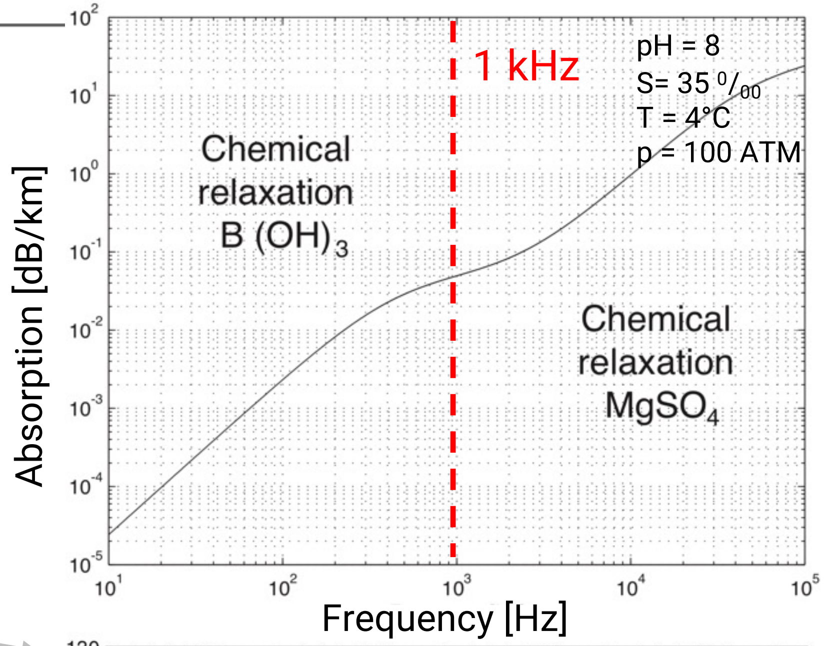

NOAA/NCEI Handbook

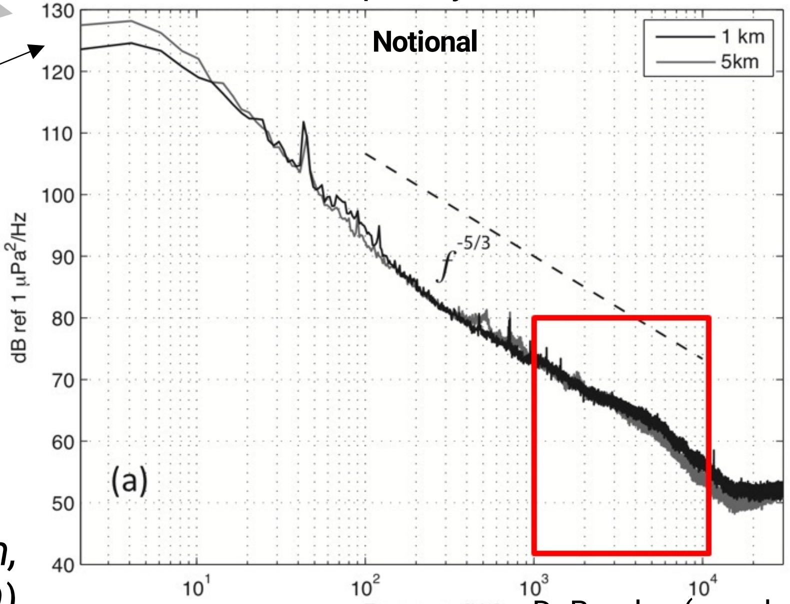


# Example: Volumetric pH Sensing via Ambient Noise

**Passively resolve pH using ambient noise:**



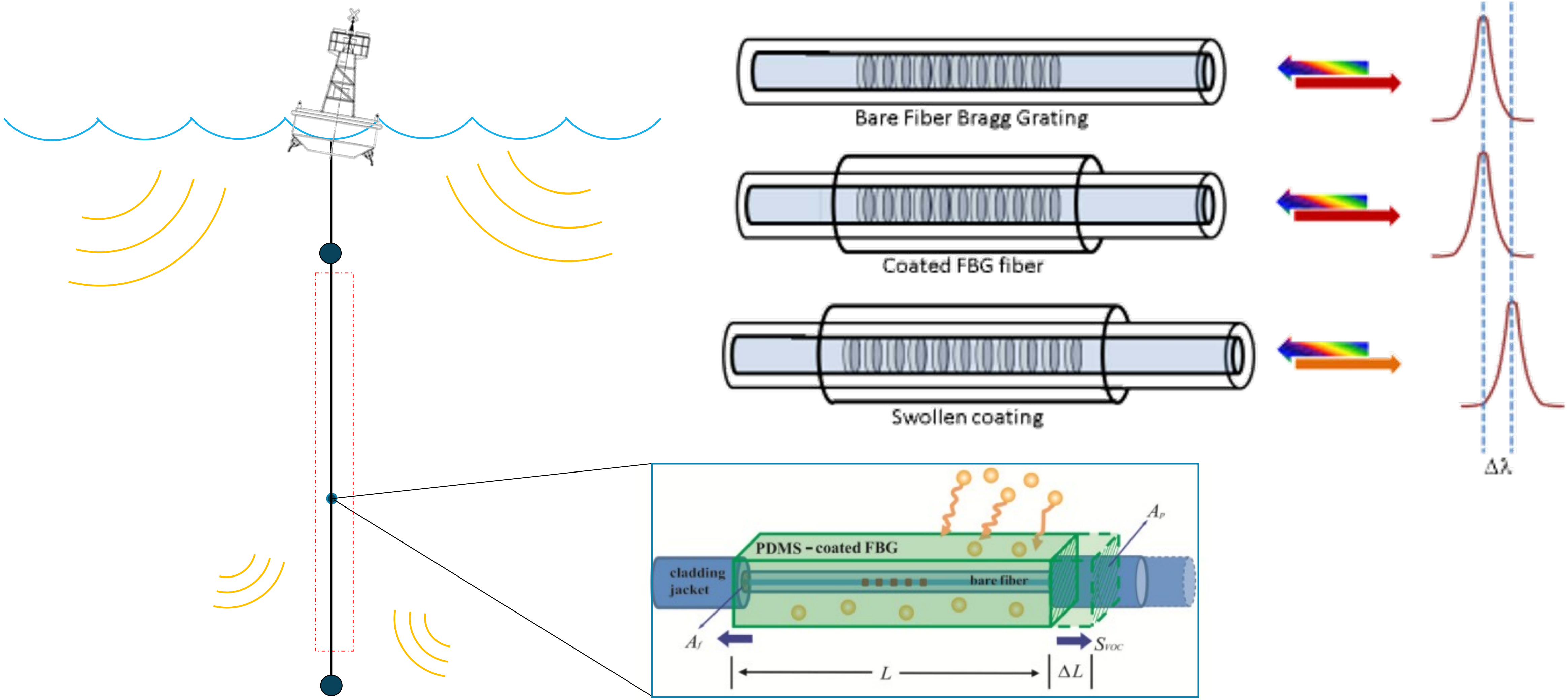



*Ambient noise Spectra at 1 km and 5 km, Philippine Sea (PhilSea '09)*

D. Barclay (unpub.)

