Dust nourishment of global ocean ecosystems

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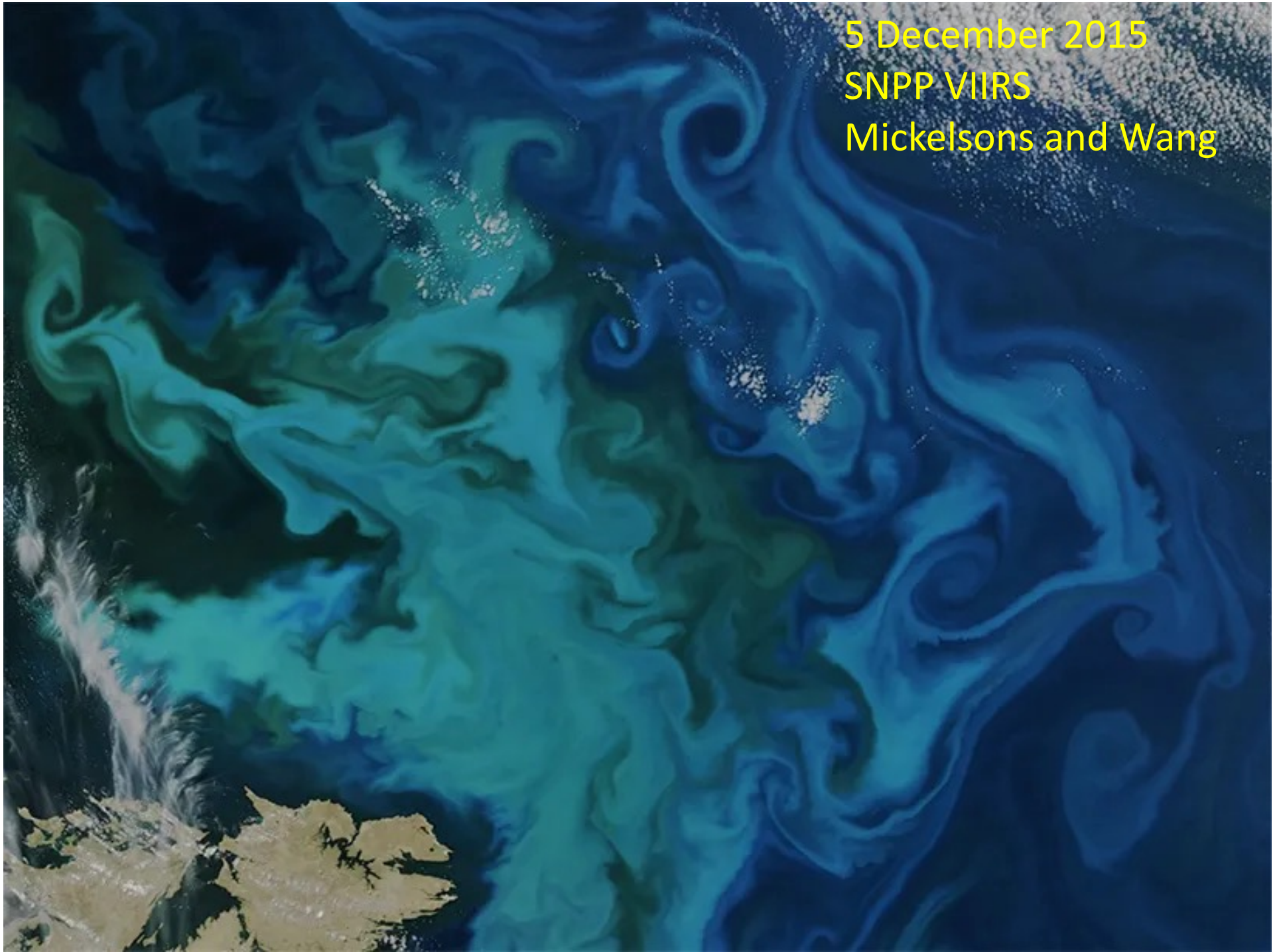
