SCSIO
中国科学院南海海洋研究所
South China Sea Institute of Oceanology(SCSIO),Chinese Academy of Sciences(CAS)

ExOIS Forum Mon. Oct. 16 2023

Fertilization of aluminum and iron together in the HNLC oceans as a possible CDR strategy

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17 October, Online

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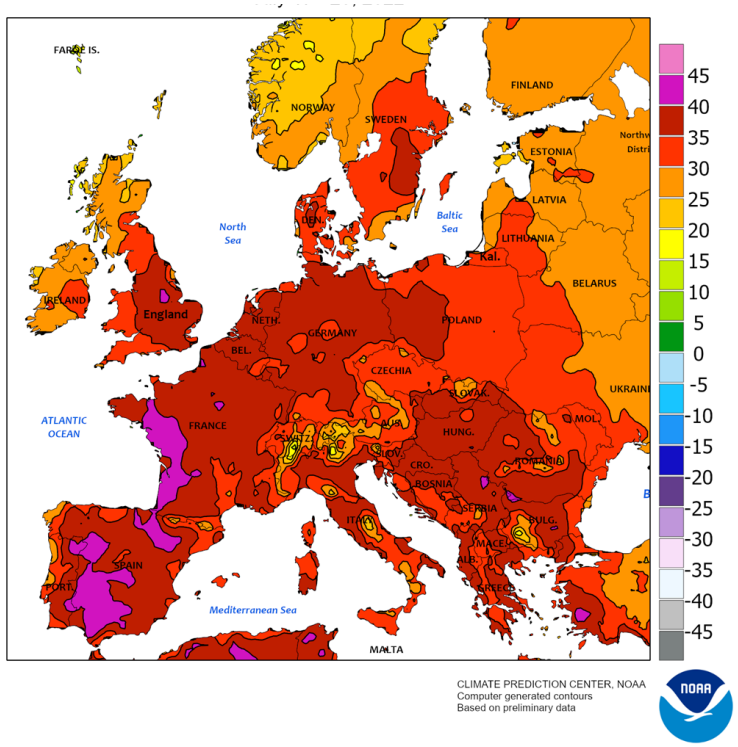
Global warming contributes to extreme events



Almost dried up
the largest freshwater lake in China

High temperatures >40 ºC occurred in the northern hemisphere in summer

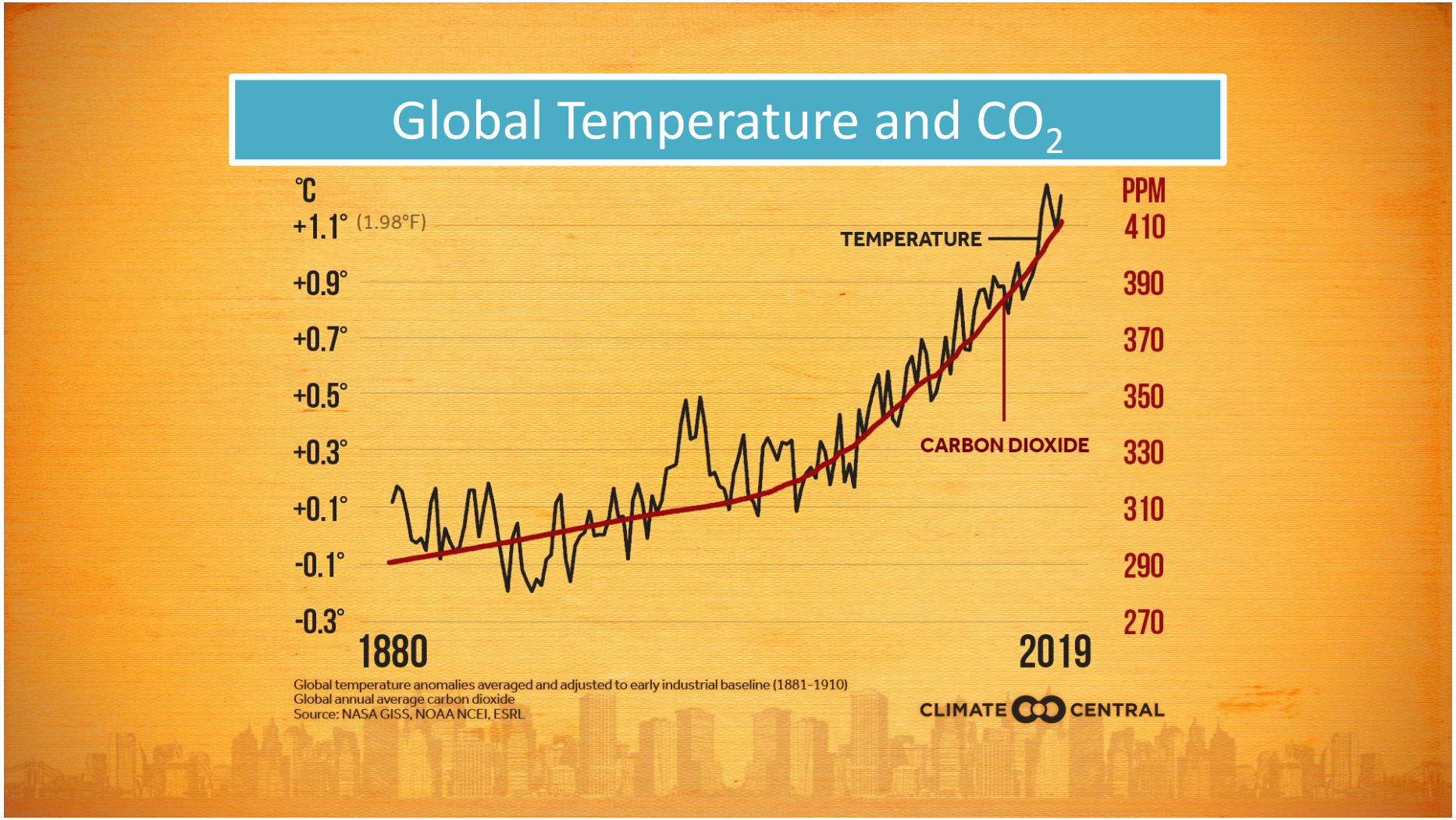
>350 disasters, >180 million affected, >28 000 deaths, >200 billion $ loss

Top 10 disasters that caused mortality- 2022

Europe[10]	Heat Wave	16,305	Nigeria	Flood	603
Uganda	Drought	2,465	South Africa	Flood	544
India	Flood	2,035	Philippines	Tropical Storm 'Megi'	346
Pakistan	Flood	1,739	Indonesia	Earthquake	334
Afghanistan	Earthquake	1,036	Brazil	Flood	272

CRED Crunch 66 - Disasters Year in Review 2022

Greenhouse gas emissions drive global warming

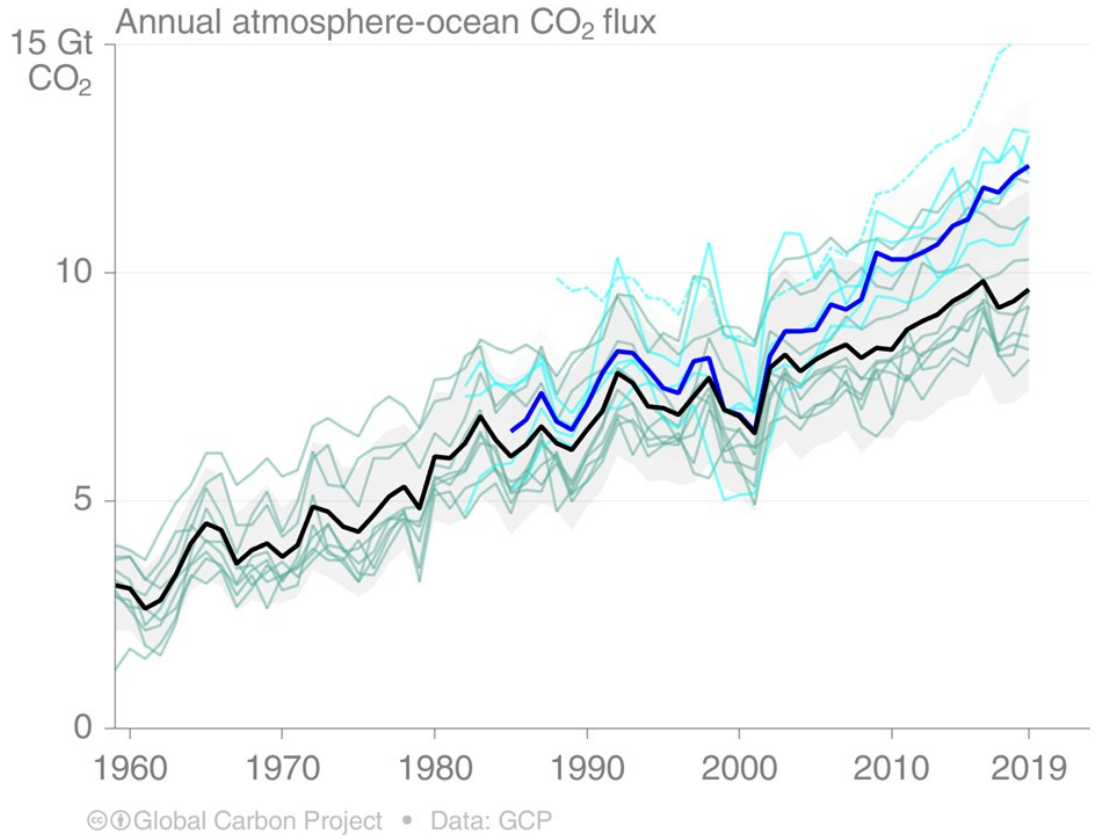


CO_2 removal techs are needed to achieve Paris Agreement goals

- **Remove 100-1000 billion tons of CO_2 out of the air during this century to achieve the 1.5°C target**