# Example: Fiber Bragg Grating Arrays for DIC Measurement

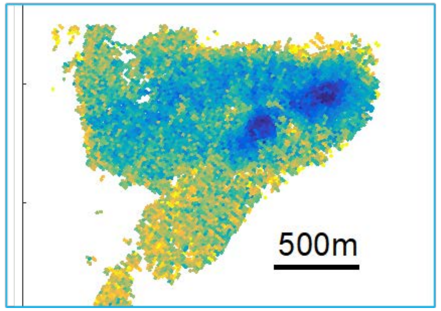




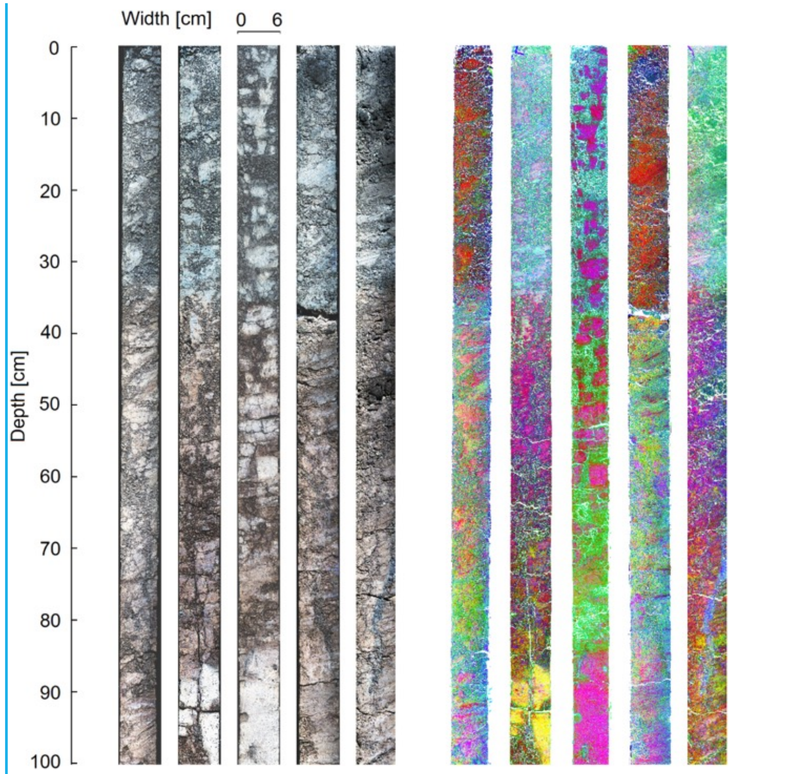
Rao Y J **1997** In-fibre Bragg grating sensors Meas. Sci. Technol. 8 355–75.
Kerstin Schroeder et al 2001 Meas. Sci. Technol. 12 757
Techlink, techlinkcenter.org.

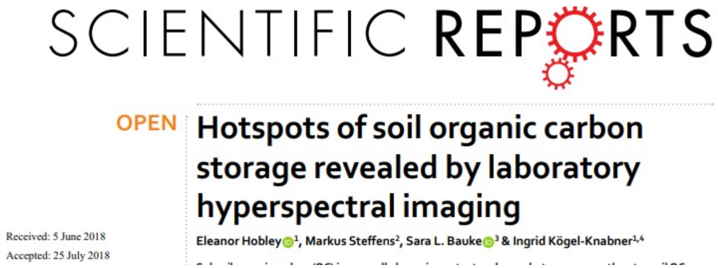
# Example: Hyperspectral Evaluation of POC