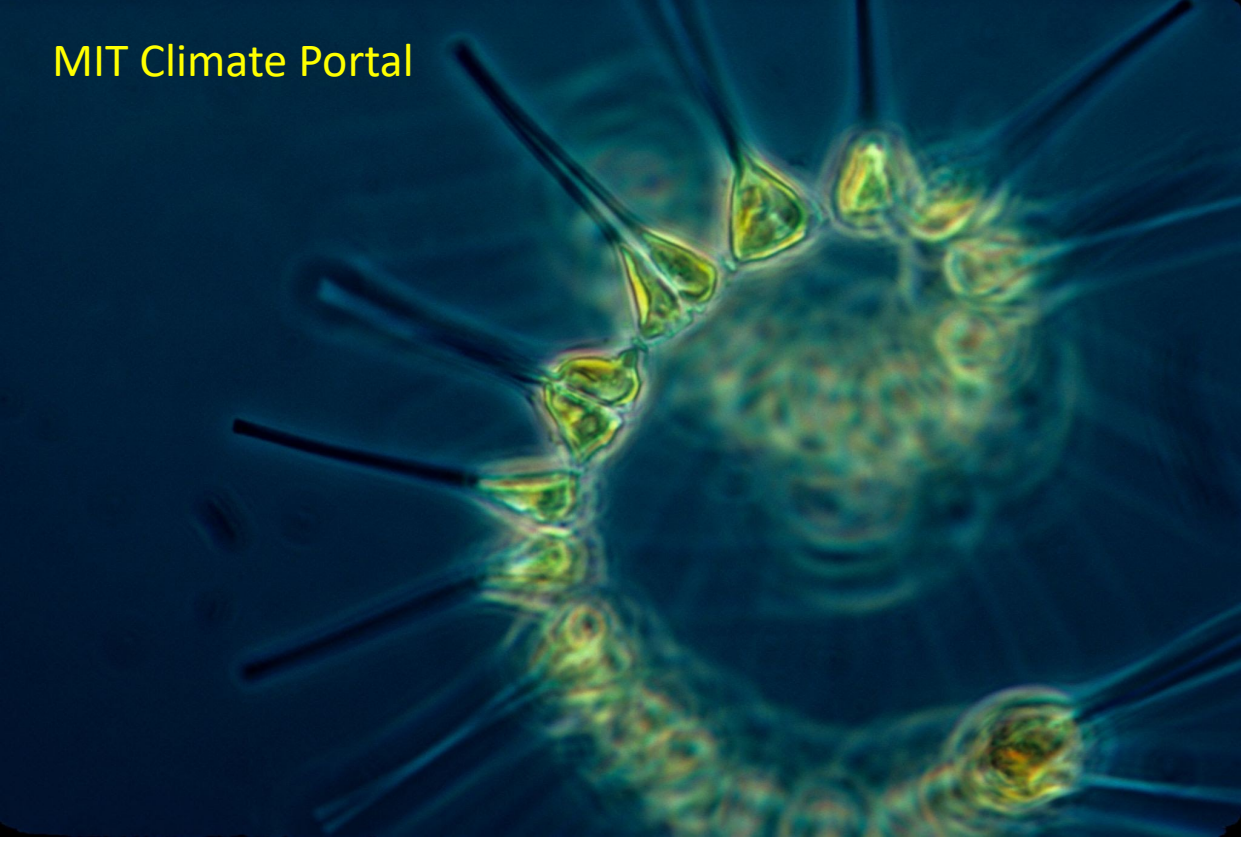
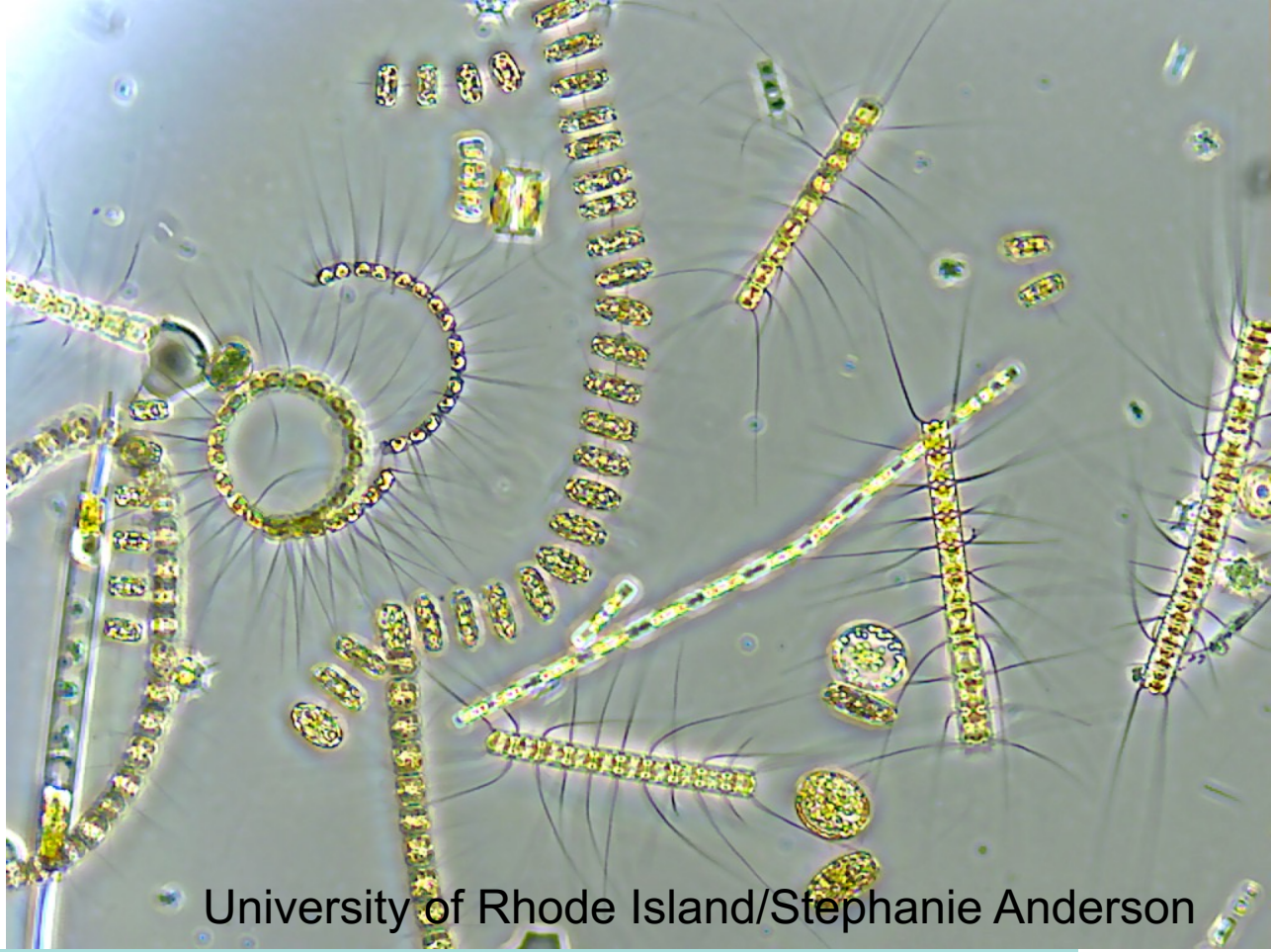