Sources: 10 New Insights in Climate Science 2018; United Nations

Ocean is the largest active carbon pool

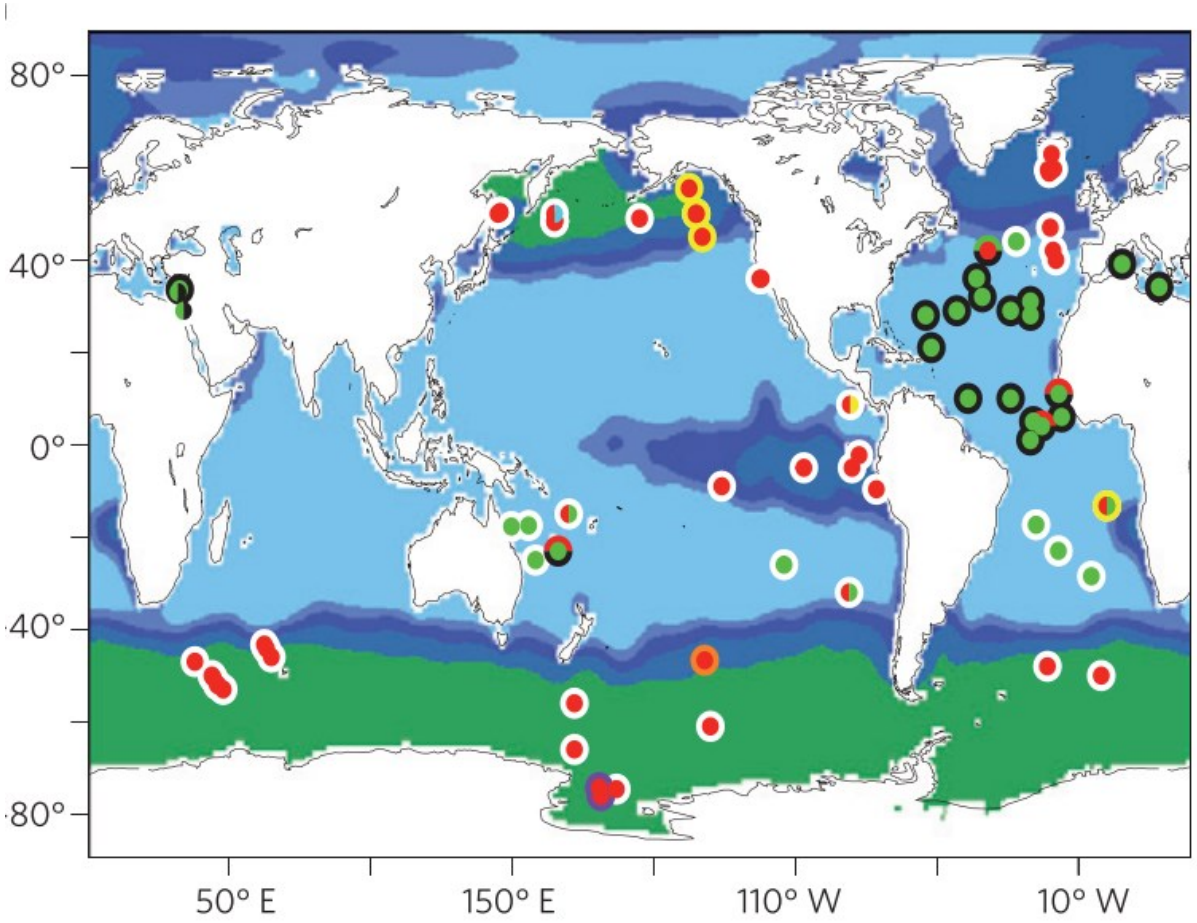


The ocean uptakes 9.2 ± 2.1 $GtCO_2$/yr for 2010–2019

Ocean has a huge potential for removing CO_2 from the air

Source: Global Carbon Budget 2020

Phytoplankton regulates ocean uptake of CO_2

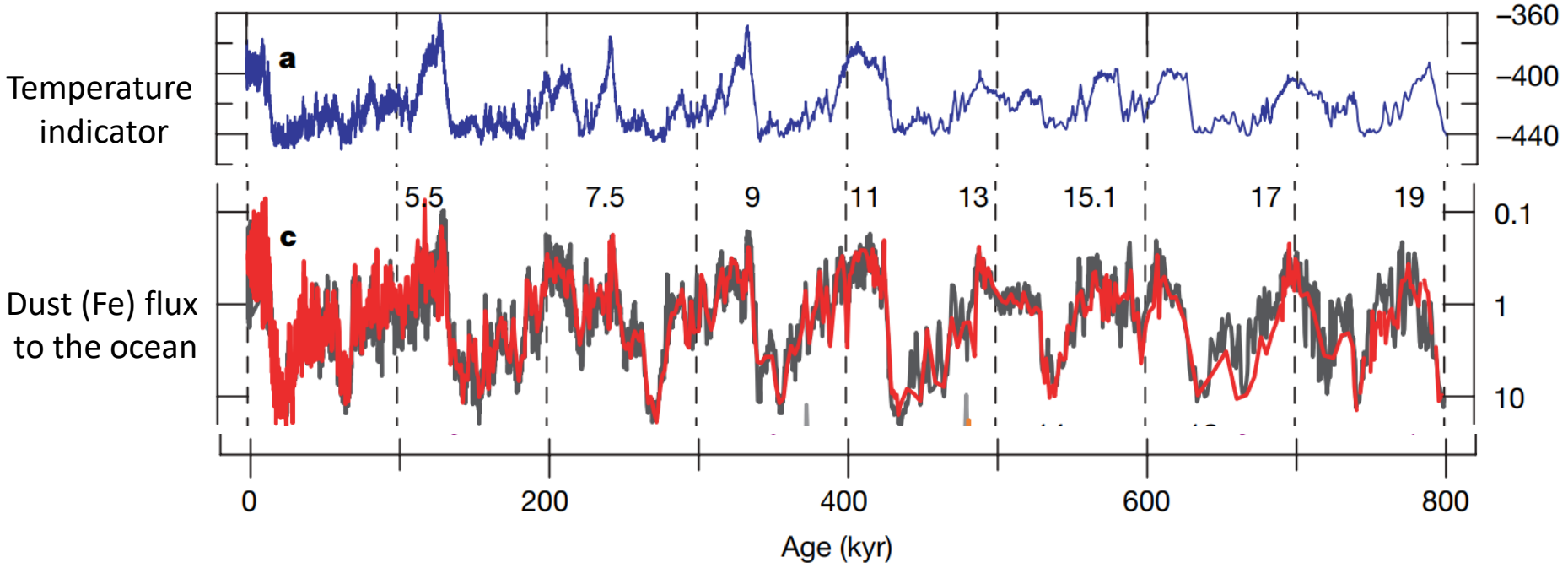


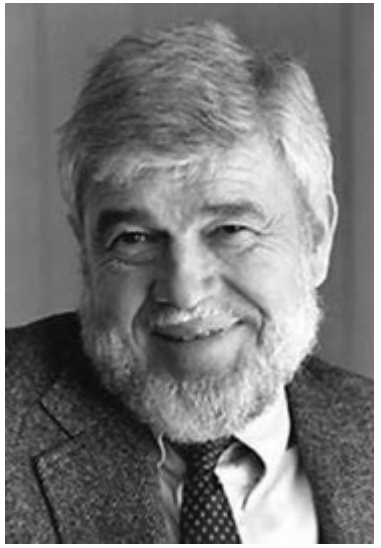
One third of the ocean is Fe-limited

Red dots indicate iron-limitation

Source: Moore et al., 2013 Nature geosciences

Iron Hypothesis:
ocean Fe fertilization cools the Earth





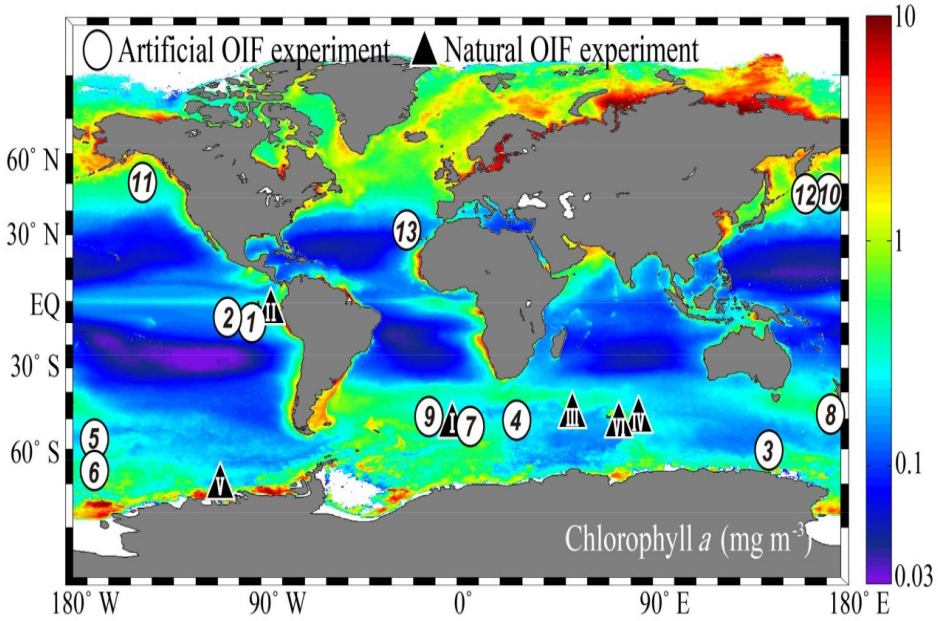
John Martin

Eight cold glacial climates occurred in the past 800 kyrs

"Give me half a tanker of iron and I'll give you the next ice age"

Sources: Lambert et al. 2008; The Iron Hypothesis by Al Trujillo

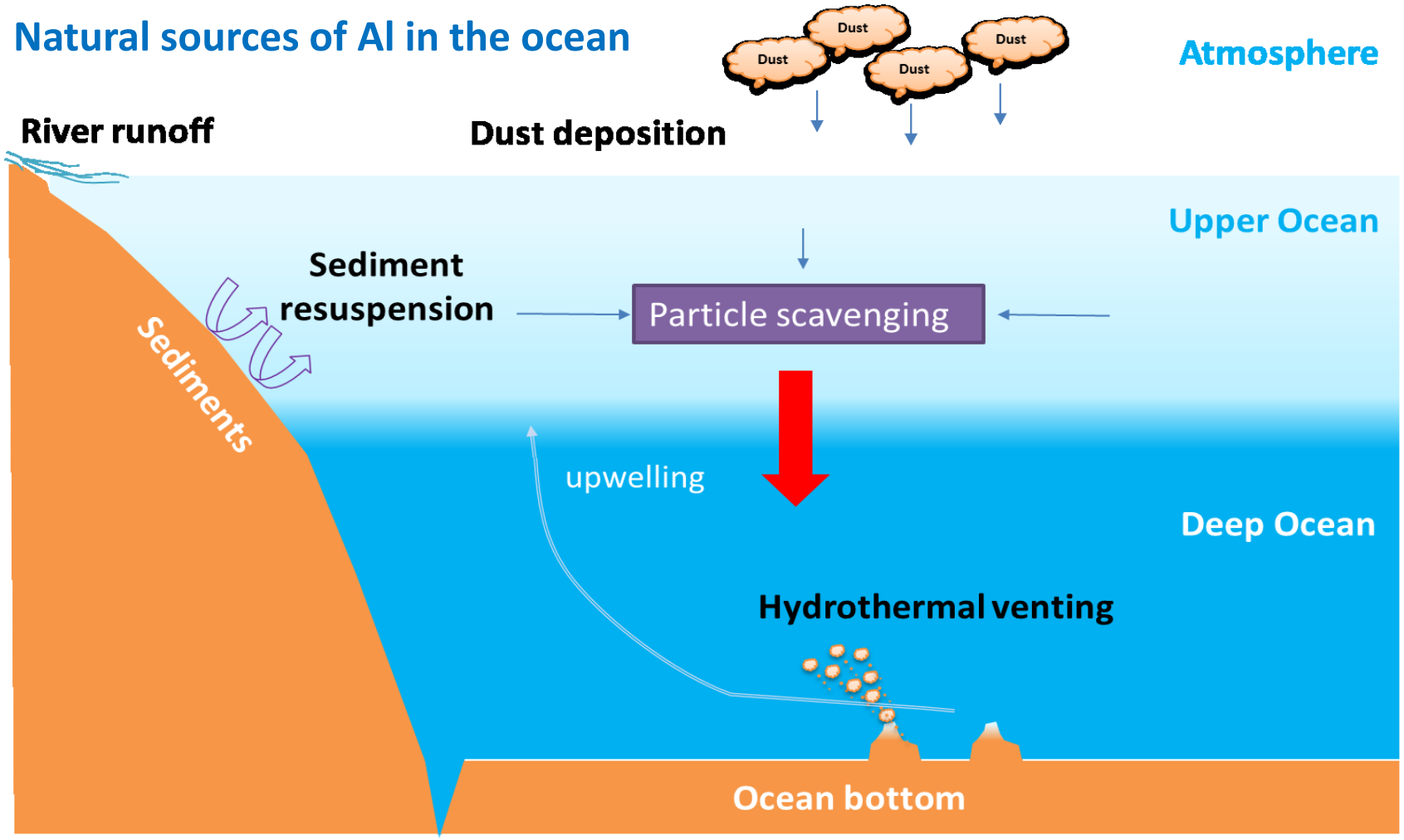
Ocean iron fertilization experiments did not fully support the Iron Hypothesis



- Significant increase in phytoplankton growth and carbon fixation
- Low carbon export to deep depths (remineralization in the upper layer)
- Low efficiency of iron use (only around 1-10% of natural iron fertilization)

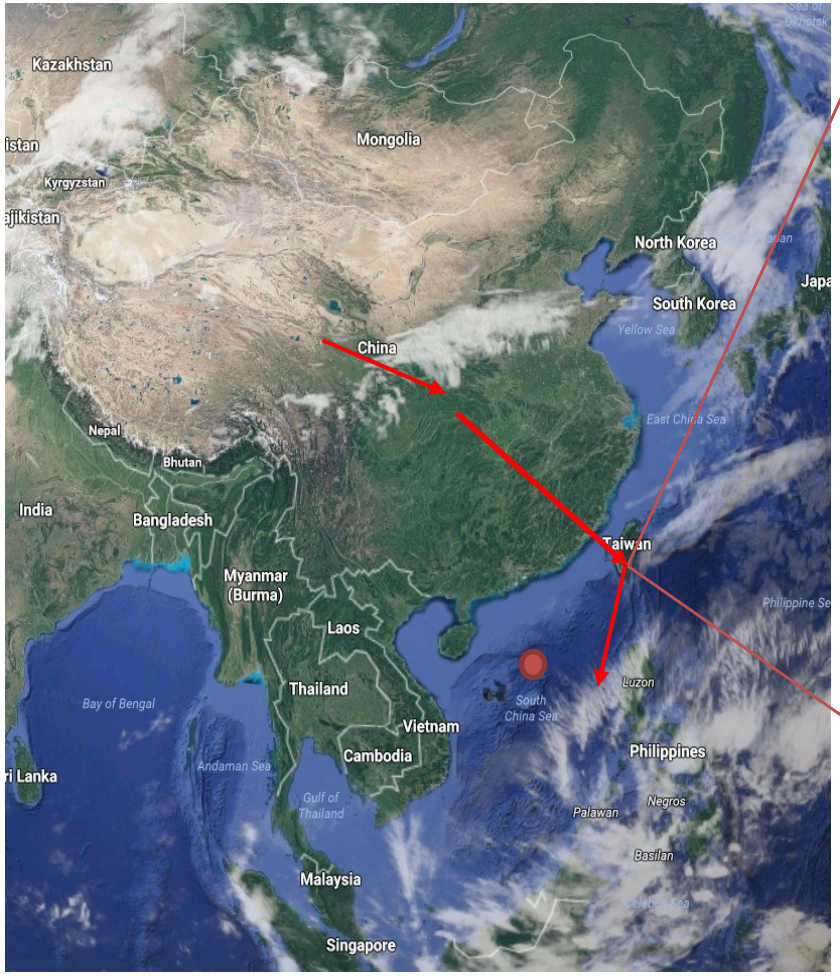
Sources: Boyd et al. 2004, 2007; Martin et al. 2013; Yoon et al. (2018); Zhou et al. (2018)

