1921-2021
厦门大学
XIAMEN UNIVERSITY

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

POTENTIAL SYNERGIES BETWEEN MITIGATION AND ADAPTATION FOR OCEAN CARBON SINK AND HOW TO EVALUATE OPPORTUNITIES AND TRADEOFFS

surface.ocean solas lower.atmosphere.study

Minhan Dai

13th meeting of the SBSTA Research Dialogue
2 June 2021

MEL
近海海洋環境科學國家重點實驗室（厦門大學）
State Key Laboratory of Marine Environmental Science (Xiamen University)

OUTLINE

The ocean and humans are inextricably linked
(90% shipping; 50 % population)

Earth has one big ocean
with many features

The ocean makes Earth habitable

($50\%\ O_2$; H_2O cycle; 80 % habitable

"The Earth Needs the Ocean as Life Needs Water"
“海洋之于地球，犹如水之于人类”

features of Earth

weather and climate

(89% anthropogenic
heat; $30\%\ CO_2$)

The ocean supports
a great diversity of
life and ecosystems

The ocean is largely
unexplored

GLOBAL CARBON PROJECT

Fate of anthropogenic CO_2 emissions (2010–2019)

Sources = **Sinks**

34.4 $GtCO_2$/yr

86%

14%

5.7 $GtCO_2$/yr

18.6 $GtCO_2$/yr

46%

31%

12.5 $GtCO_2$/yr

23%

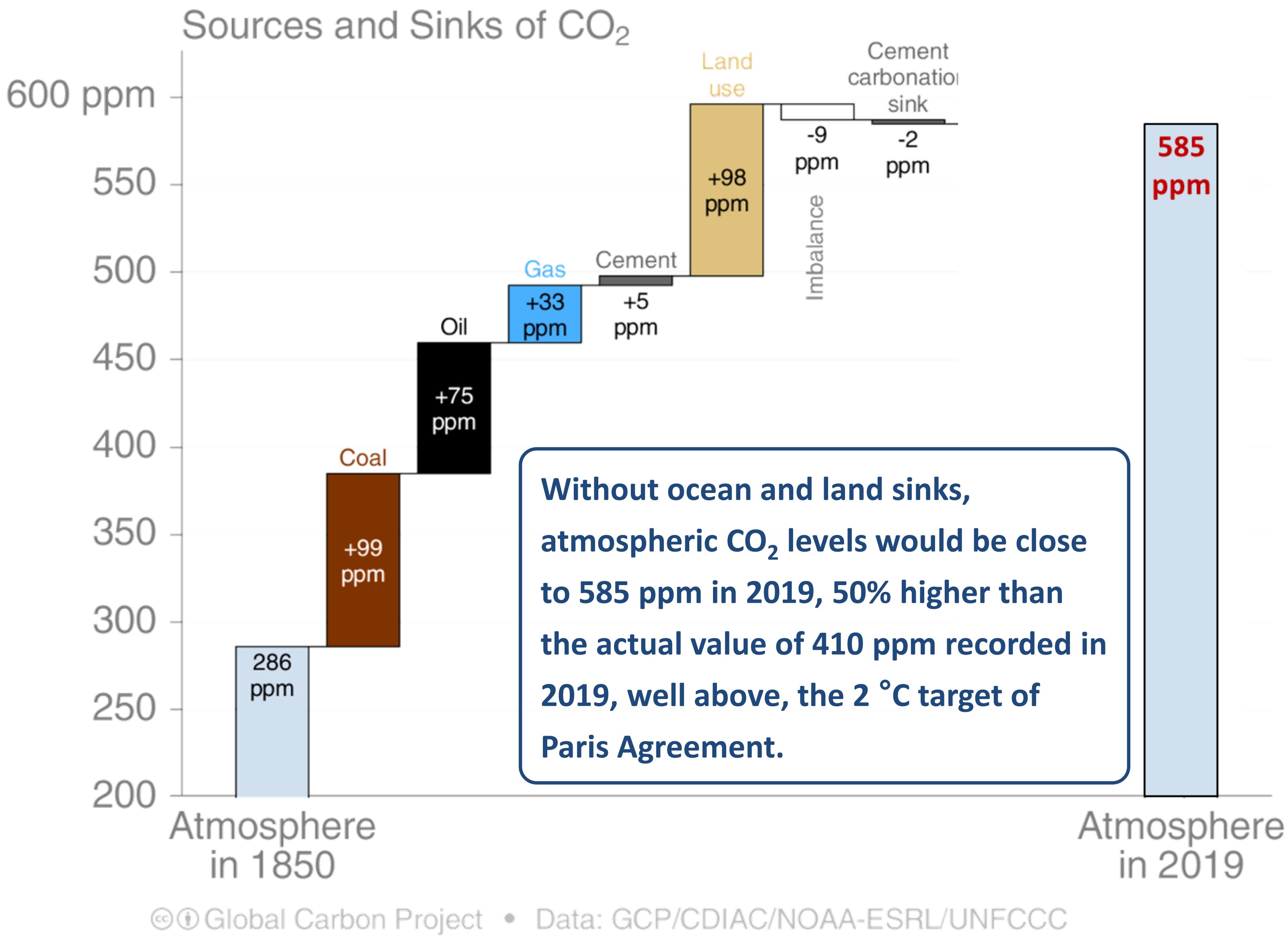
9.2 $GtCO_2$/yr

Budget Imbalance:
(the difference between estimated sources & sinks)

0.4%
0.2 $GtCO_2$/yr

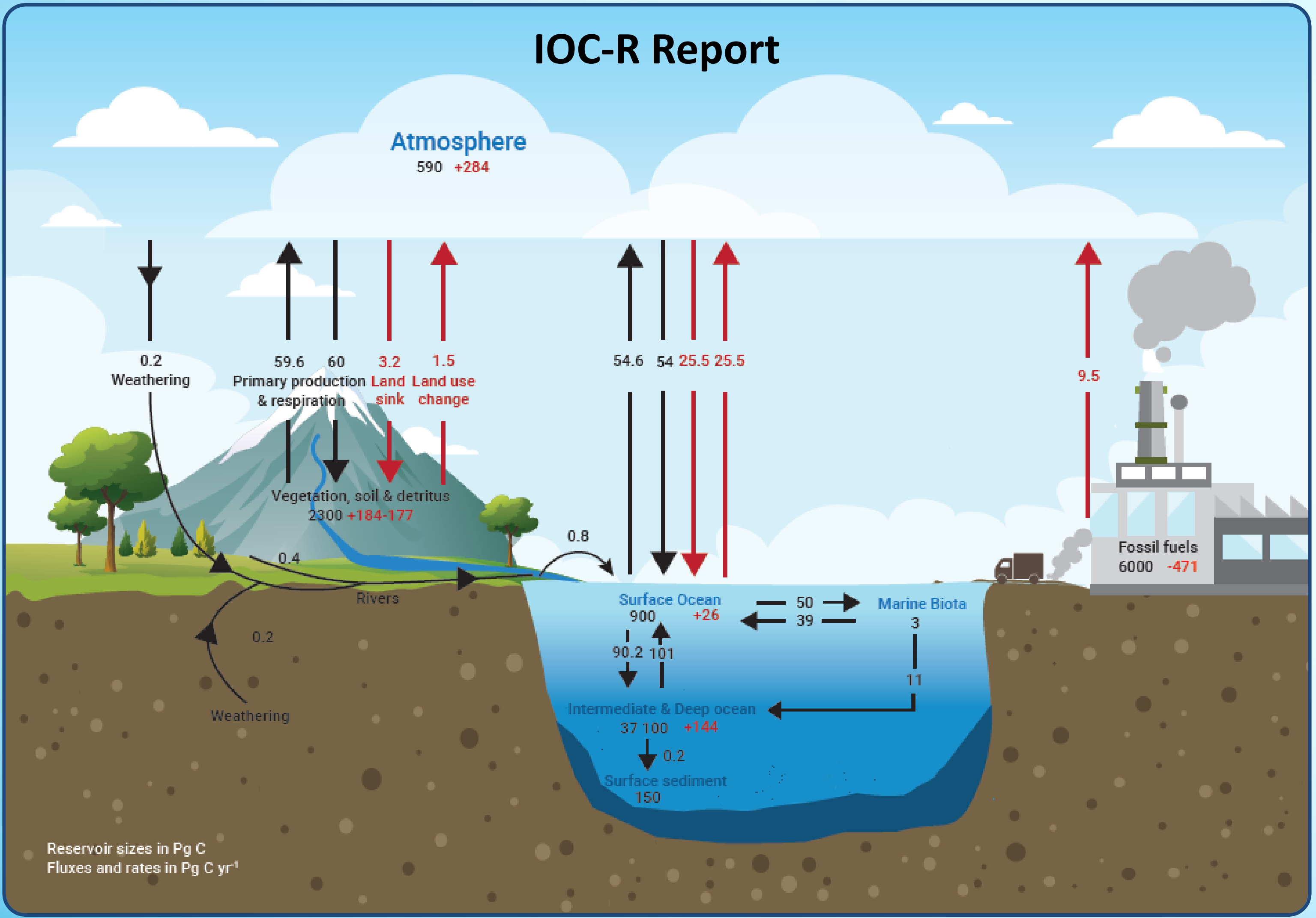
Source: Friedlingstein et al 2020; Global Carbon Budget 2020

Natural carbon sinks (land + ocean) have been of paramount importance



Without ocean and land sinks, atmospheric CO_2 levels would be close to 585 ppm in 2019, 50% higher than the actual value of 410 ppm recorded in 2019, well above, the 2 °C target of Paris Agreement.