## Hyperspectral sensing of Particulate Organic Carbon




ARPA-E MARINER, UCSB/WHOI





SCIENTIFIC REPORTS

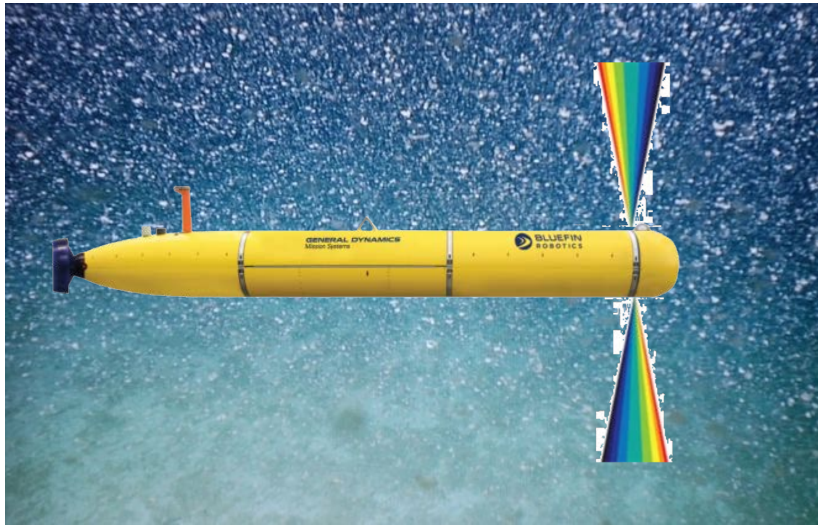
OPEN

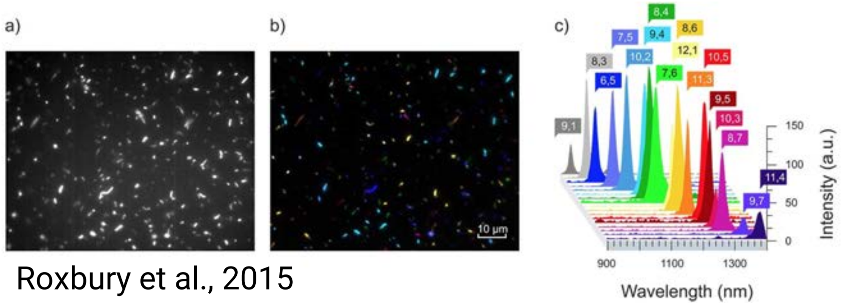
Hotspots of soil organic carbon storage revealed by laboratory hyperspectral imaging


Received: 5 June 2018
Accepted: 25 July 2018



Eleanor Hobley[1], Markus Steffens[2], Sara L. Bauke[3] & Ingrid Kögel-Knabner[1,4]