Natural Fe fertilization provides not only Fe but also Al



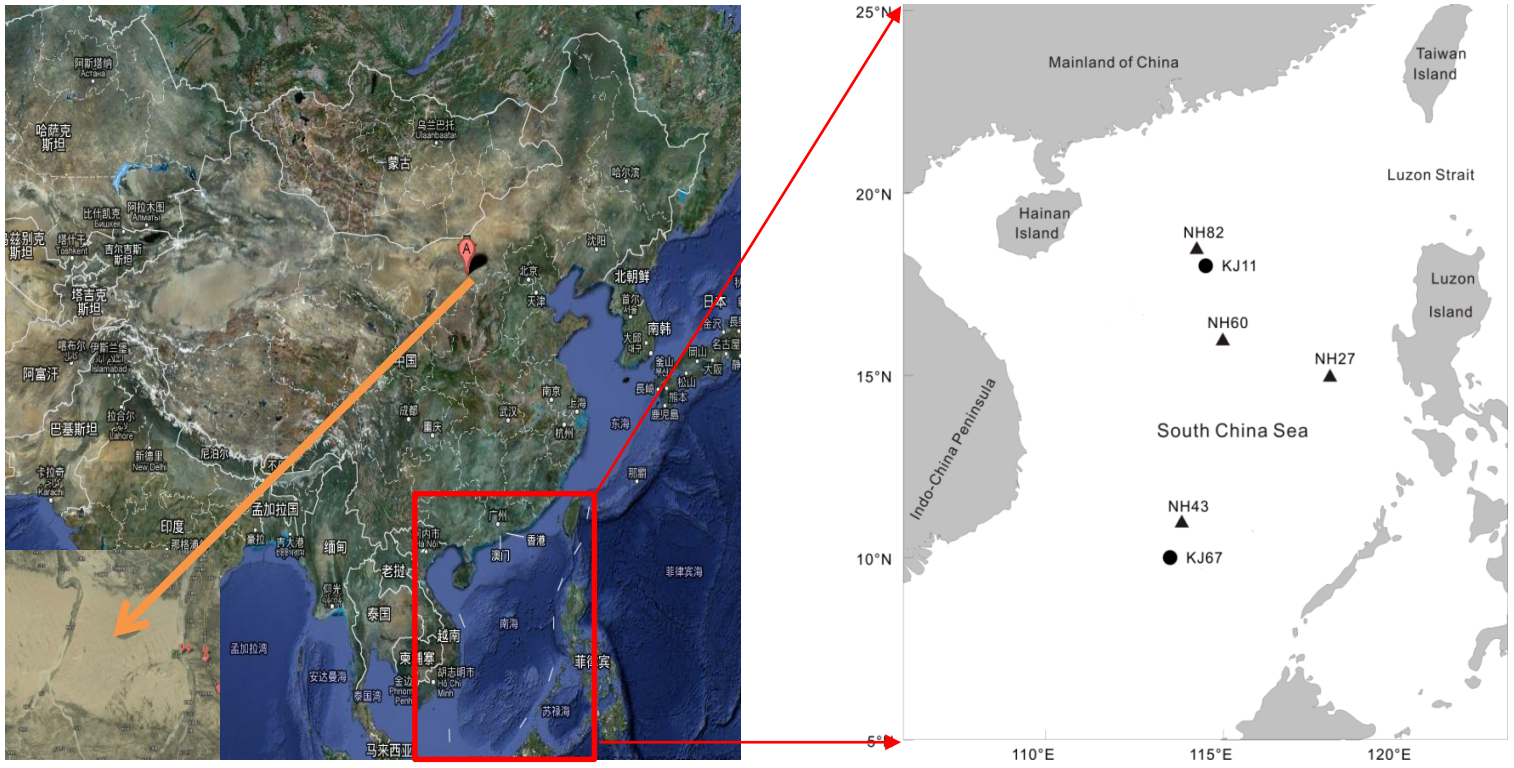
Source: Zhou et al. (2018) Biogeochemistry

Heavy dust transport to the ocean



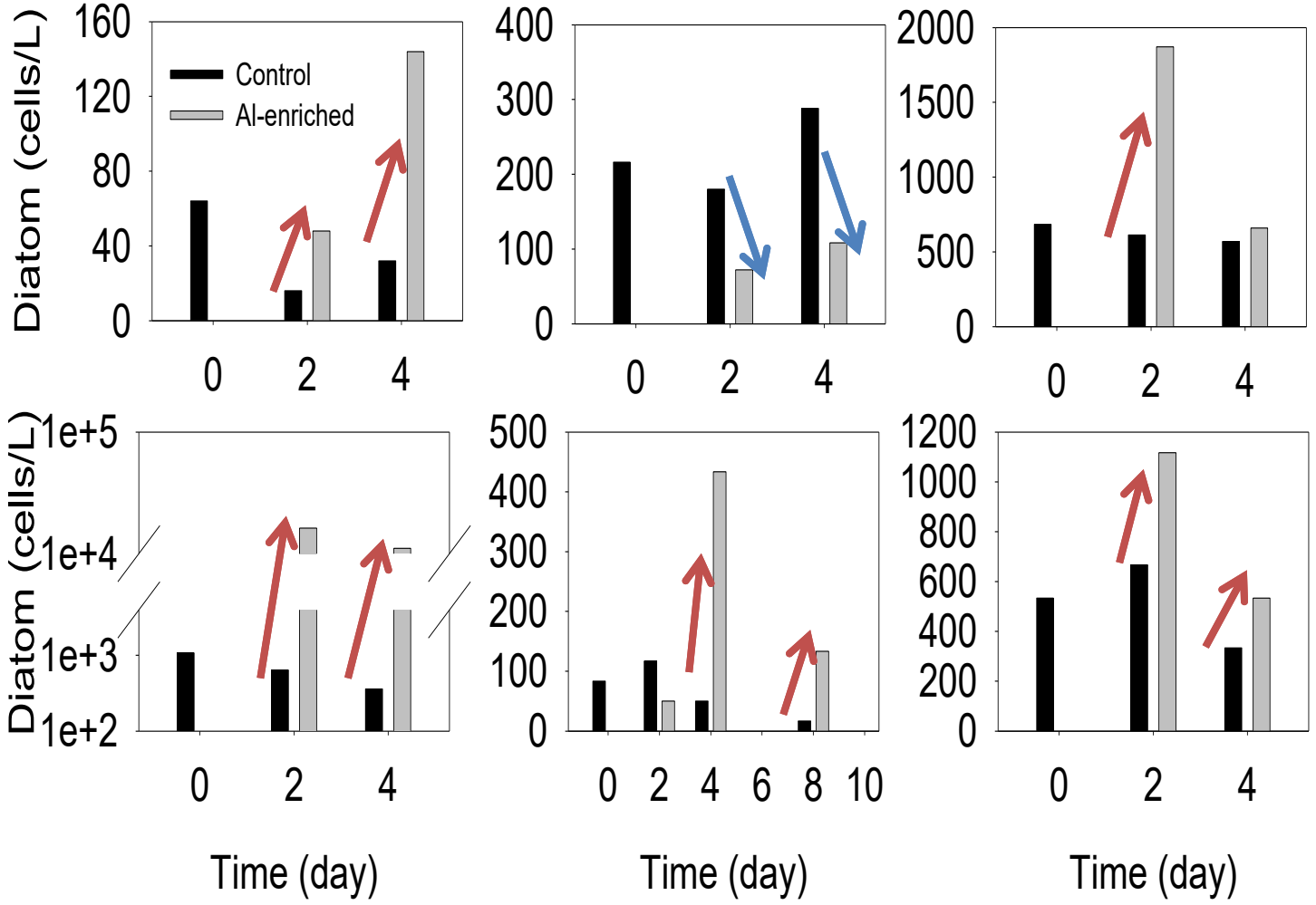
Dust storm even brought dim weather to the Taiwan Island almost 3000 km away from its origin on March 21, 2010

Dust and aluminum addition experiments



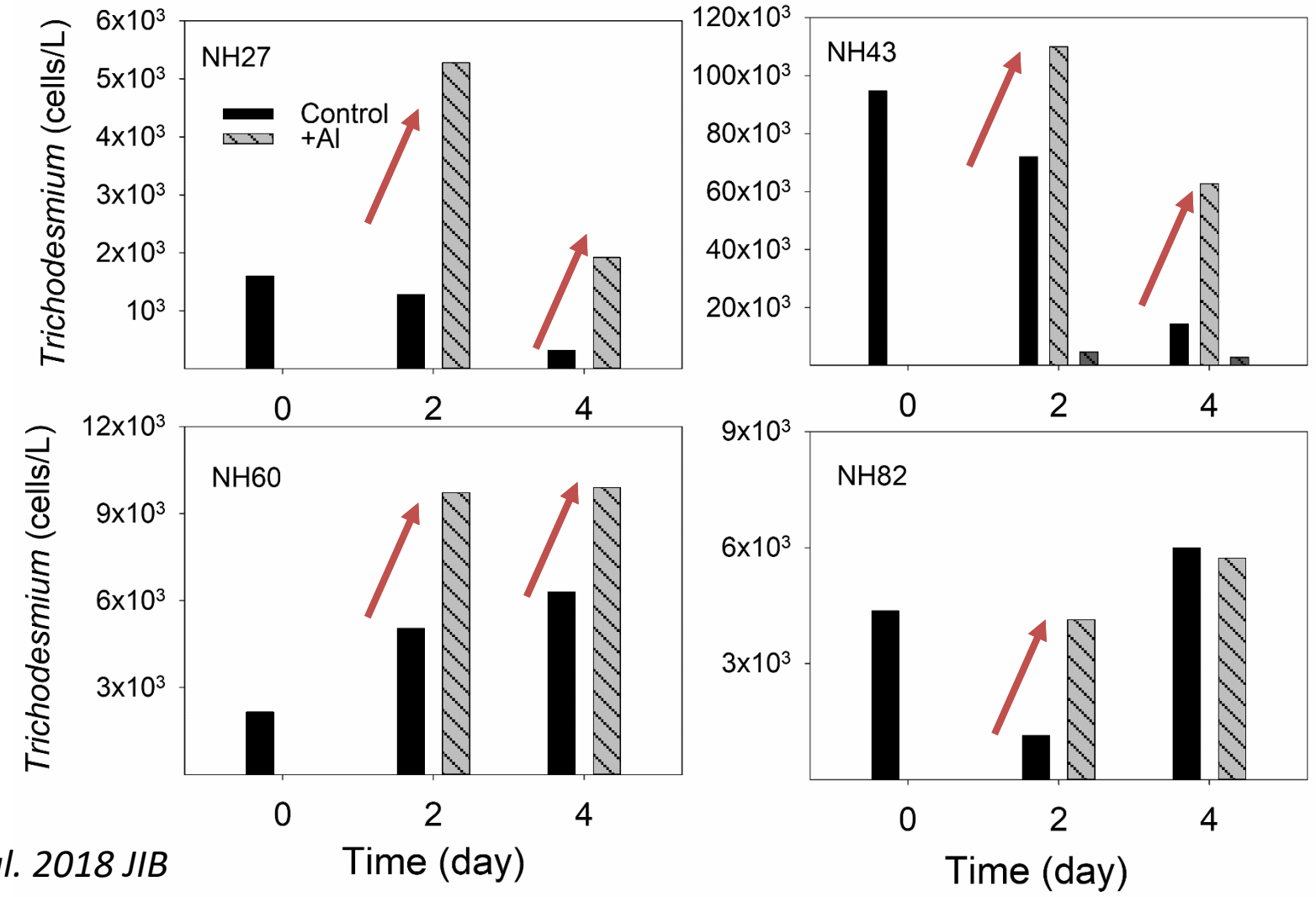
Experimental sites in the South China Sea

Aluminum addition enhanced the growth of diatoms



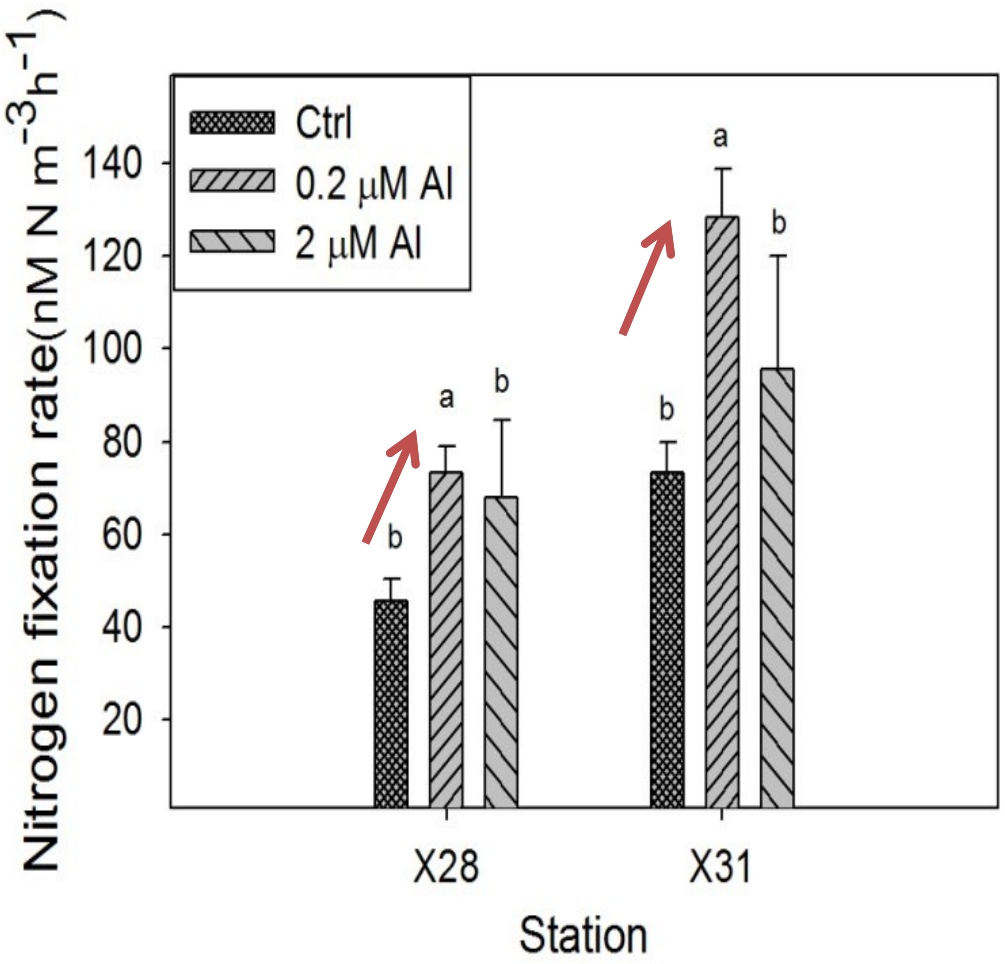
Source: Zhou et al. 2018 JIB

Aluminum addition enhanced the growth of nitrogen-fixing cyanobacteria *Trichodesmium*