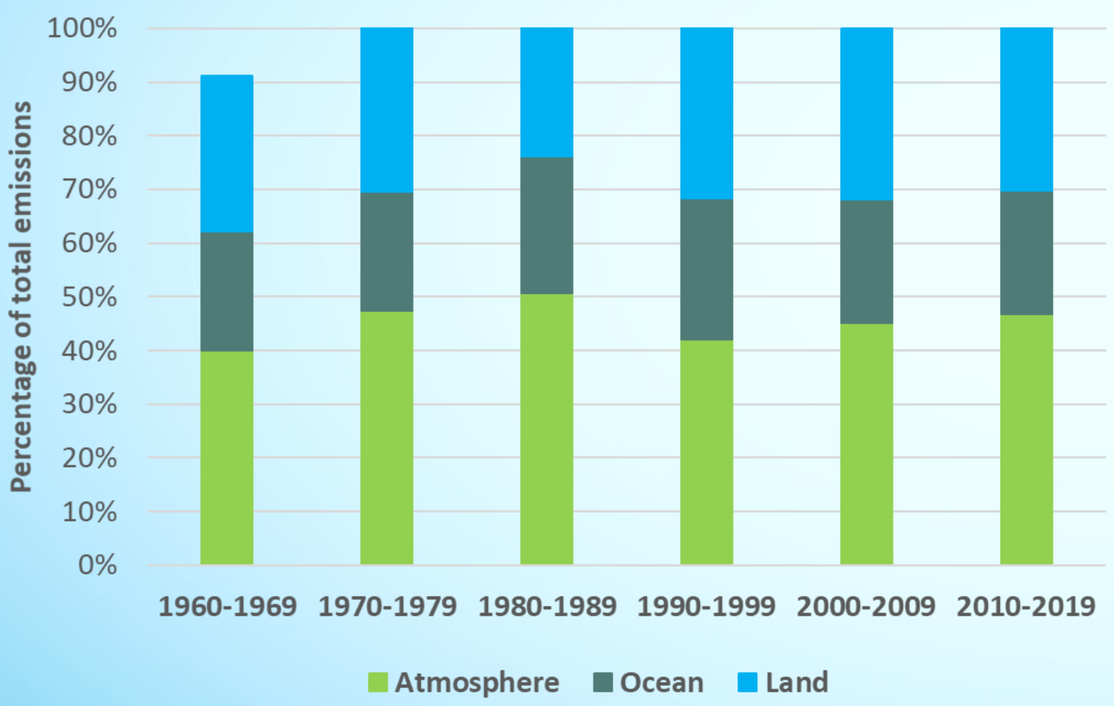
Major carbon reservoirs and fluxes of the global carbon cycle (2010-2020)



- The ocean contains > 90% of carbon contained in these reservoirs
- The ocean was a net source of carbon to the atmosphere of ~0.6 PgC/yr **in the pre-industrial Era.**
- The ocean is now a significant net carbon sink of ~1.9 Pg C/yr through an anthropogenic carbon uptake of 2.5 Pg C/yr.

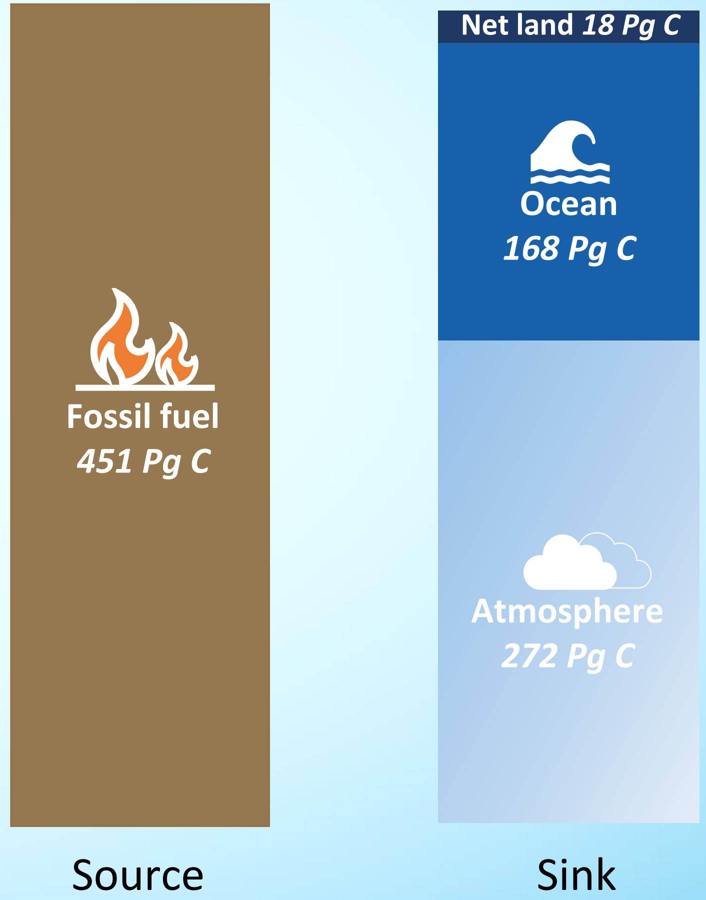
The Ocean is an important carbon sink and has been the only sustained carbon sink for the last 200 yrs

The Ocean mitigates 22-26 % of the anthropogenic CO_2 emissions comprised of fossil fuel and land use change during 1960-2019.



Data source: Friedlingstein et al. (2020)

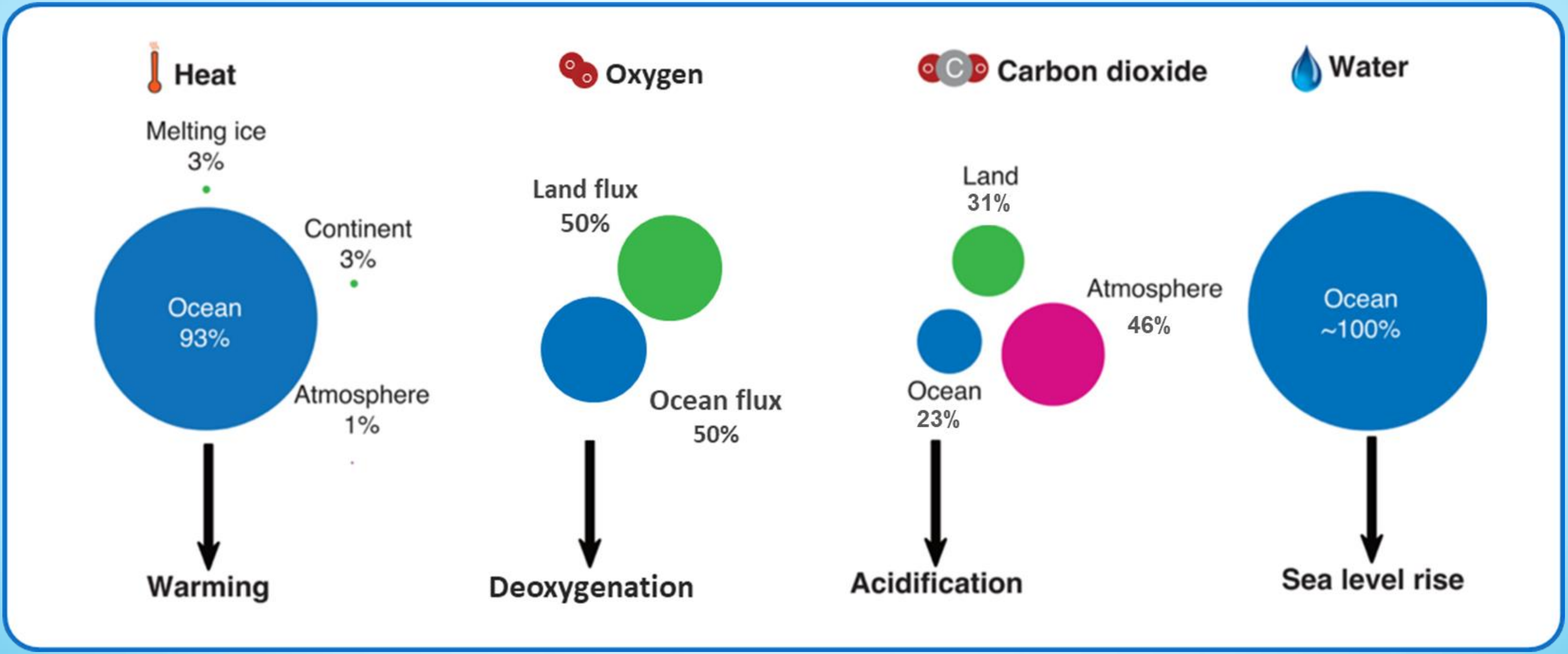
During 1875-2019, the ocean sink ~37% of fossil fuel CO_2 emissions, or ~25% of those from fossil fuel + land use change.