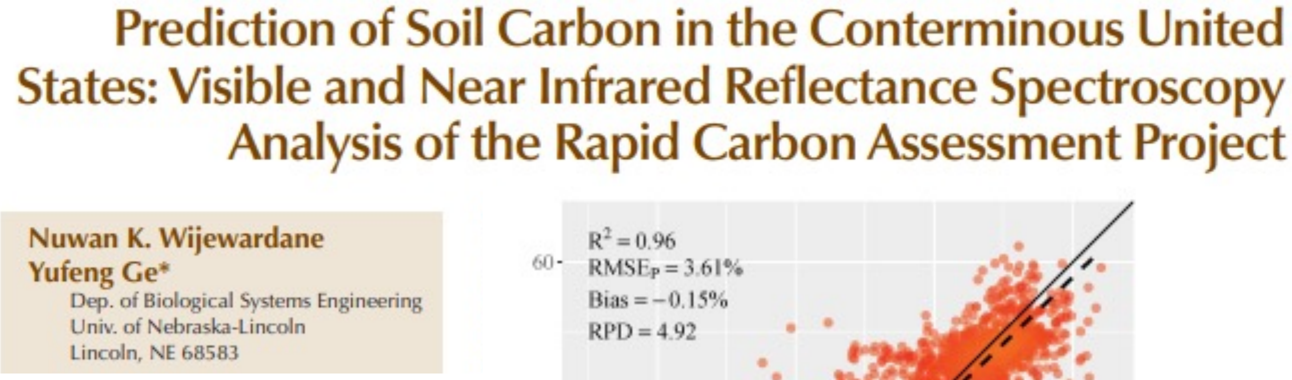



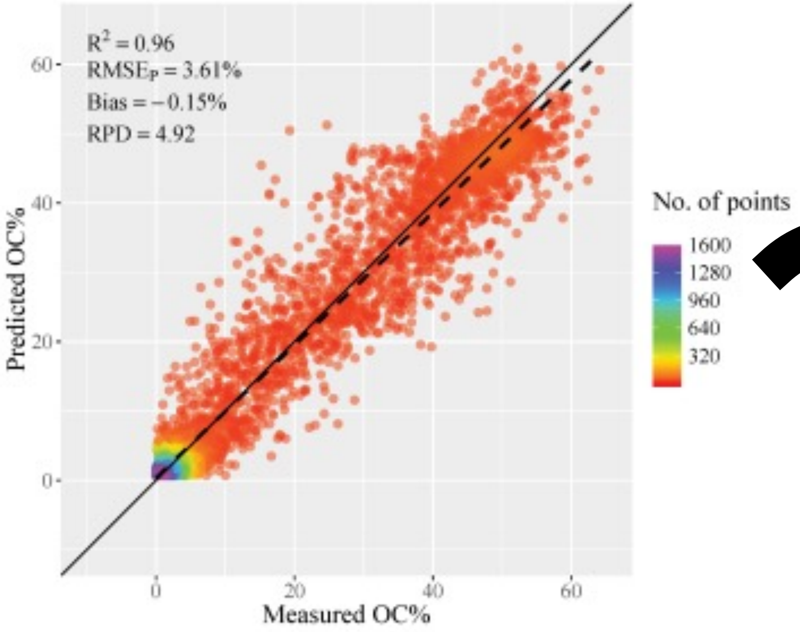

Roxbury et al., 2015

# Example: Computer Vision Based Seafloor Carbon Estimation

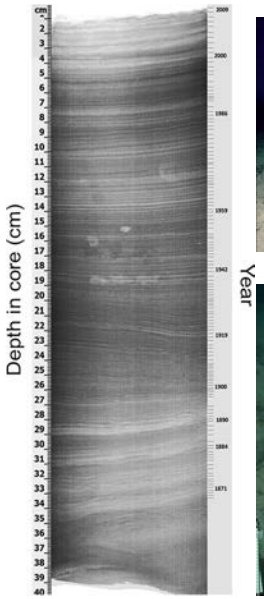
**Quantify sediment organic carbon rapidly and at scale**

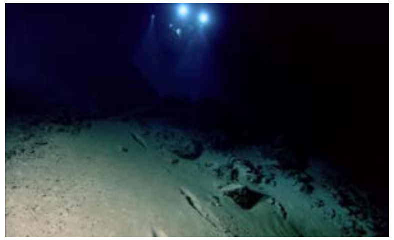

Prediction of Soil Carbon in the Conterminous United States: Visible and Near Infrared Reflectance Spectroscopy Analysis of the Rapid Carbon Assessment Project

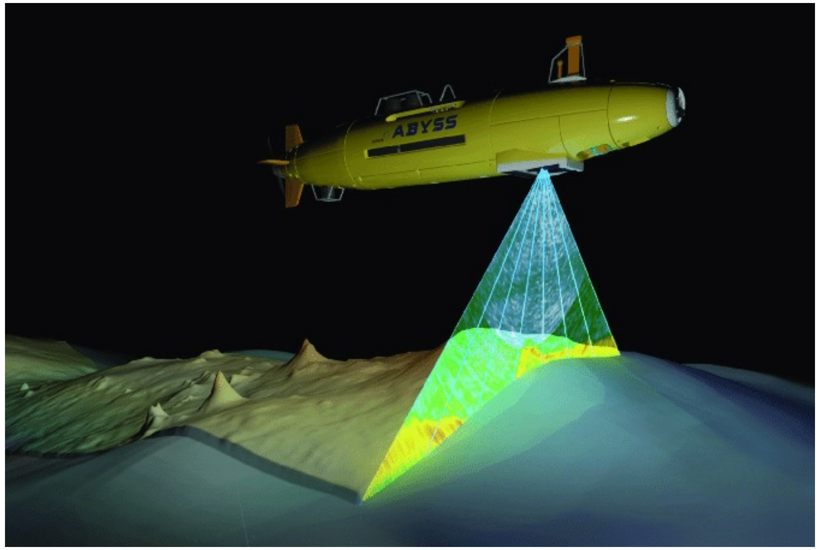
Nuwan K. Wijewardane
Yufeng Ge*
Dep. of Biological Systems Engineering
Univ. of Nebraska-Lincoln
Lincoln, NE 68583




*Wijewardane and Ge, 2017*



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# Workshop Approach

***Keynote Speakers:***

- Provide context and shared vision
- “State-of-the-art”
- What would they do to advance ocean CDR MRV, given the chance
- How MRV can create a viable ocean CDR industry

***Climate NGO/Philanthropic Panel:***

- Their interest in marine CDR
- Desired outcomes from an MRV program

***Four Breakout Sessions:***

1. Framing the challenge: High level, fundamental questions about marine CDR MRV
2. Temporal and spatial challenges: a timeline of operations and what’s needed at each step
3. Technical development areas: Sensors, platforms and models
4. Program planning, metrics and structure, technology-to-market strategies

# Final Notes

A multidisciplinary challenge, not just within science but also legislative, regulatory, financial and social.

- The best teams contain a diversity of skills and backgrounds
- Please engage folks outside your area of expertise!

We are looking for ‘white space’ where any publication may be seminal and risk of failure is high.

- “*The question is often harder than the answer*”
- “*Leave your hammers at the door*”

ARPA-E are here to listen to your ideas. Engage us and share your vision for how to enable a marine carbon market

Have Fun!