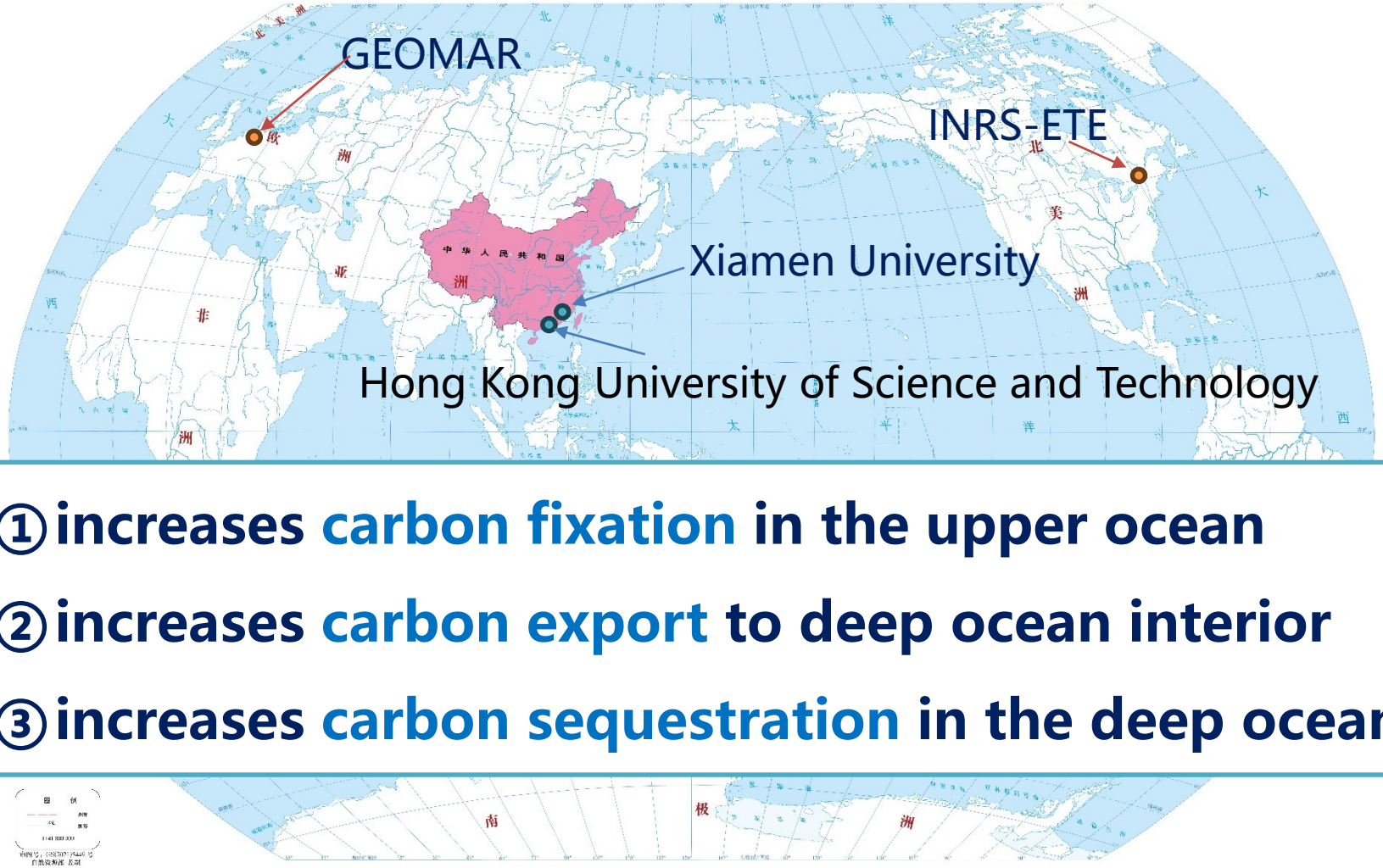
Source: Zhou et al. 2018 JIB

Aluminum addition enhanced the nitrogen fixation rate



Sources: Liu et al. (2018) MPB

Aluminum may enhance marine carbon sinks



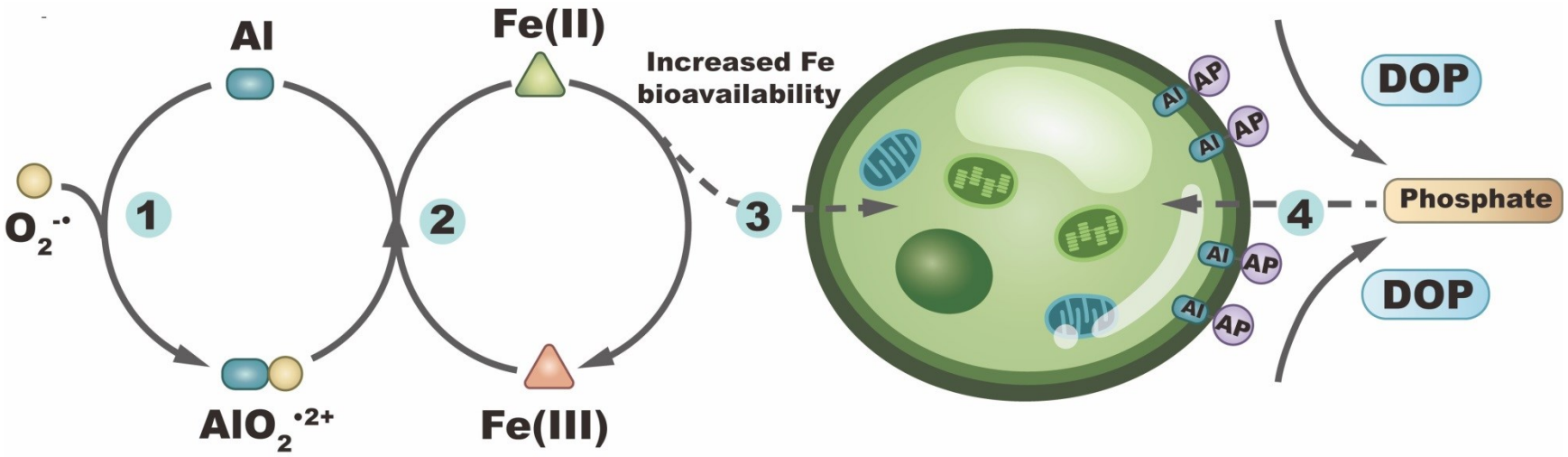
①increases carbon fixation in the upper ocean

②increases carbon export to deep ocean interior

③increases carbon sequestration in the deep ocean

① Carbon fixation

Aluminum enhances the use of DOP and Fe more CO_2 fixation in the upper ocean

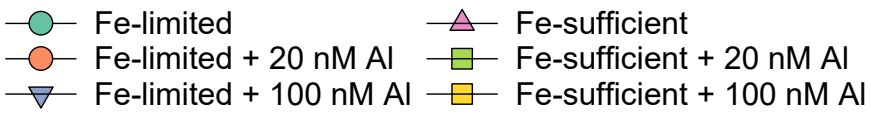


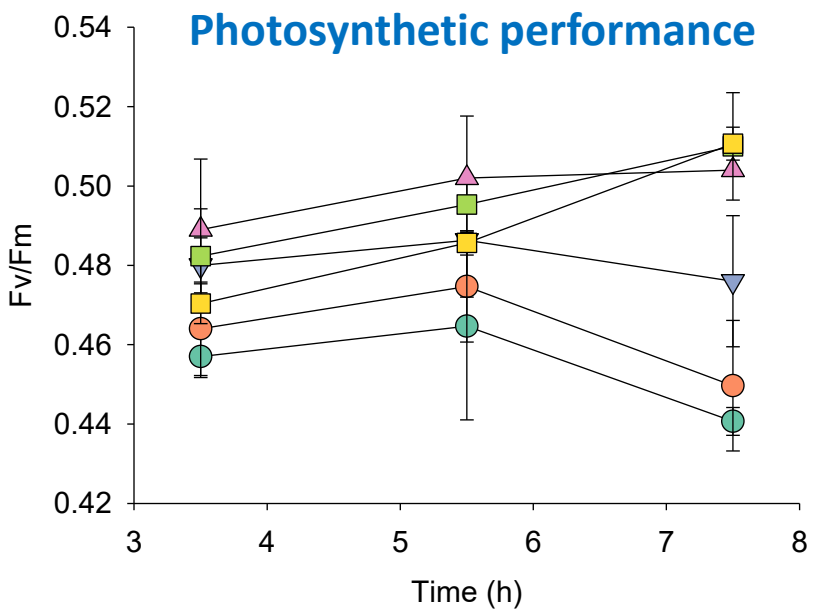
Schematic diagram illustrating how aluminum (Al) may facilitate the uptake of iron (Fe) and the utilization of dissolved organic phosphorus (DOP) by marine phytoplankton