Adopted from IOC-R and updated using data from Friedlingstein et al. (2020)

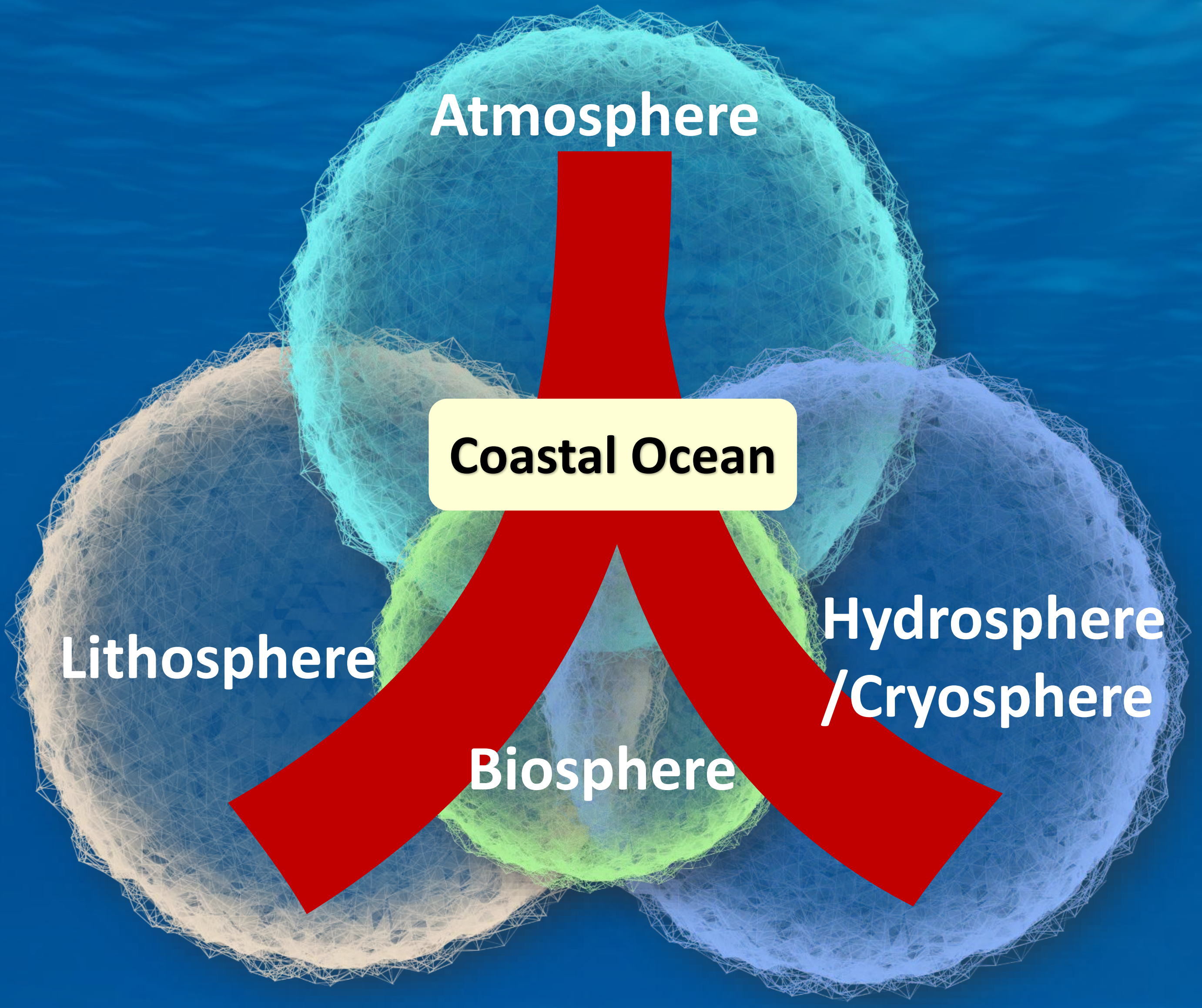
The question of whether the ocean will continue to act as a sink for carbon being emitted into the atmosphere as a result of human activities is of fundamental importance for climate science and climate policy, e.g., climate-carbon coupled systems & zero-emission strategies & actions.

Rising atmospheric CO_2 and climate change have been fundamentally altering marine ecosystems with concurrent shifts in temperature, circulation, stratification, ocean acidification and deoxygenation.



Modified based on Magan et al. (2015)

Coastal Systems & People



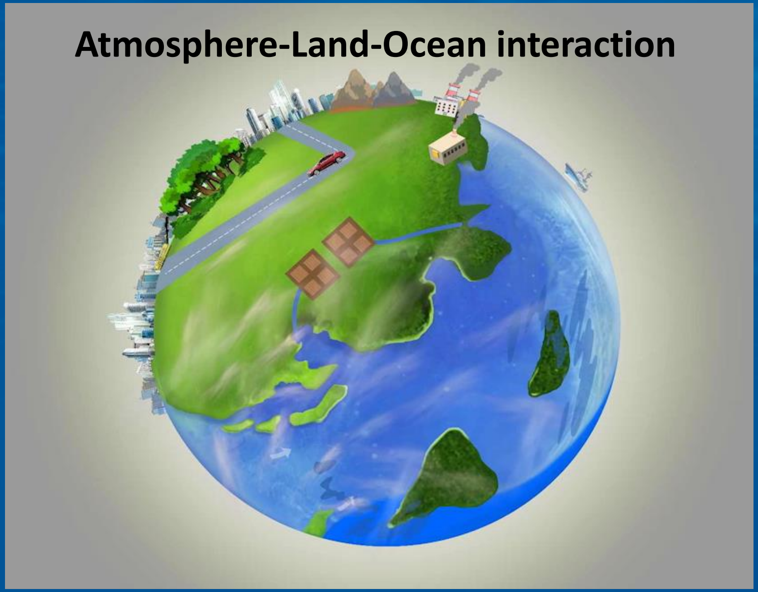
Modified from Gao Shu

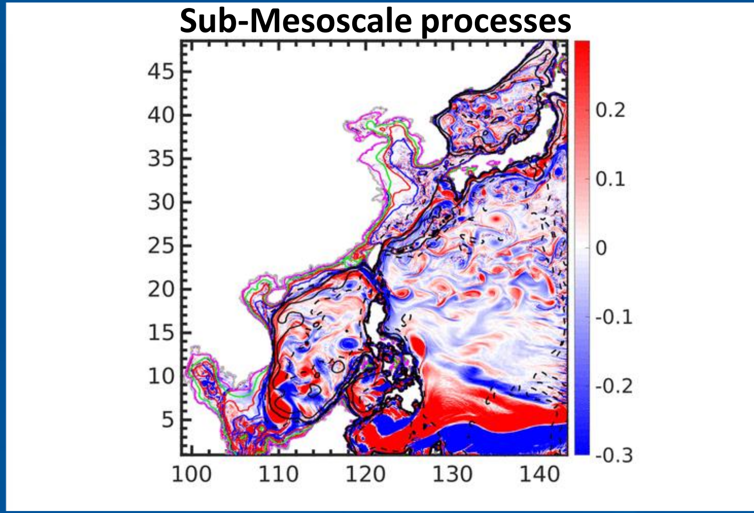
A special regime featuring Ocean-Sea-Land-Atmosphere interactions:

- ✓ Complex interfaces
- ✓ Abundant natural resources
- ✓ Fragile ecological environment
- ✓ Intensified human activities

- ✓ 7% of the global ocean
- ✓ The main reservoir of biodiversity and ecosystem diversity: species abundance ~97%
- ✓ Marine primary productivity ~25%, and fish catches ~86%
- ✓ Carbon sink ~21%, organic matter ~80%; blue carbon ~50%
- ✓ ~30% of global crude oil production

Extremely dynamic human-ocean interfaces & main engine of world economic development in the past 50 years

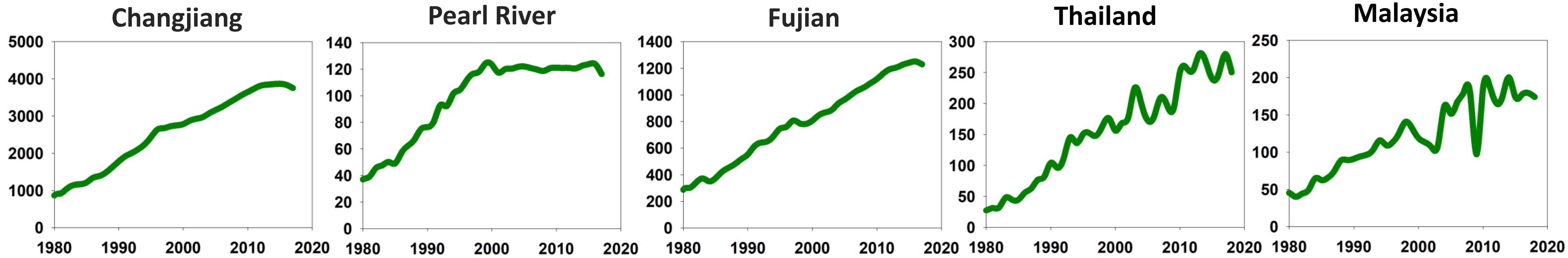




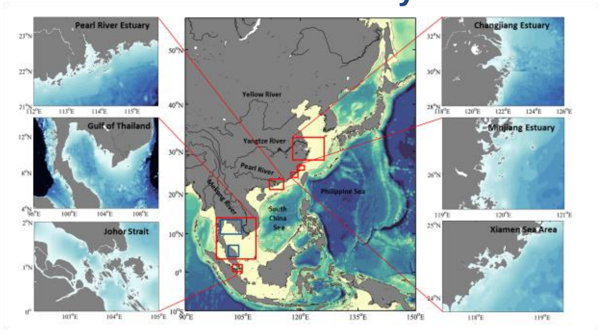
Coastal zone have been and will be the main population growth area in the world (70% of mega-cities, ~50% GDP), especially in China (55% of mega-cities, ~60% GDP)

Fertilizers - ”invisible” land-based pollutants have caused chain reactions in carbon & oxygen in coastal oceans worldwidely

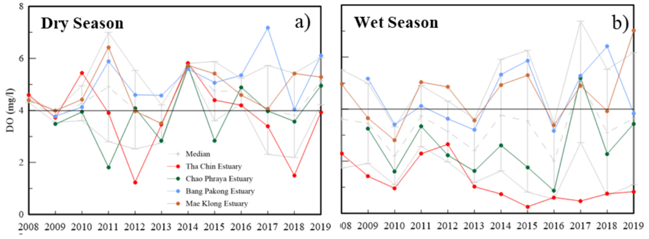
Fertilizer consumption



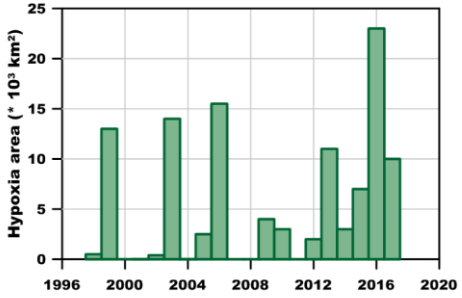
Six Model Coastal Systems

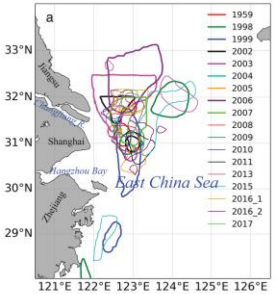


Upper Gulf of Thailand



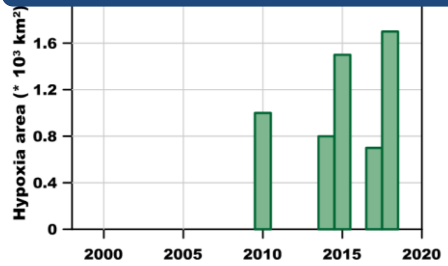
Hypoxia in Changjiang Estuary

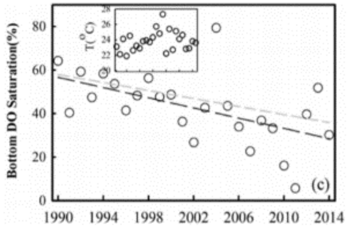




- The hypoxic area reached 20,000 km^2 in 2016, 3 times the area of Shanghai city, and has become one of the largest seasonal hypoxic zones in the world.