5 December 2015
SNPP VIIRS
Mickelsons and Wang



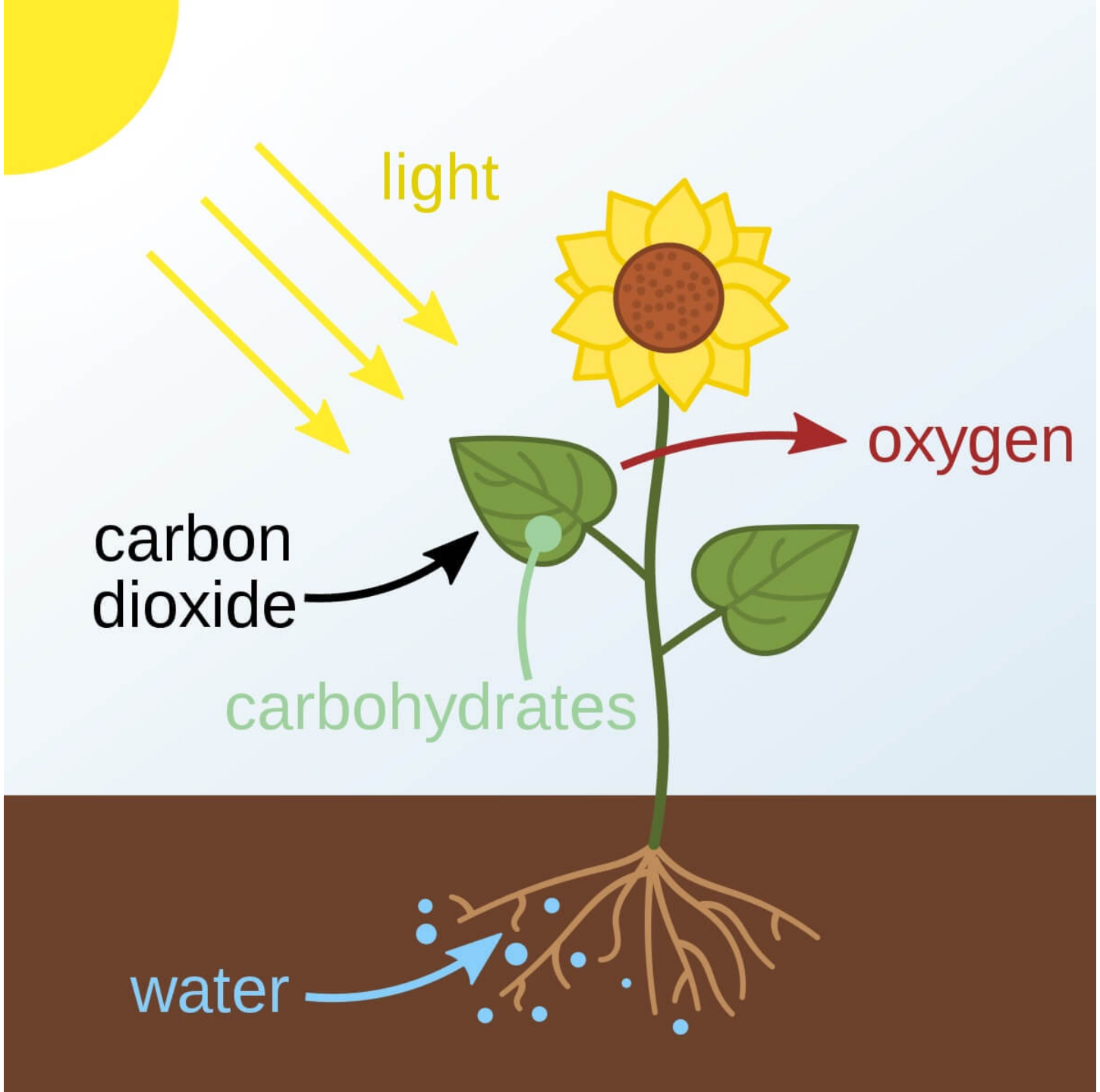


Phytoplankton are plants!

Elementary school level concept of photosynthesis

Plants make their own food

Taking energy from sunlight, carbon dioxide from the air, and water from the soil and then storing it as potential energy