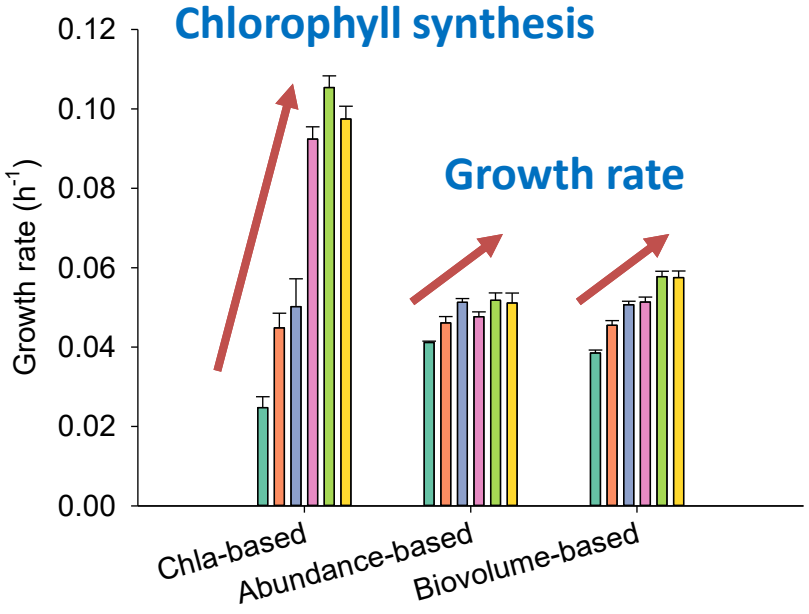
Source: Zhou et al. (2021) L&O

① Carbon fixation

Aluminum enhanced diatom photosynthesis & growth under Fe-limitation



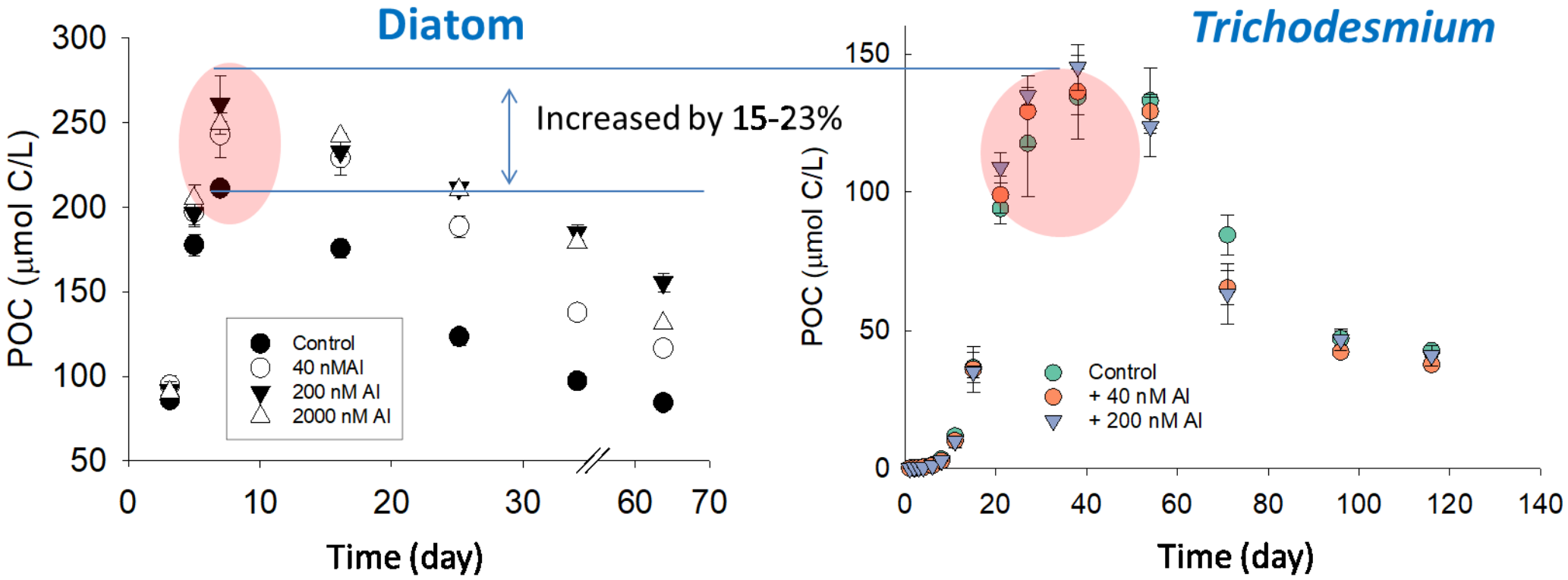




Source: Zhou et al. submitted to L&O revision

① Carbon fixation

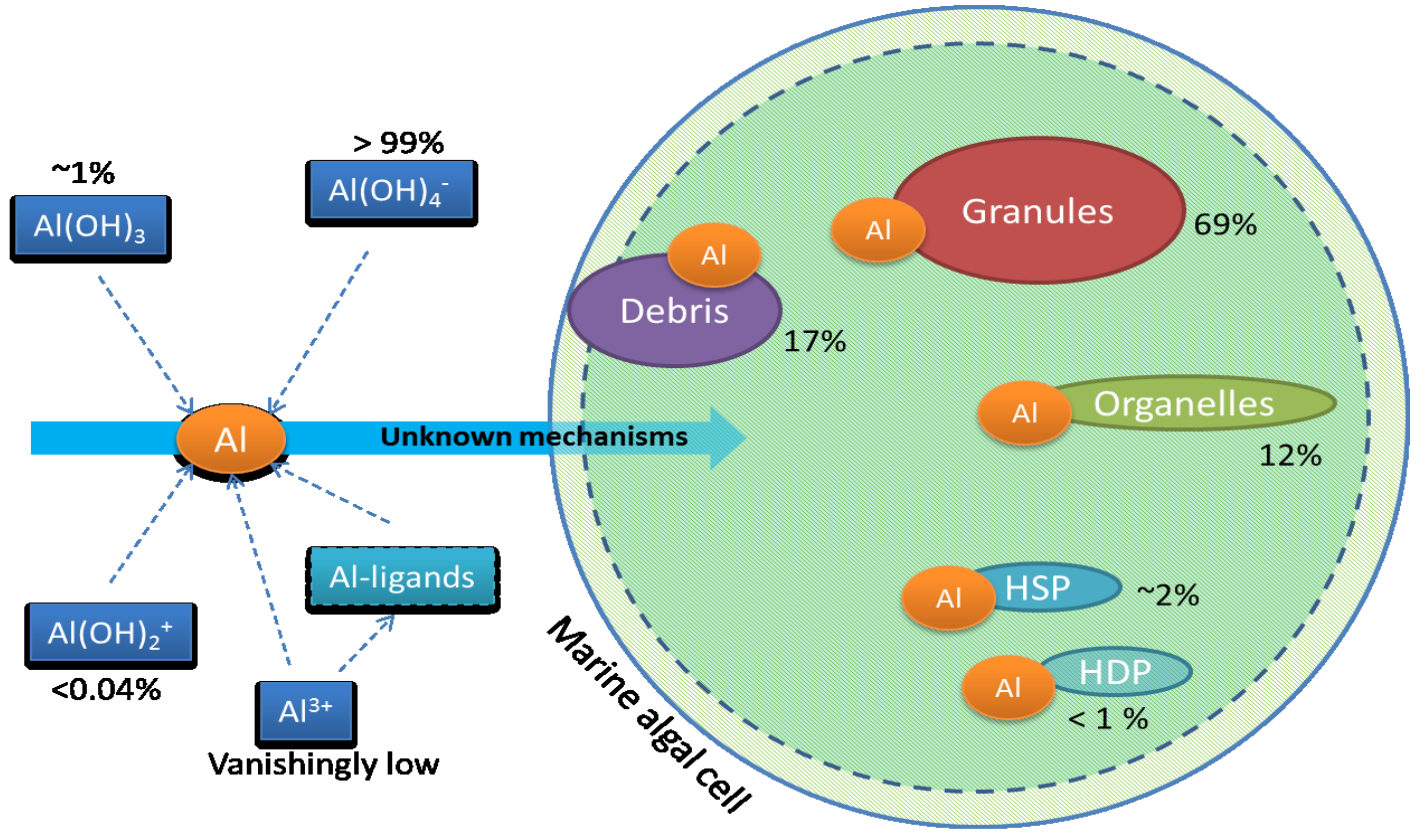
Aluminum addition led to higher net carbon fixation



Source: Zhou et al. (2021) L&O; Zhou et al., (2023), Biogeochemistry

② Carbon export

Diatoms uptake Al into frustules and cytoplasm

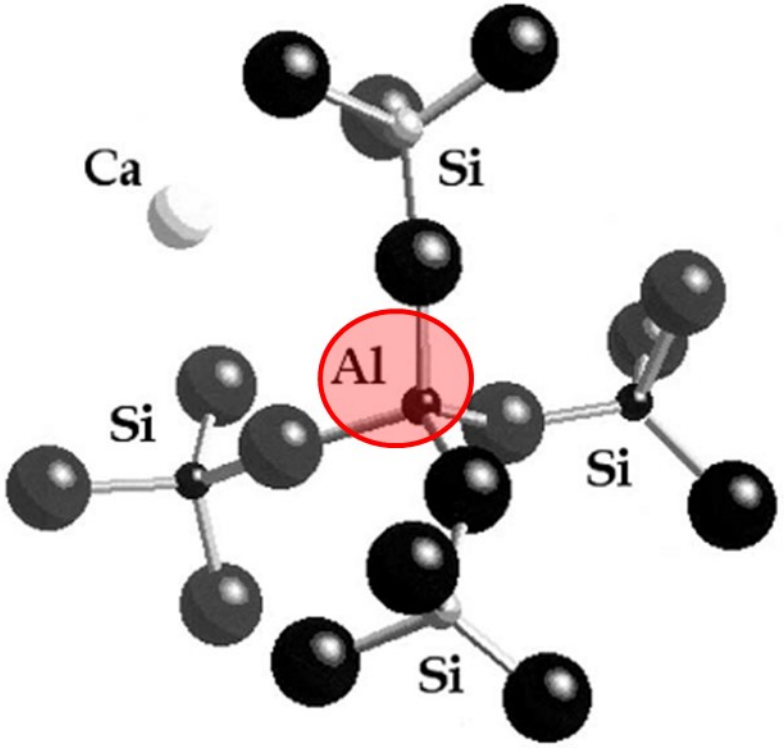


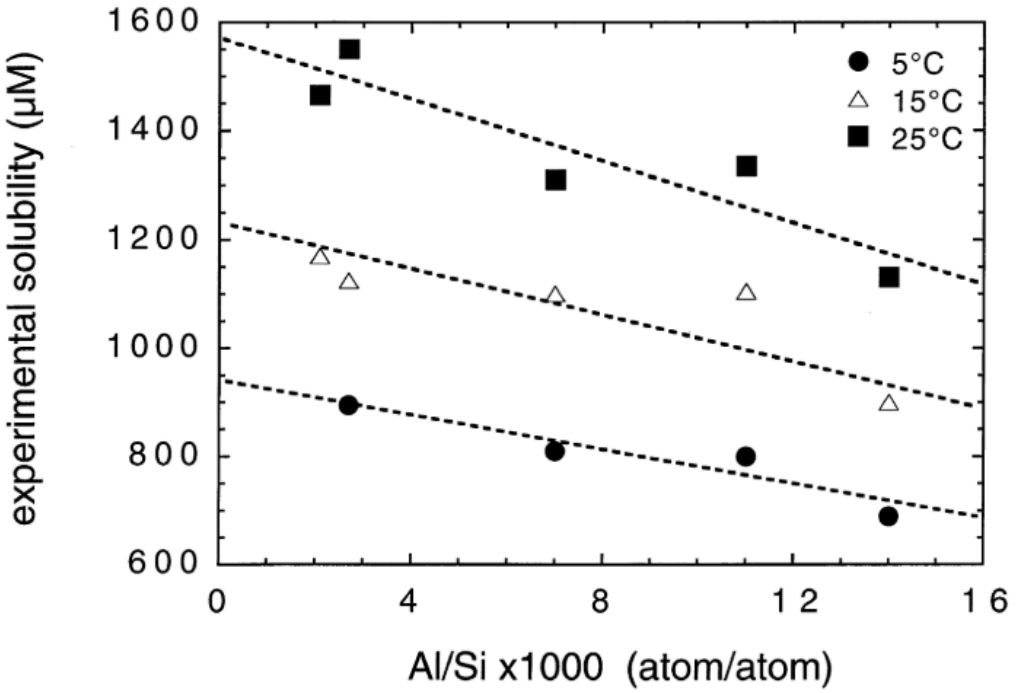
Al reacts with biomolecules to form strong bonds and structures

Sources: Liu et al. 2019 EES; Song et al. 2014; Exley and Mold 2015; Mujika et al. 2018