Hypoxia Pearl River Estuary





- In the last decade, summer hypoxia was frequently observed off the Pearl River Estuary with an increasing area and intensity

Integrated Ocean Carbon Research: A Summary of Ocean Carbon Knowledge and a Vision for Coordinated Ocean Carbon Research and Observations for the Next Decade

Research Needs:

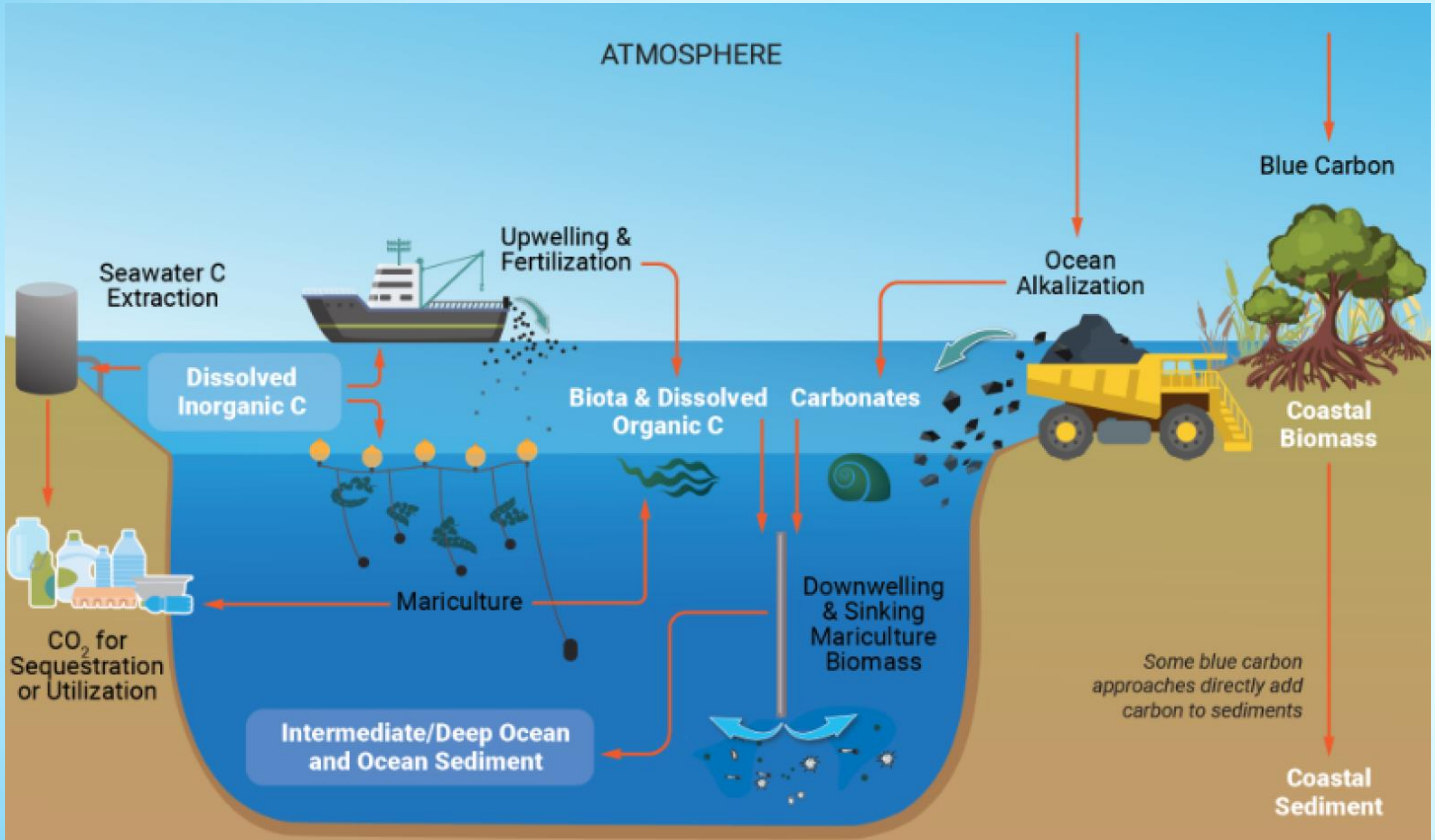
- Will the ocean uptake of anthropogenic CO_2 continue as primarily an abiotic process?
- What is the role of biology in the ocean carbon cycle, and how is it changing?
- What are the exchanges of carbon between the land-ocean-ice continuum and how are they evolving over time?
- How are humans altering the ocean carbon cycle and resulting feedbacks, including possible purposeful carbon dioxide removal (CDR) from the atmosphere?

Policy implications:

- the ocean as a [changing] sink for human-produced CO_2 and its climate change mitigation capacity
- Vulnerability of ocean ecosystems to increasing CO_2 levels
- Our ability and need to adapt to changing ocean conditions.

OUTLINE

Marine Carbon Dioxide Removal



EFI, 2020

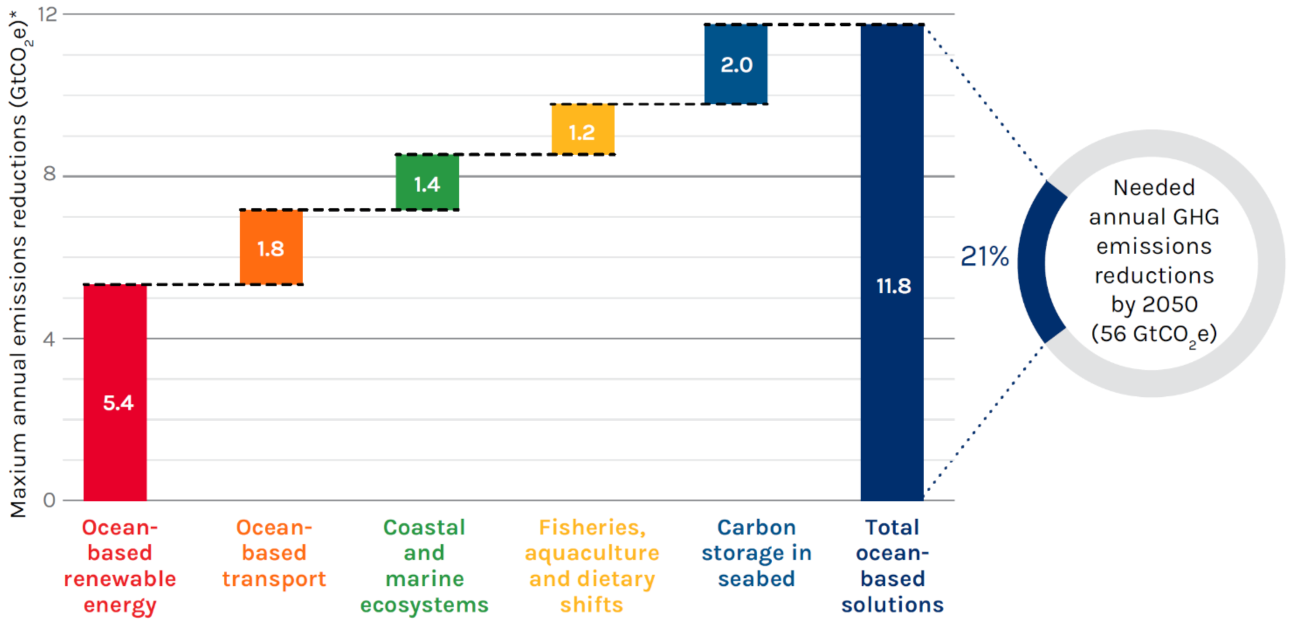
Biological pathways:

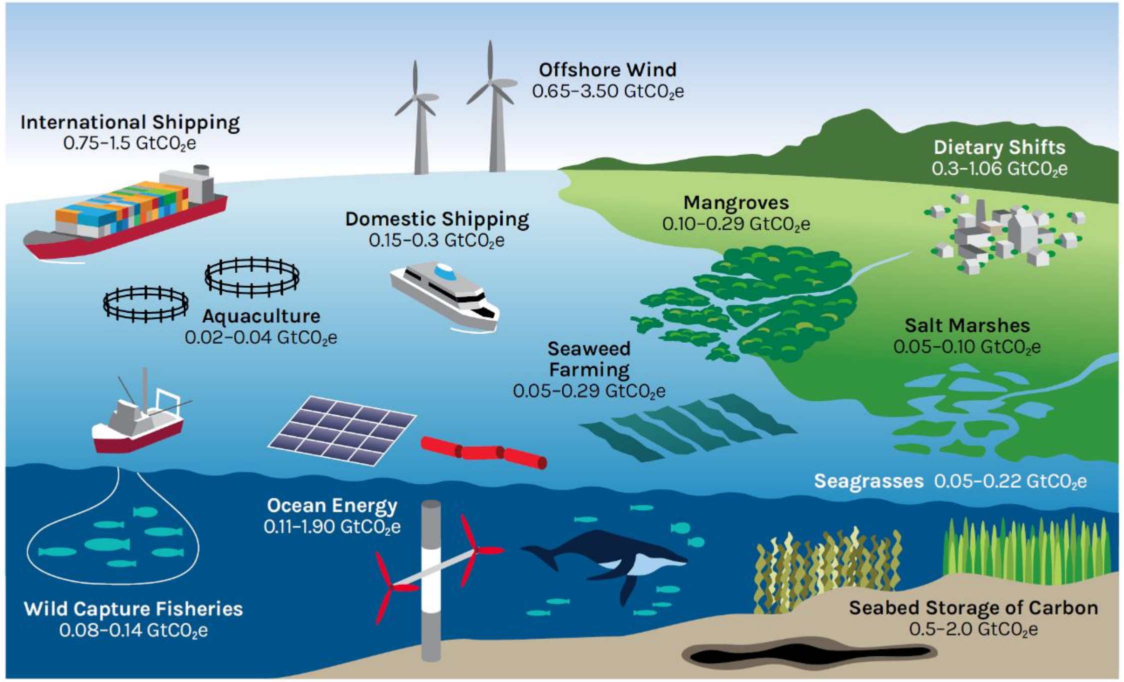
- coastal ecosystem restoration;
- enhanced microalgae cultivation, including boosting surface ocean nutrients through fertilization or upwelling;
- increased cultivation and harvesting of marine-based plants;
- downwelling of seawater as a means of sequestering CO_2 dissolved in upper ocean waters.

Chemical pathways:

- ocean alkalinization;
- electrochemical extraction of carbon from seawater.

Ocean-based Mitigation Options Associated Annual Mitigation Potential in 2050



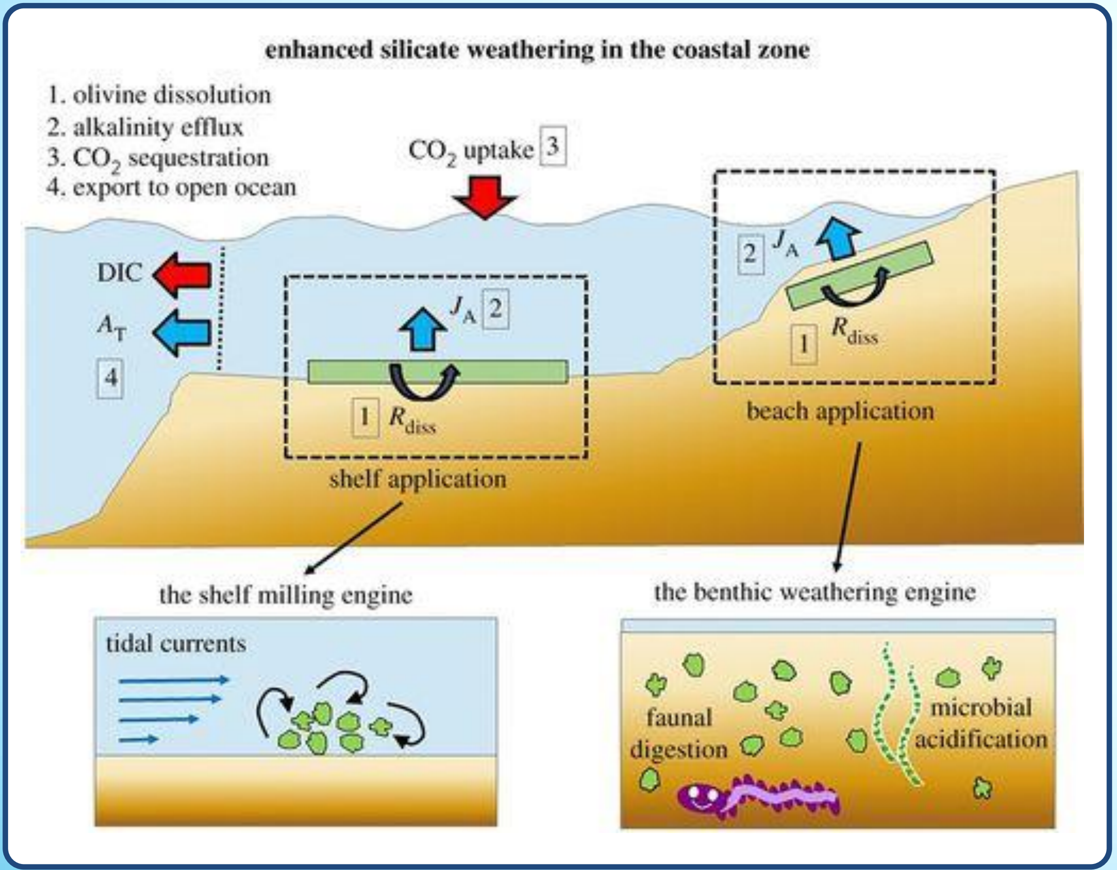


Hoegh-Guldberg et al. (2019)

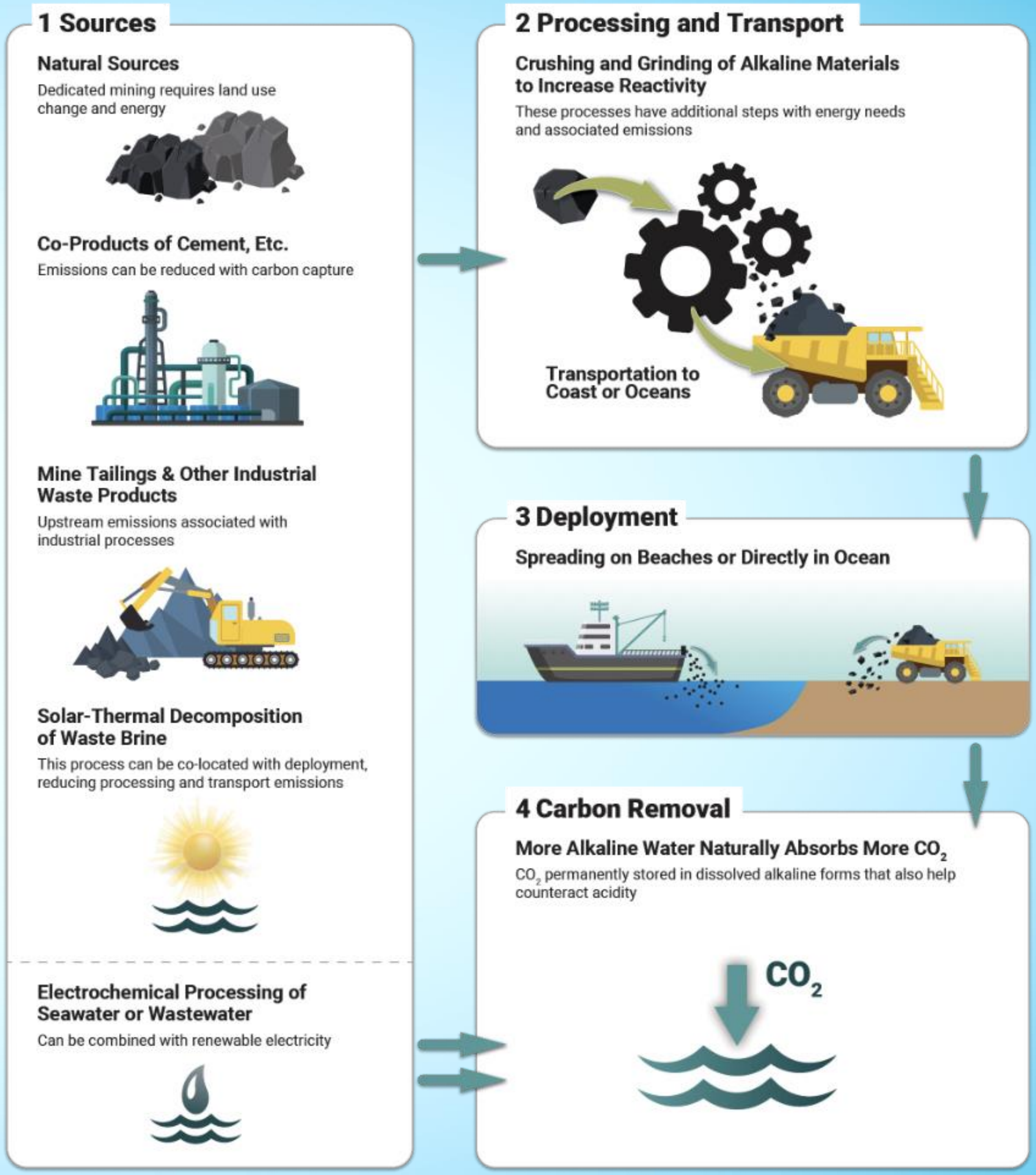
- Ocean-based mitigation options could reduce global GHG emissions by ~4 billion tones of CO_2 equivalent per annum in 2030 and by >11 billion tones per annum in 2050, reducing the “emissions gap” by up to ~21% on a 1.5°C pathway, and by a~25% on a 2.0°C pathway
- Reductions of this magnitude are larger than the annual emissions from all current coal-fired power plants worldwide.

Artificial ocean alkalinization (AOA)

Increase the alkalinity of the upper ocean to chemically increase the carbon storage capacity of seawater and thus, increase CO_2 uptake.