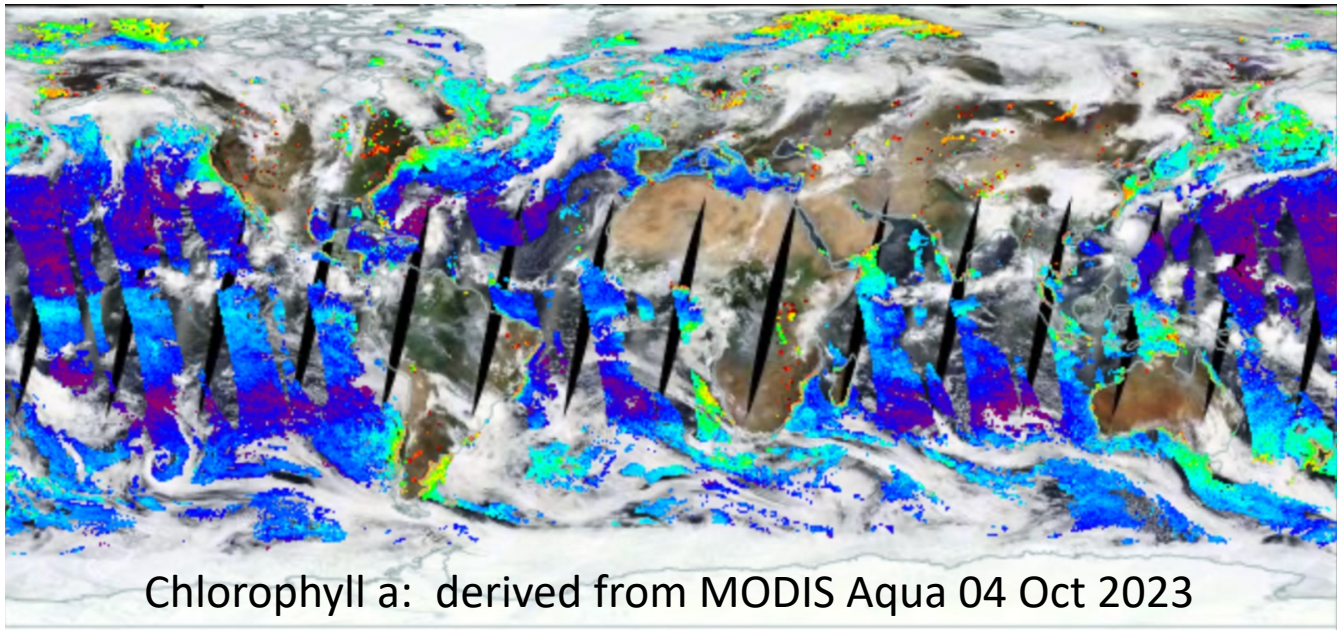


Middle school concept of photosynthesis

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{2H_2O} + \underset{\text{light energy}}{\text{photons}} \rightarrow \underset{\text{carbohydrate}}{[CH_2O]} + \underset{\text{oxygen}}{O_2} + \underset{\text{water}}{H_2O}$$

Pigment called chlorophyll necessary to capture the photons

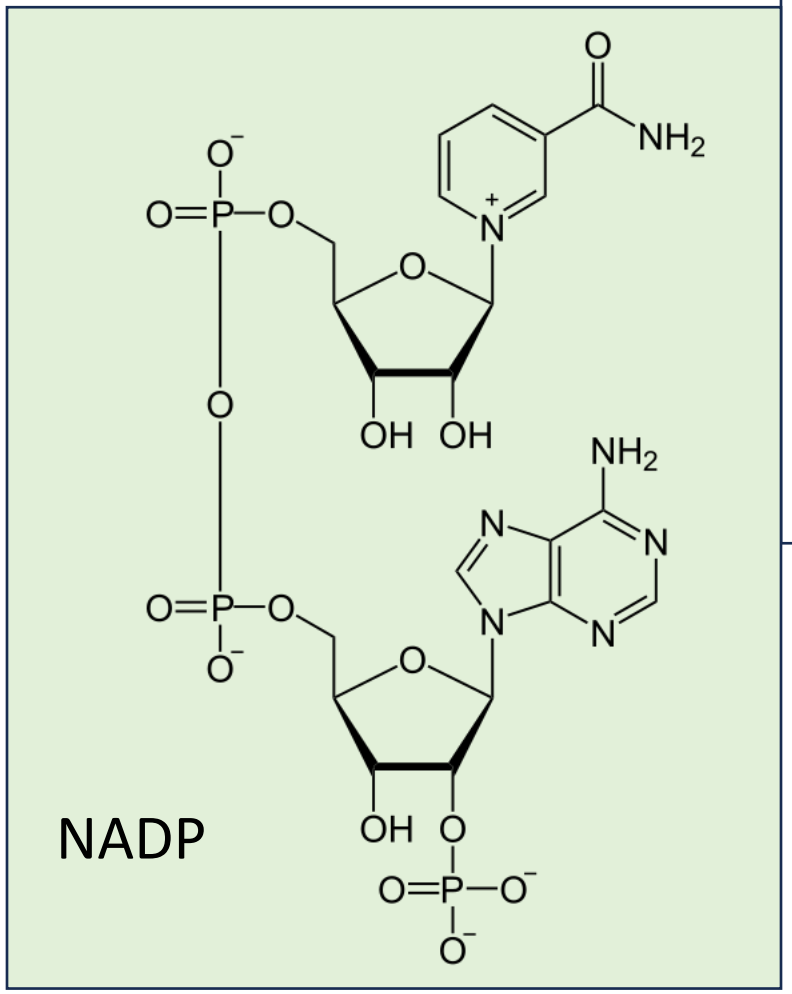
Chlorophyll absorbs light and creates the plant's color