② Carbon export

Al incorporates into diatom frustules and decreases its dissolution rate



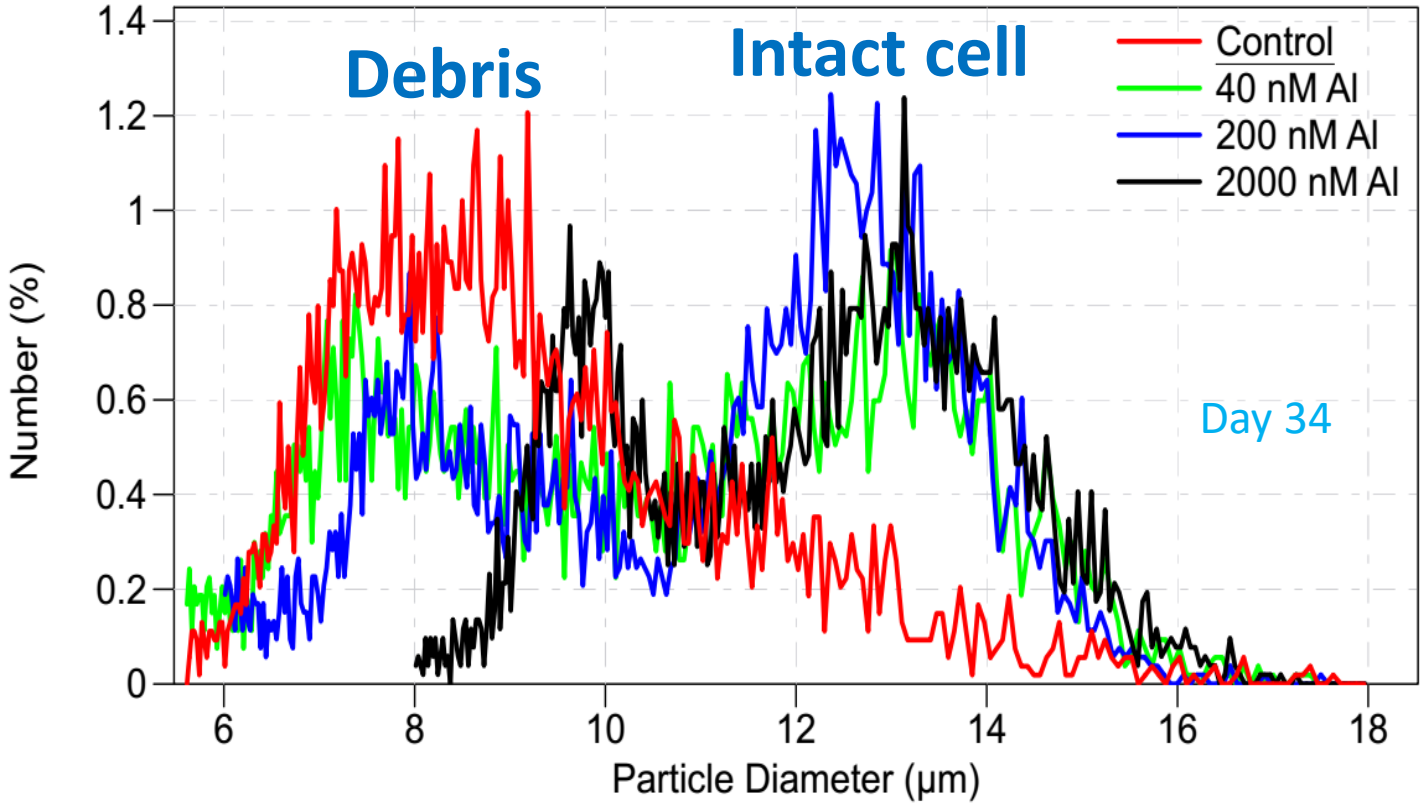


Al incorporate into frustule and form stable structure

Al decreases frustule dissolution rate

Sources: Lewin et al. 1961; Gehlen et al., 2002; Dixit et al., 2001

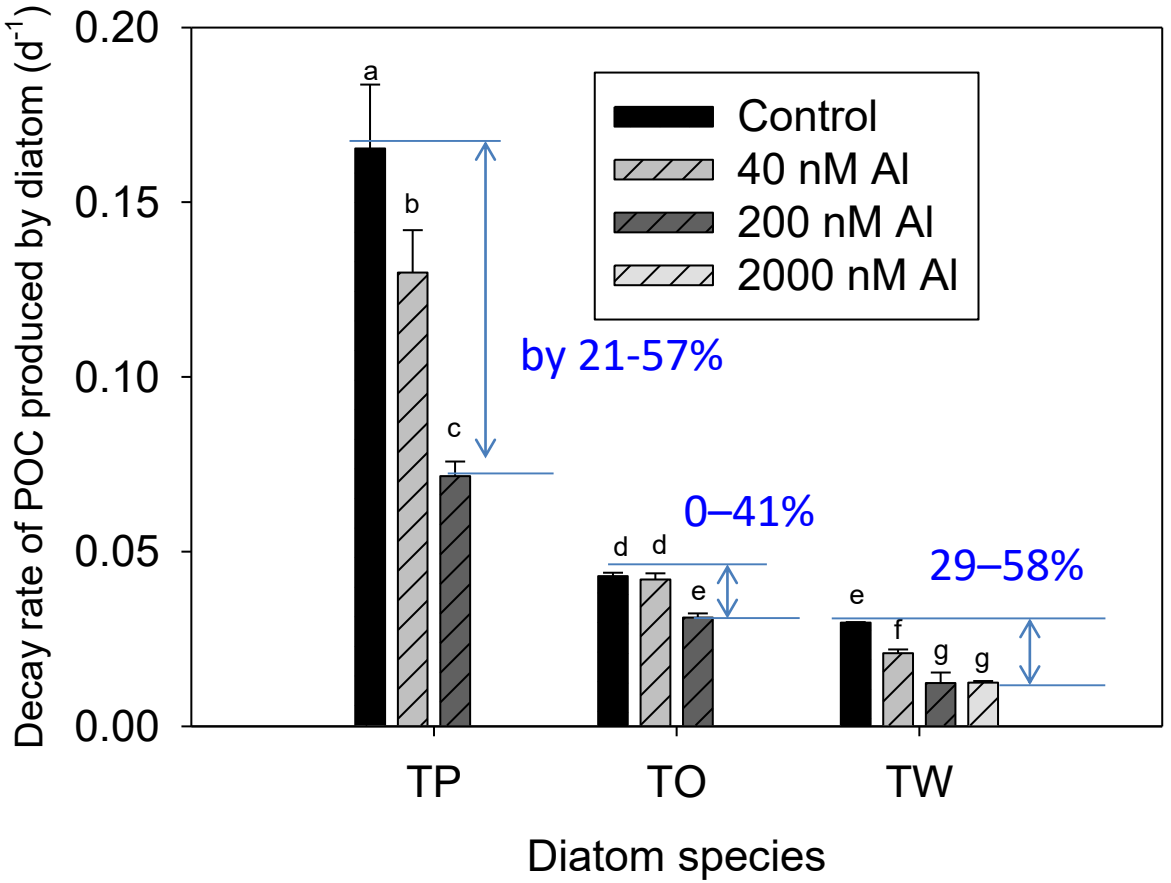
Aluminum delayed diatom cell breakdown



Source: Zhou et al. (2021) L&O

② Carbon export

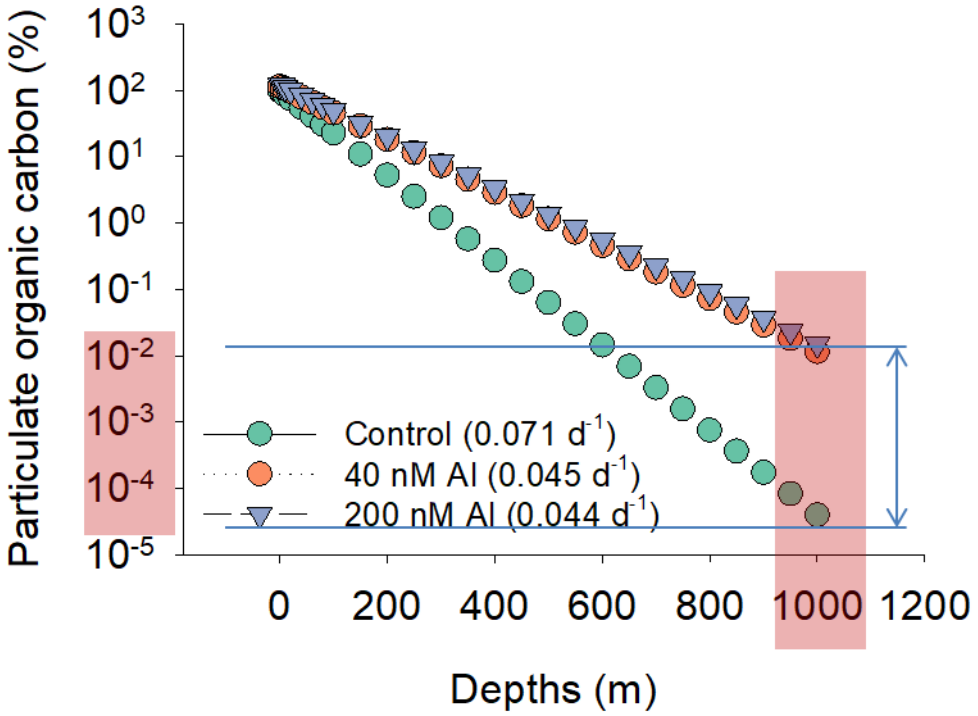
Aluminum decreases POC decomposition rate for diatoms with different sizes



Source: Zhou et al. (2021) L&O

② Carbon export

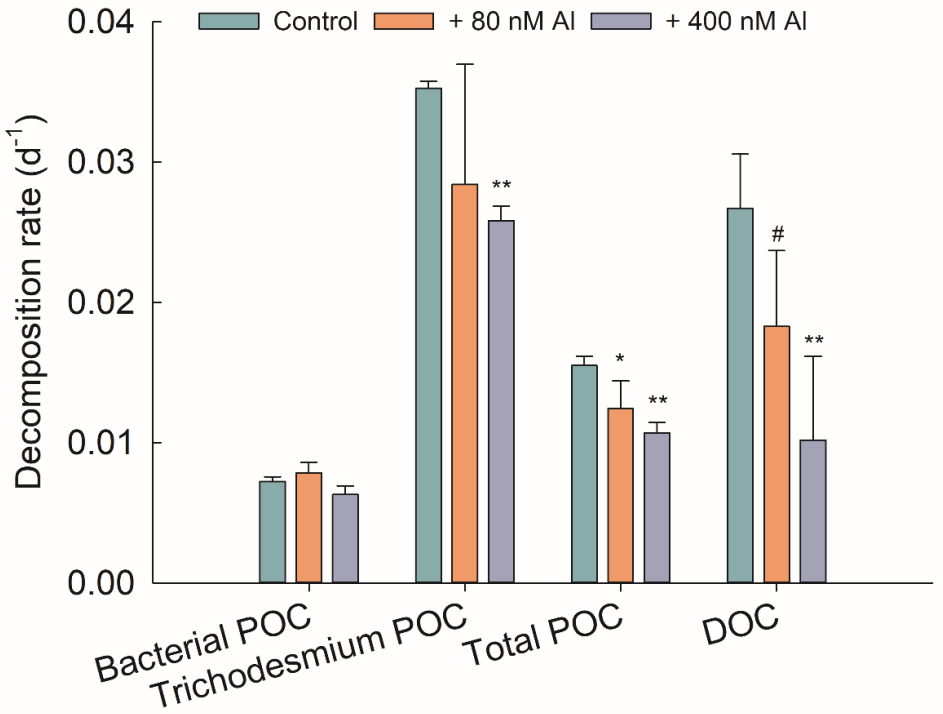
Aluminum increases diatom carbon export to deep ocean interior



Al addition may double the carbon export to 100 m,
and increase the carbon export to 1000 m by 3 orders of magnitudes

Source: Zhou et al. (2021) L&O

Aluminum may preserve organic carbon in marine sediments by decreasing its decomposition rates

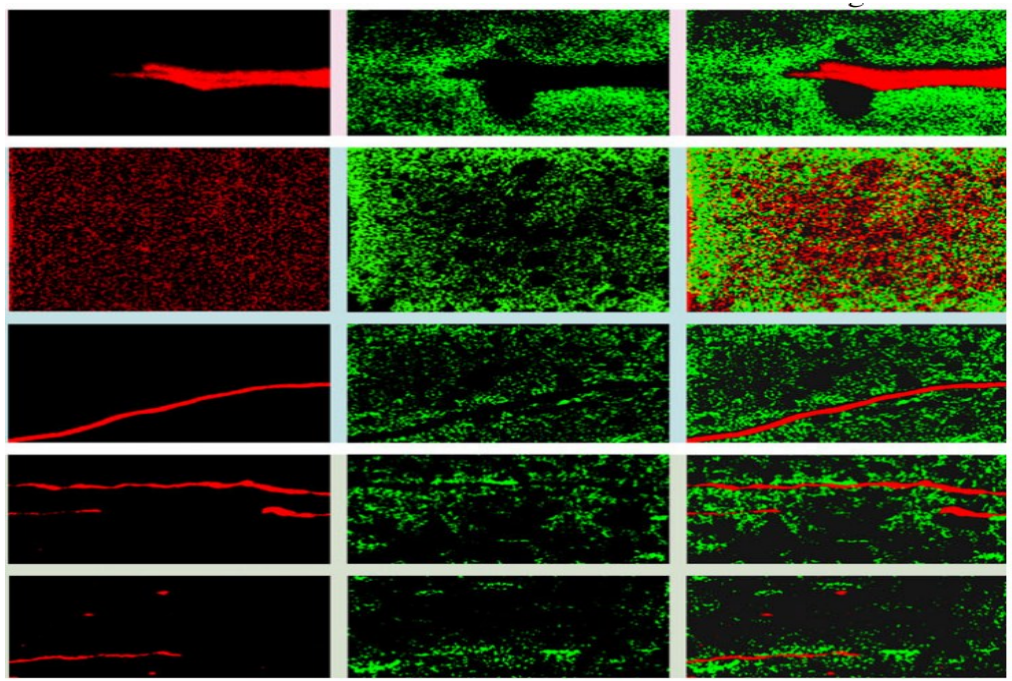


Simulated Al concentrations in marine sediments significantly decreased the decomposition rates of *Trichodesmium* POC and DOC released by decaying *Trichodesmium*

Source: Zhou et al. 2023 Biogeochemistry

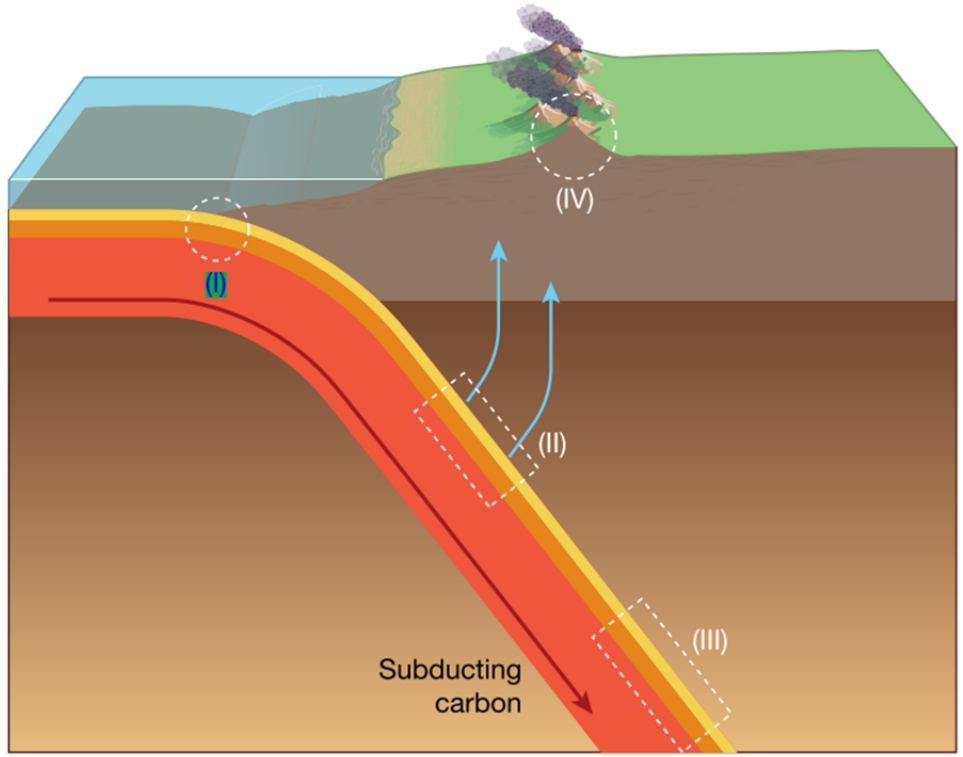
Aluminum can help to sequestrate carbon in geological time