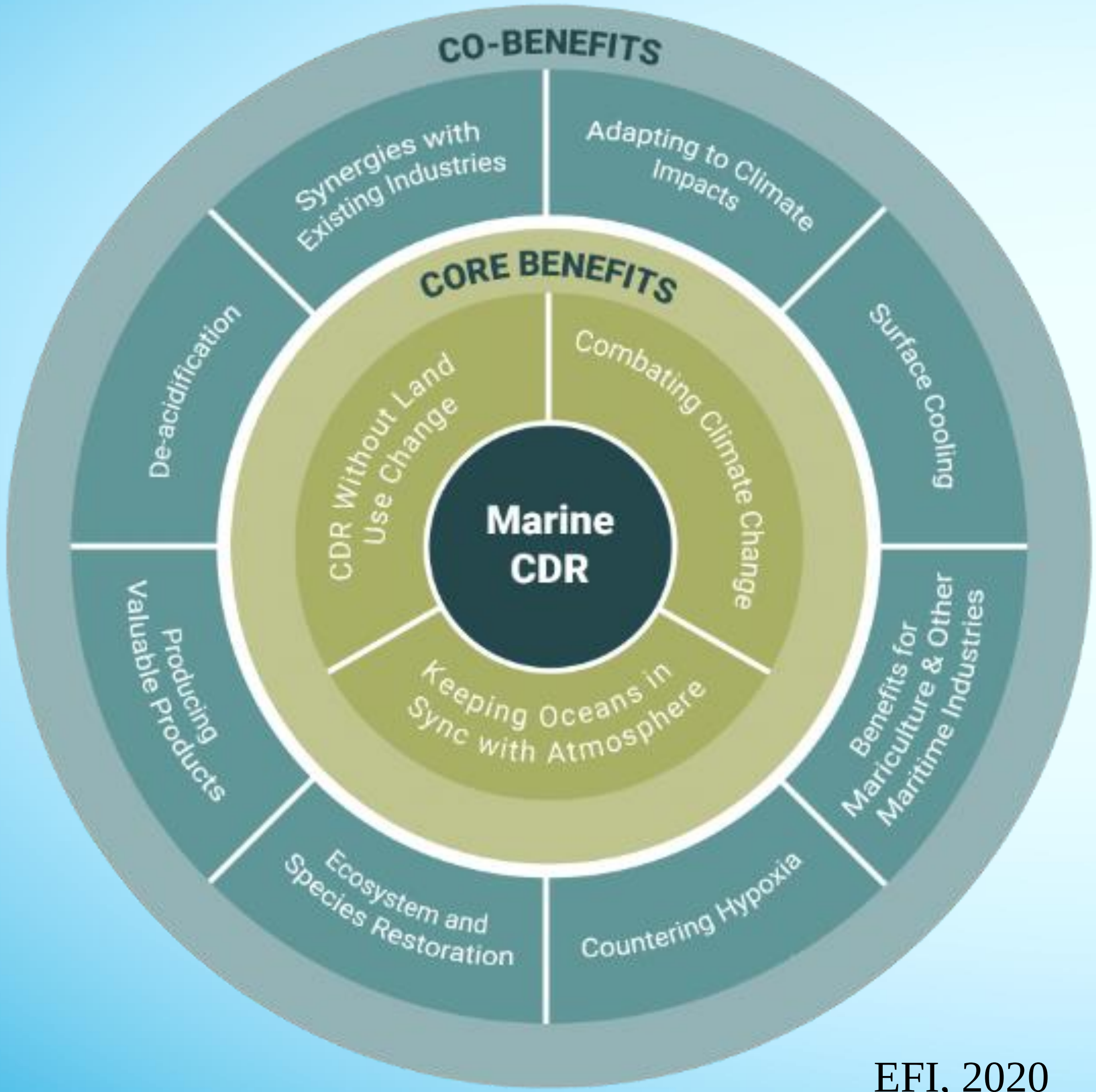


Renforth et al. (2017)



EFI (2020)

Potential Co-benefits of Marine CDR



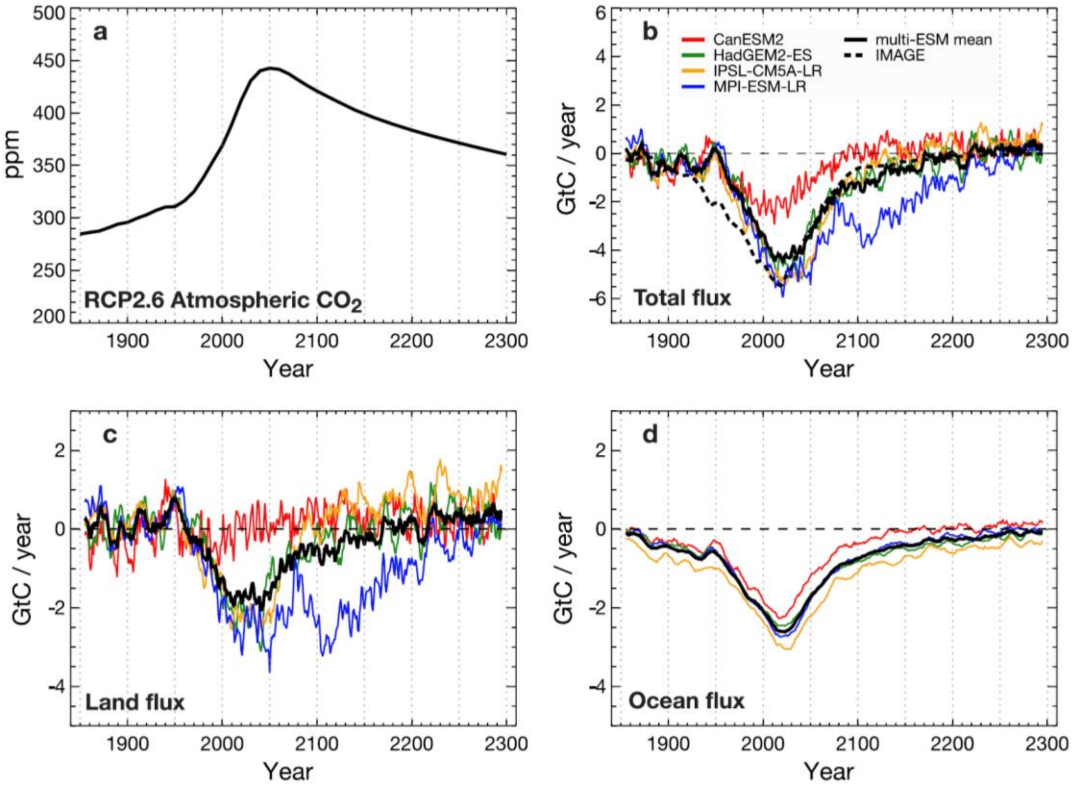
EFI, 2020

R&D & Policy Needs

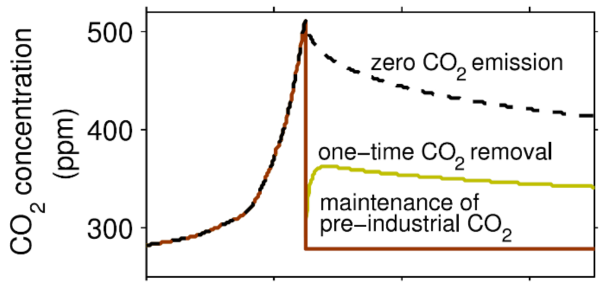
- Defining the RD&D portfolio of specific biological and nonbiological CDR pathways for technology development, optimization and scalability, including anticipating new and emerging pathways;
- Improving the methods for monitoring, quantifying, and verifying CDR benefits, ecosystem effects, and lifecycle impacts;
- Developing predictive modeling and planning tools for siting and operations;
- Creating markets for co-products from ocean CDR pathways and integration into carbon markets;
- Enhancing public engagement and support;
- Creating enabling national and international governance frameworks.

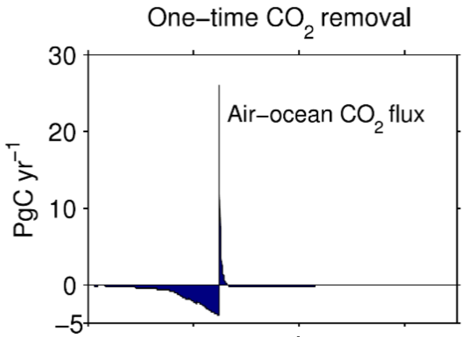
Earth system response to negative emissions

Predicted carbon exchanges from six global models under the RCP 2.6 scenario

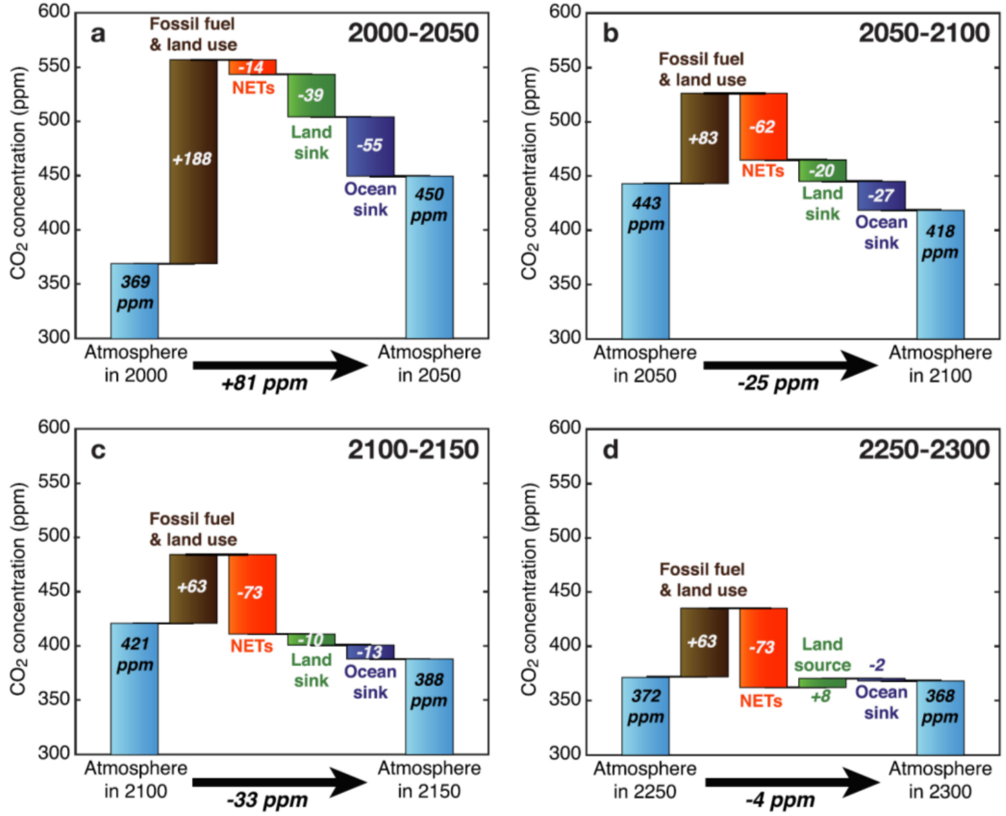


Jones et al., 2016





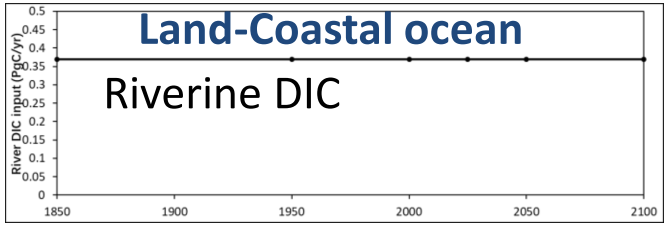
Cao et al., 2010

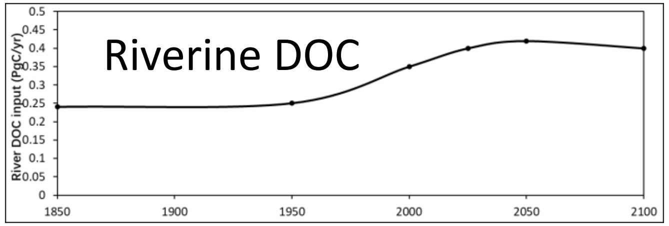


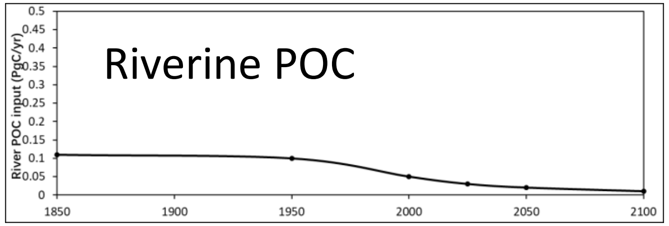
- **The Earth system models suggest significant weakening, even potential reversal, of the ocean and land sinks under future low emission scenarios**
- **To maintain atmospheric CO_2 and temperature at low levels, not only does anthropogenic CO_2 in the atmosphere need to be removed, but anthropogenic CO_2 stored in the ocean and land needs to be removed as well when it outgasses to the atmosphere.**

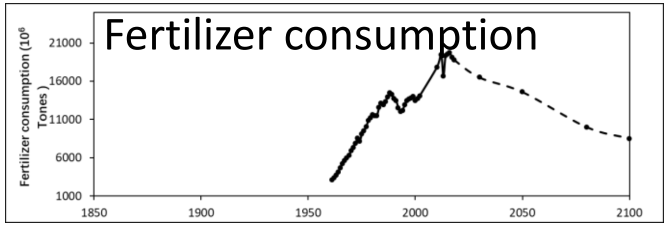
Future Land-Coastal Ocean-Open Ocean Continuum?

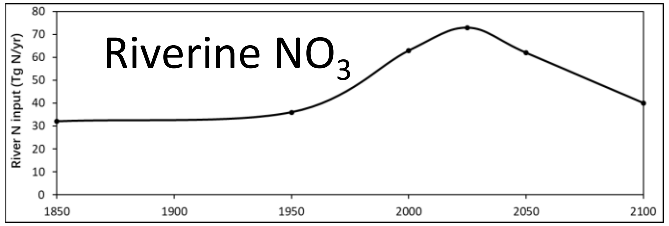
Land-Coastal ocean

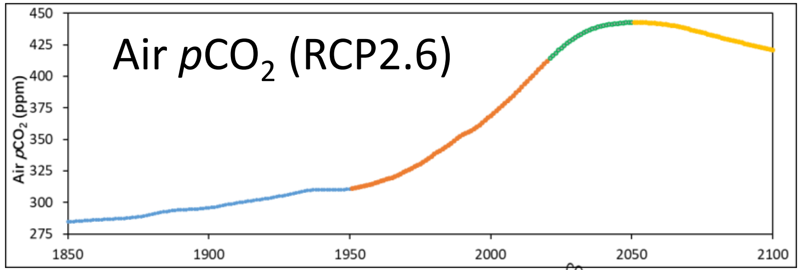


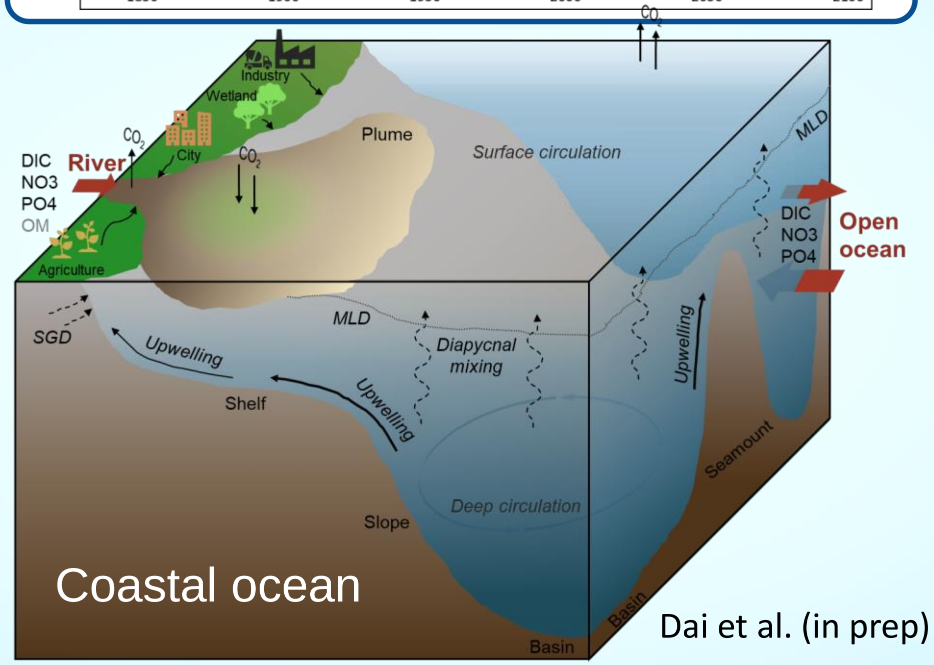




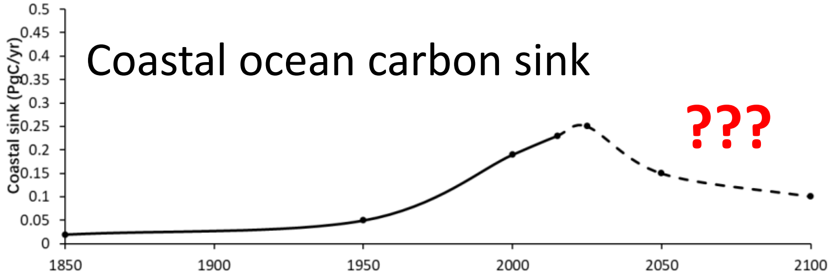




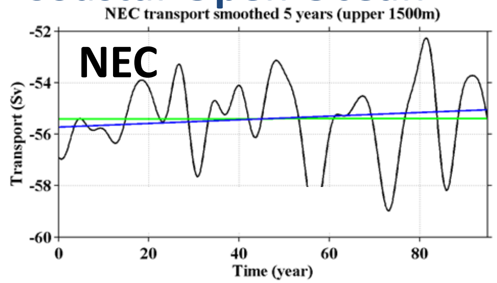


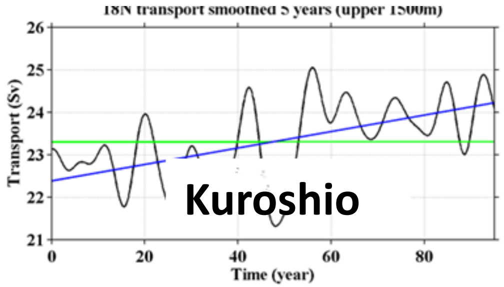


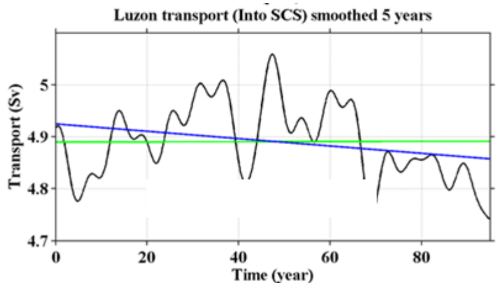
Dai et al. (in prep)



Coastal-Open Ocean

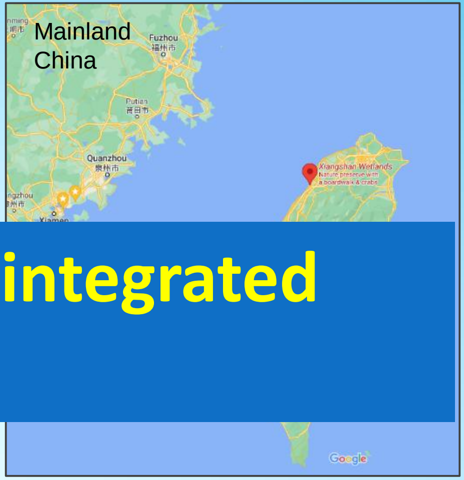






Kuroshio intrusion to the South China Sea

The removal of mangroves in Siang-shan Wetland, Taiwan



Siangshan Wetland is an important muddy wetland with abundant species and biodiversity in NW Taiwan. The mangroves of Siangshan Wetland were planted since 1969. In 2000, the mangrove area covered ~107