Al preserves carbon for 800 million years



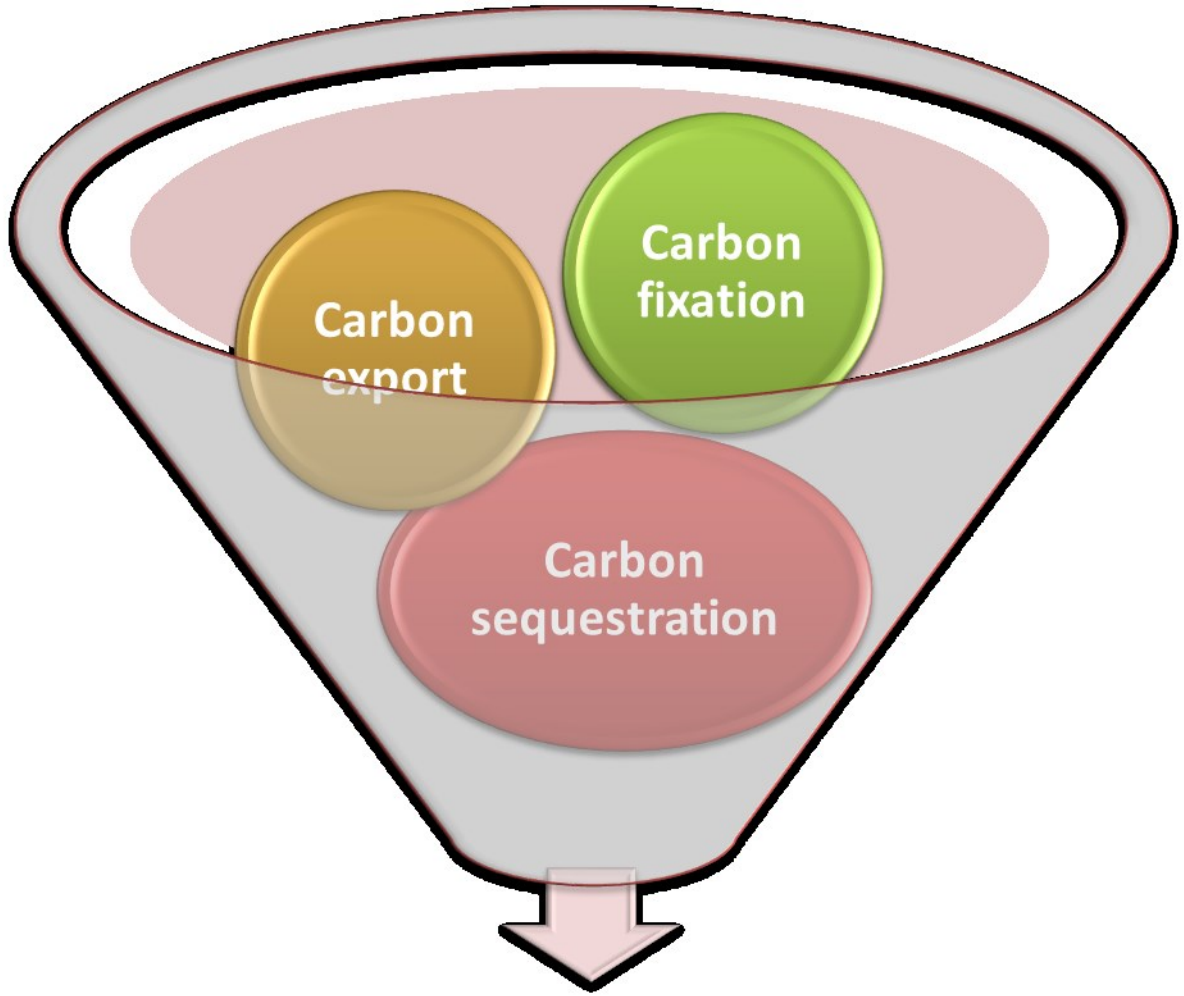
carbon aluminum merged

Source: Anderson et al. (2020) Interface Focus



Al-preserved carbon participates in the deep carbon cycle

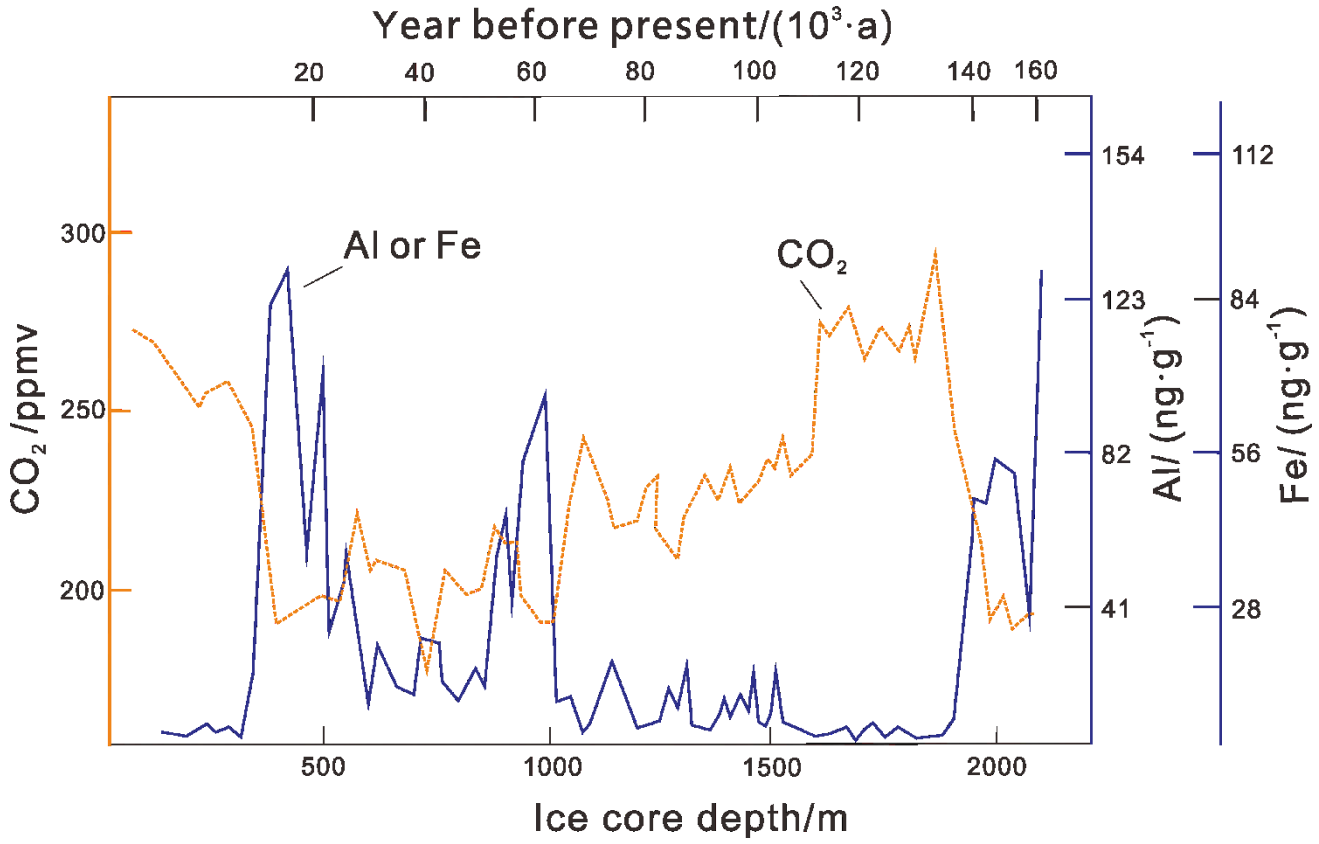
Source: Plank and Manning 2019 Nature



Influences climate change?

④linked to climate change

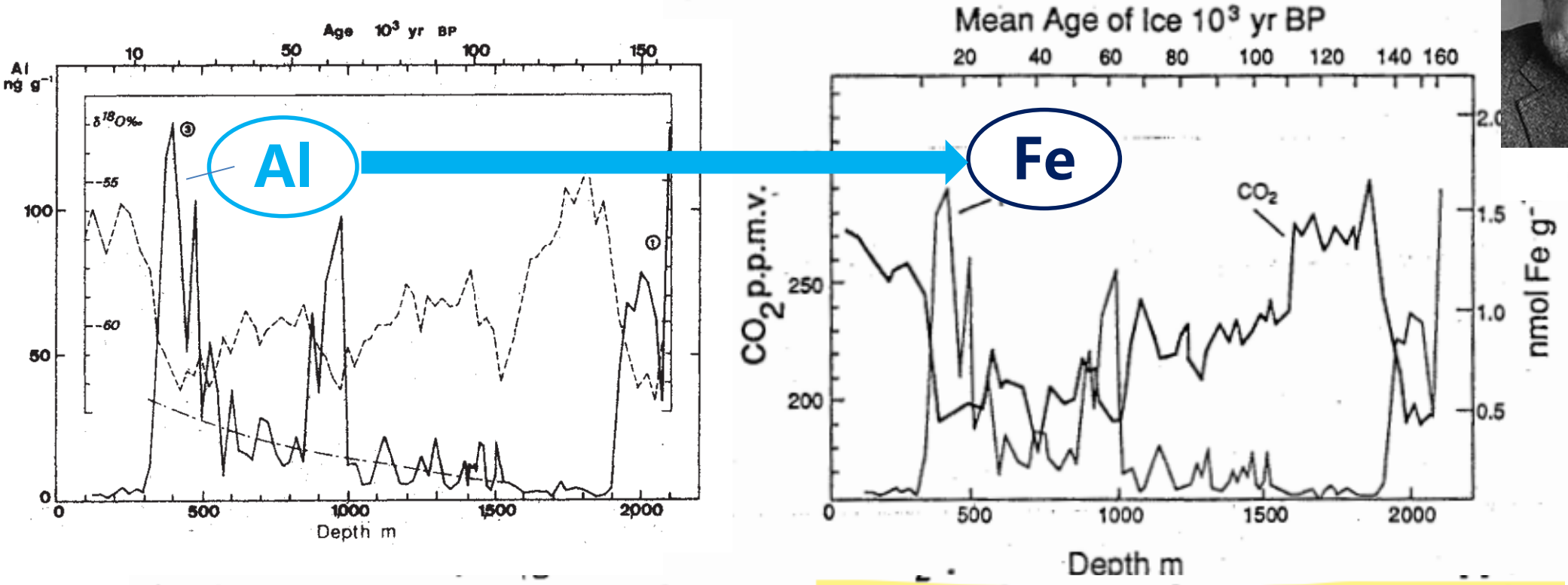
Aluminum & Fe Input to the Southern Ocean inversely correlated with atmospheric CO_2 in the past 160 kyrs



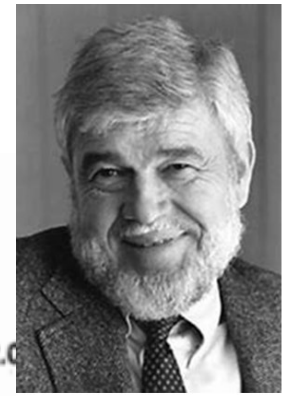
Source: Zhou et al. 2018 Biogeochemistry

④link to climate change

Fe was calculated based on Al and the ratio of Al/Fe in Earth’ s crust



in ice, versus mean age of air. Original figure taken from De Angelis et al. [1987]. Their Al data were converted to Fe estimates using Taylor's [1964] crustal abundance values. Age data are from Lorius



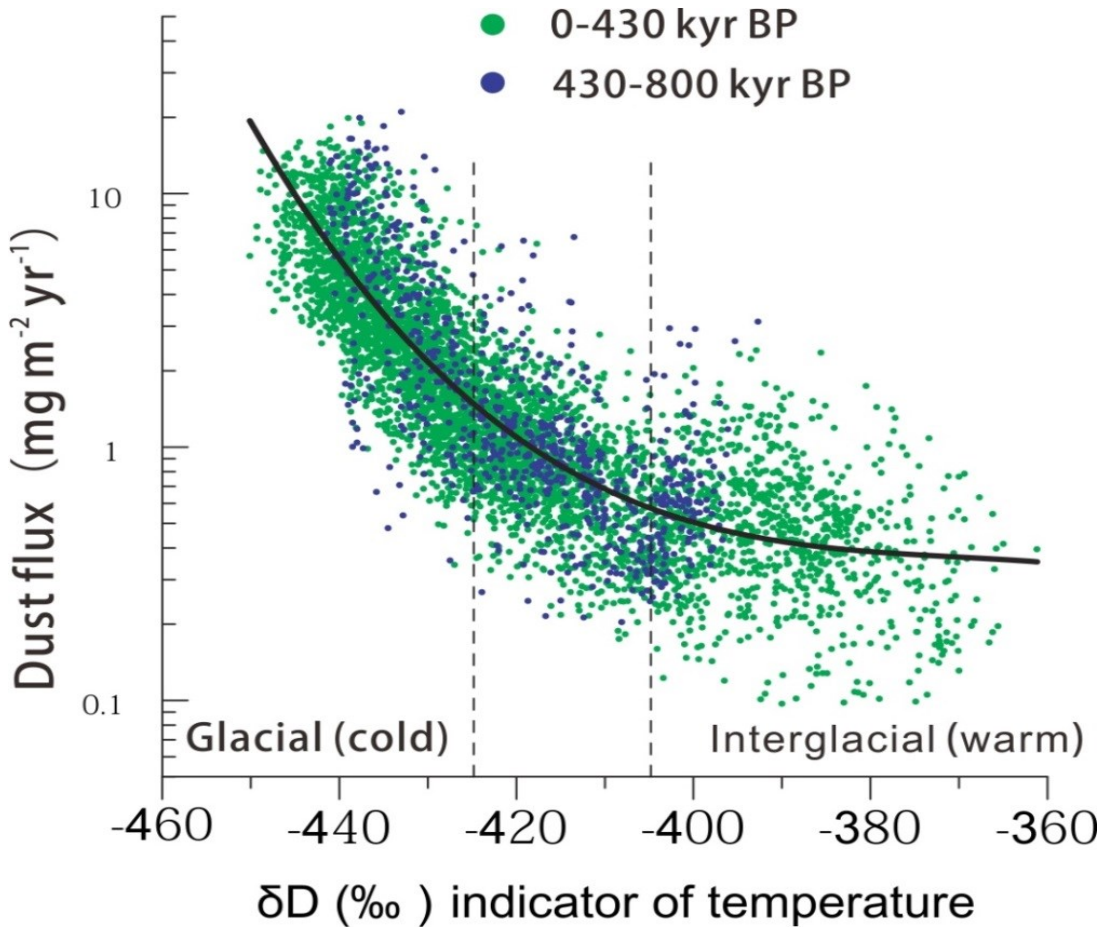
John Martin

De Angelis et al., 1987

Martin, 1990

④linked to climate change

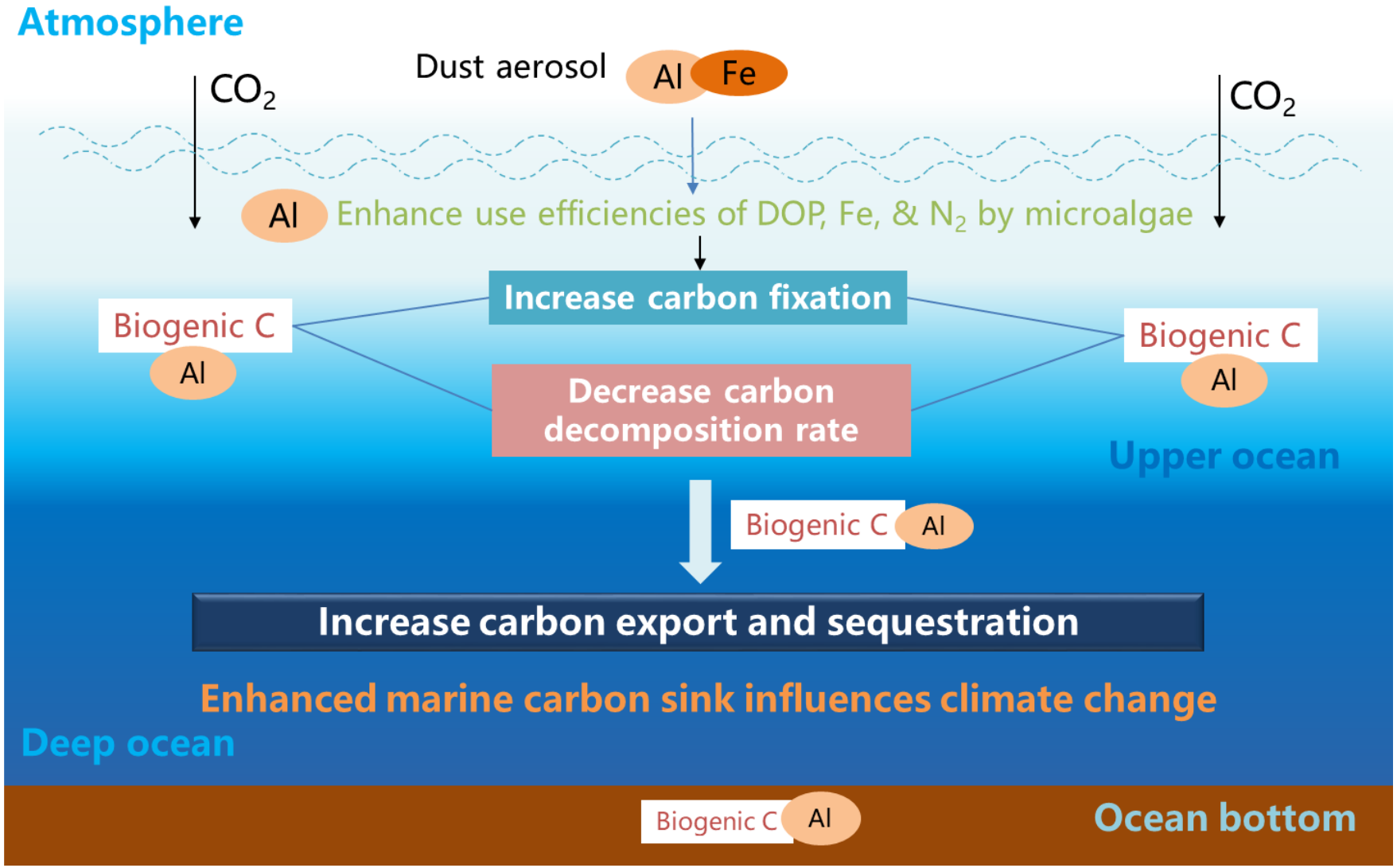
High natural Aluminum and Fe fertilization through dust deposition linked to cold climates in the past 800 kyrs



Source: Lambert et al. (2008) Nature

④linked to climate change

Iron-Aluminum Hypothesis



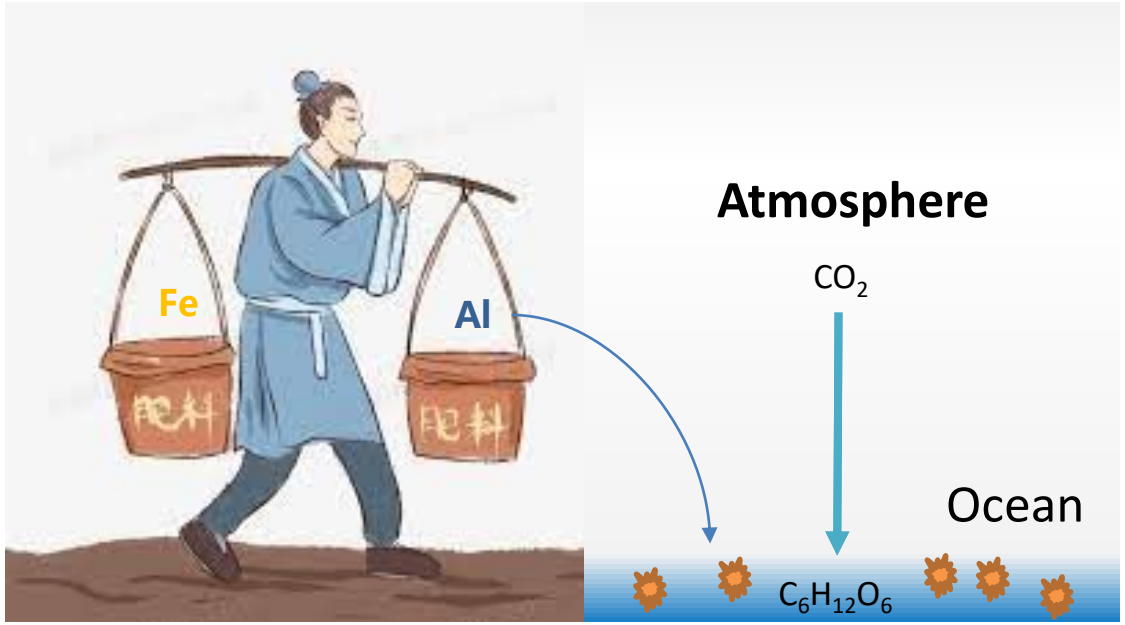
④linked to climate change

Heavy dust deposition may increase Al concentration by 20-200 nM over the world ocean in glacial times

- Two to three fold increases in dust flux in most of the world oceans
- Twenty-five fold increase in dust flux in the Southern Ocean
- Dissolved Al in the upper ocean is strongly correlated to dust flux

Sources: Measures and Vink 2000; Kienast et al. 2016; Menzel Barraqueta et al. 2020

Ocean Al fertilization as a CO_2 removal strategy

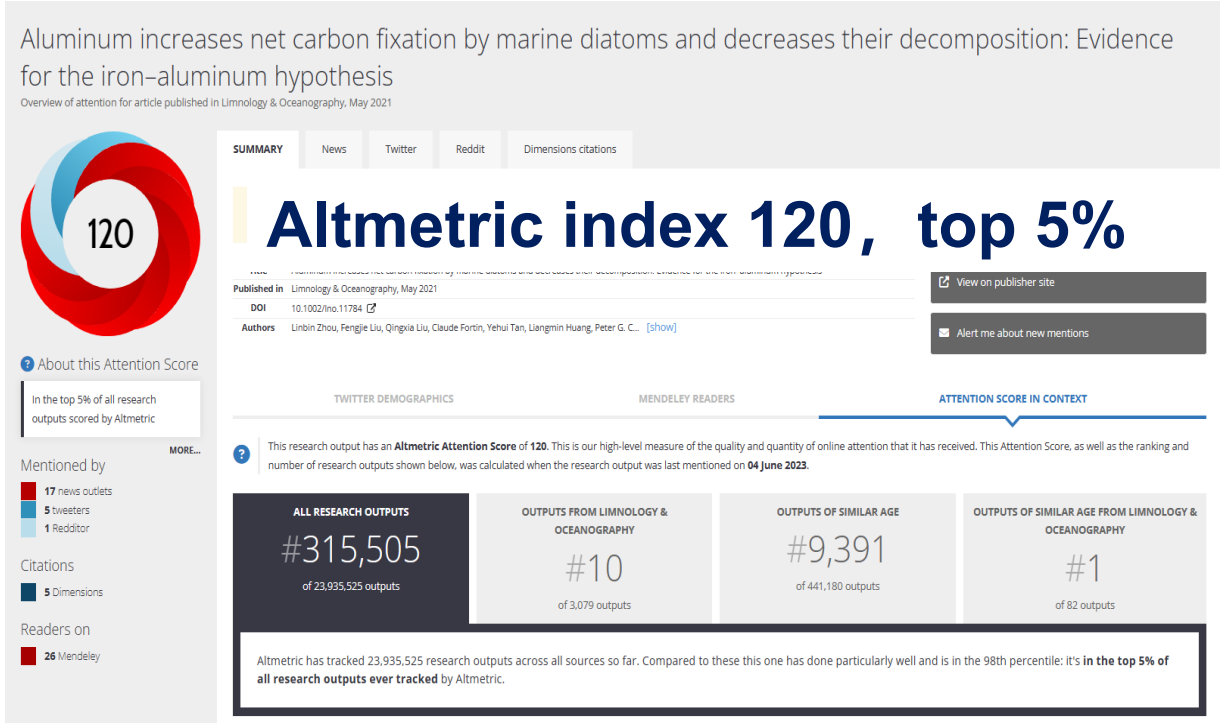


Will ocean Al fertilization be effective?

- Large-scale Fe fertilization: 0.5-1.4 Gt C/yr
- Al fertilization doubles the carbon export to 100 m
- Al fertilization removes another **0.5-1.4 Gt C/yr**
- European carbon emissions in 2021: 0.7 Gt C

Sources: Oschlies et al., 2010; Güssow et al., 2015; Global carbon budget

Ocean Al Fertilization receiving wide attention



Reported and reprinted by nearly 100 news network media in multiple languages

Dear Linbin,

On behalf of the planning and organizing committee for the ASLO 2023 Aquatic Sciences Meeting, we would like to confirm your participation.

PRESENTATION INFORMATION

Abstract Title: Ocean aluminum fertilization as a carbon dioxide removal strategy
Abstract Number: 4938
Session: EP006A Author Spotlight: Recent High-Impact Articles From the ASLO Journals
Session Organizer: Rita Franco-Santos
Presentation: https://aslo.secure-platform.com:443/2023/gallery/rounds/13/details/6324
Room Number/Location: Sala Menorca A
Session Start Date, Time: 6/5/2023 08:30 AM (Central European Summer Time)

We appreciate your dedication and interest in ASLO, and we look forward to working with you in the future at other ASLO meetings!

Sincerely

Dear Dr. Linbin Zhou,

Your article, "Aluminum increases net carbon fixation by marine diatoms and decreases their decomposition: Evidence for the iron–aluminum hypothesis", published in the ASLO journal *Limnology and Oceanography* on 3 May 2021 (http://dx.doi.org/10.1002/lno.11784), has been selected as one of 15 outstanding articles published in the ASLO journal portfolio from 2020 – 2021. ASLO would like to take this opportunity to congratulate you AND thank you for your excellent contribution to the ASLO journals. It is because of authors like you that our journals continue to be some of the highest ranked in the areas of Oceanography and Limnology.

One of 15 outstanding articles published in the ASLO journal portfolio from 2020-2021

Adding to John Martin's quote:

"Give me half a tanker of iron and a quarter tanker of aluminum, and ....."

Ken O. Busesseler

Take-home messages

- Aluminum may play an important role in increasing marine carbon sinks and regulating climate change
- **Fertilization of aluminum and iron together in the high-nitrate low-chlorophyll oceans as a possible CDR strategy to remedy global warming**

Thanks for your attention !

- Collaborators

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