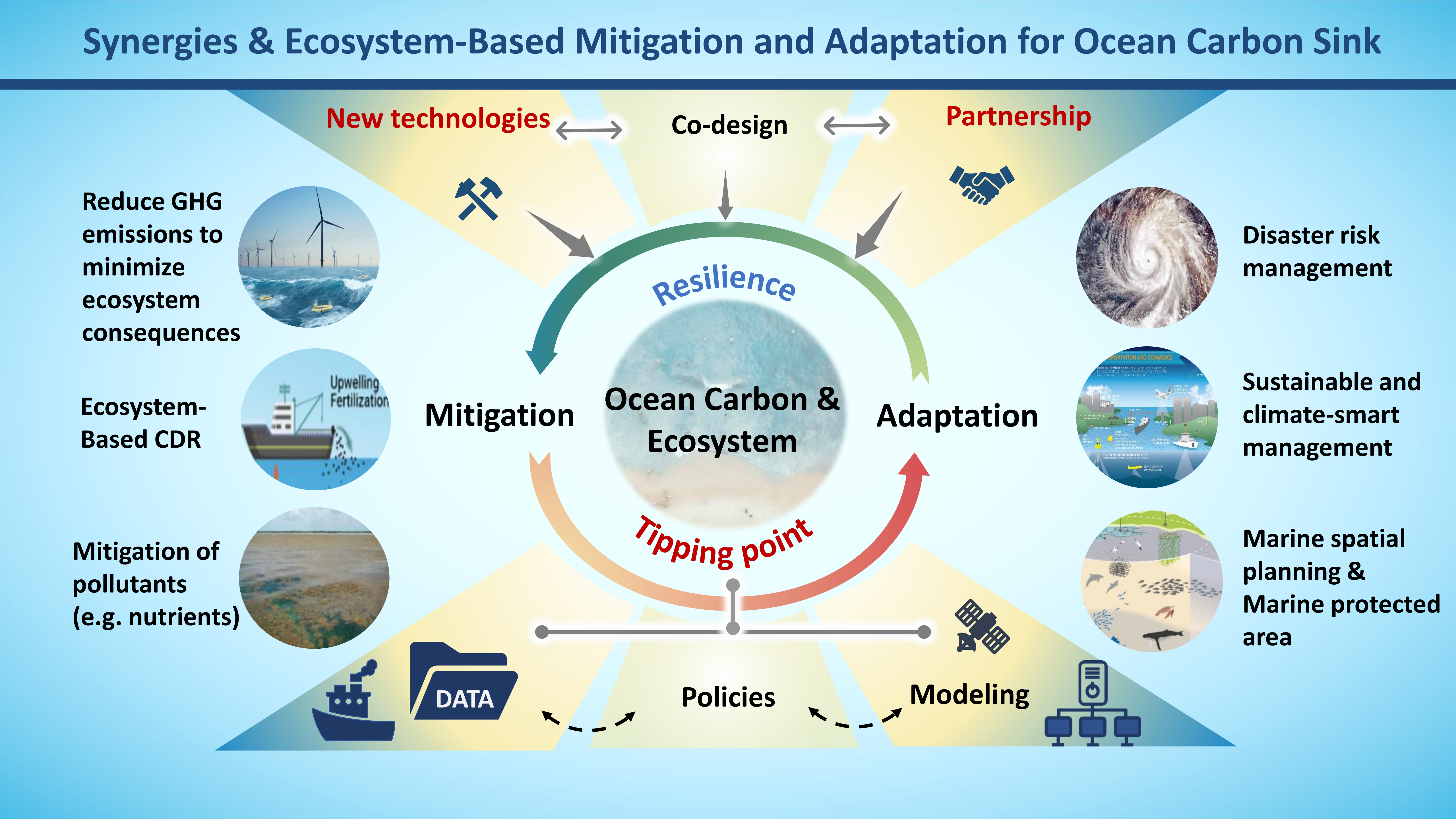
Carbon-sink is only one of the crucial ecosystem services: integrated ecosystem-based governance

benthic organisms;

- Serious impact on the foraging and habitat of birds;
- Serious threat to the endemic Taiwanese fiddler crab species;
- Sediment to accumulate with estuary flooding in heavy rain;
- Invasions of the small black mosquito (Forcipomyia taiwana)

Therefore, mangrove removal projects was launched since 2000.

Chen& Shih, 2019; The Society of Wilderness, 2015

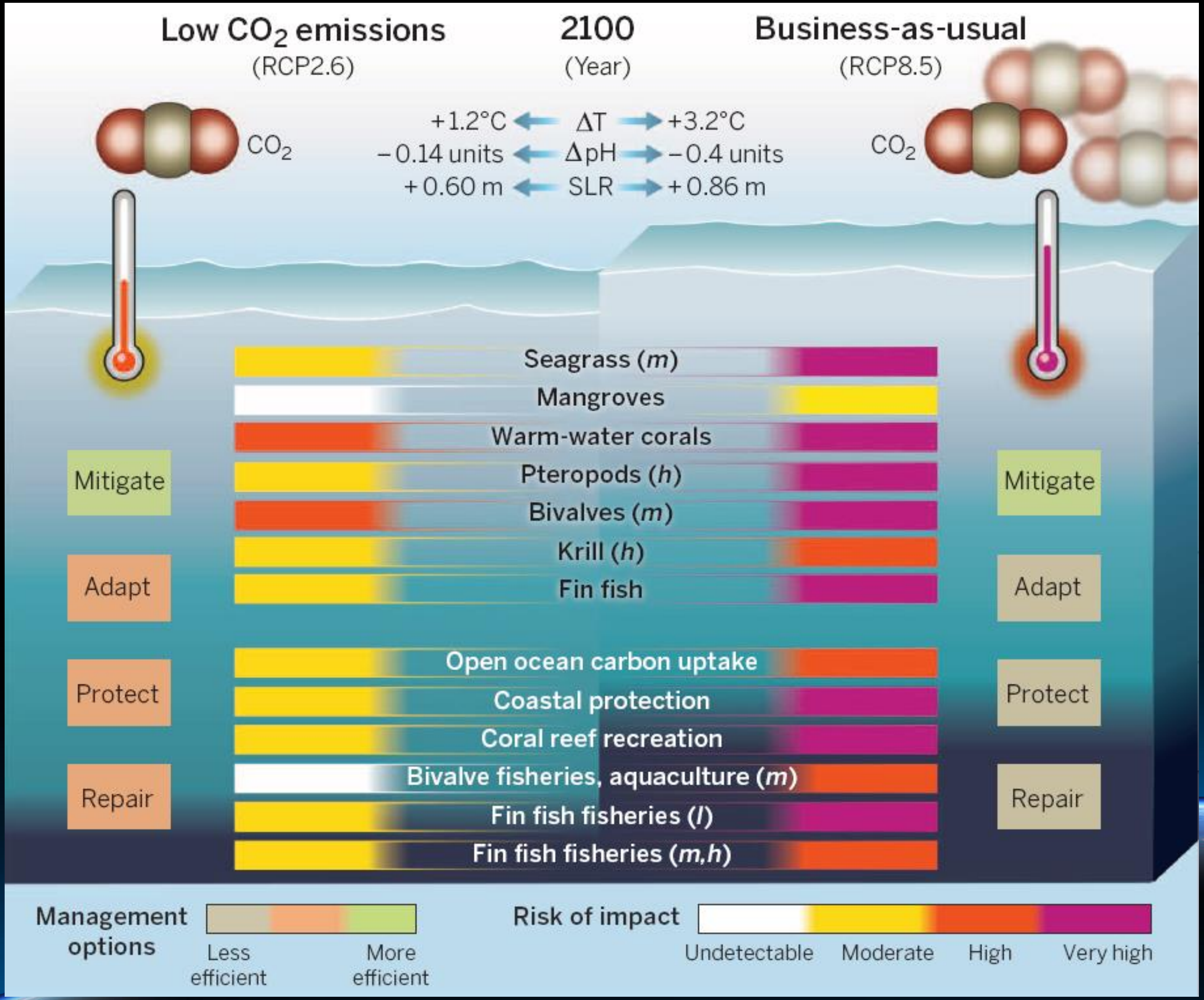

Synergies & Ecosystem-Based Mitigation and Adaptation for Ocean Carbon Sink
New technologies
Co-design
Partnership
Reduce GHG emissions to minimize ecosystem consequences
Ecosystem-Based CDR
Upwelling Fertilization
Mitigation of pollutants (e.g. nutrients)
Resilience
Mitigation
Ocean Carbon & Ecosystem
Adaptation
Tipping point
Disaster risk management
Sustainable and climate-smart management
Marine spatial planning & Marine protected area
DATA
Policies
Modeling

Concluding Remarks

- The ocean has been the only sustained natural carbon sink for the last 200 years. However, the future trend of ocean carbon sink is subject to large uncertainty, especially under net-zero and in land-ocean-atmosphere coupled system.
- CO_2 and climate changes have caused negative consequences to ocean ecosystems
- Marine CDR is crucial in both mitigation and sustaining ocean carbon sink, possibly ocean health as well as under zero-emission
- Ocean-based solutions provide great opportunities for both mitigation and adaptions and should be considered to be included in Nationally Determined Contributions and UNFCCC deliberations
- Ecosystem-based approaches should be enforced in both mitigation and adaptions and thus, *The UN Decade of Ocean Science for Sustainable Development and of Ecosystem Restoration* could be organized in a more coherent way


UN Decade of Ocean Sciences: *The science we need for the ocean we want*

Opportunities & risks



Gattuso et al. (2015)

Thresholds: +1.5 °C and -0.2 pH units relative to preindustrial

- **RCP8.5: 69% of the ocean surface will exceed both thresholds**
- **RCP2.6: < 1% of the ocean surface will exceed both thresholds**
- **In the surface ocean, the ongoing deoxygenation will largely stop once CO_2 emissions are stopped.**