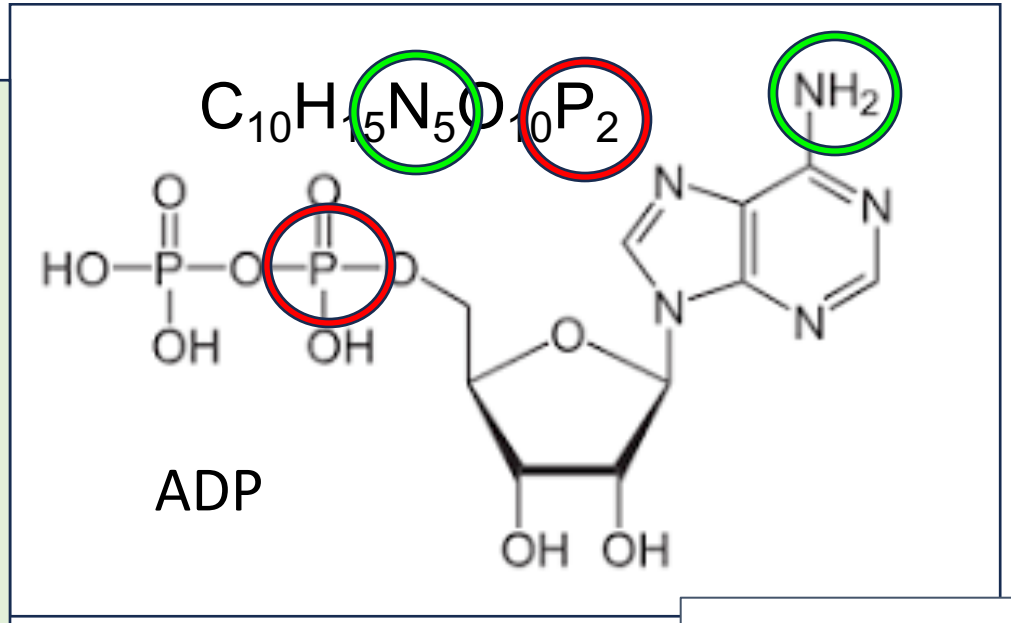


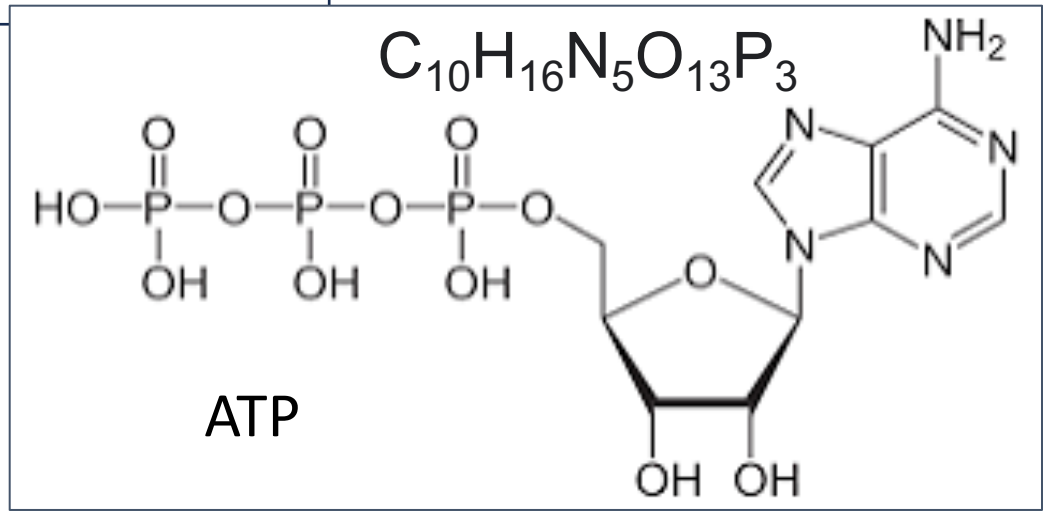
Chlorophyll a: derived from MODIS Aqua 04 Oct 2023

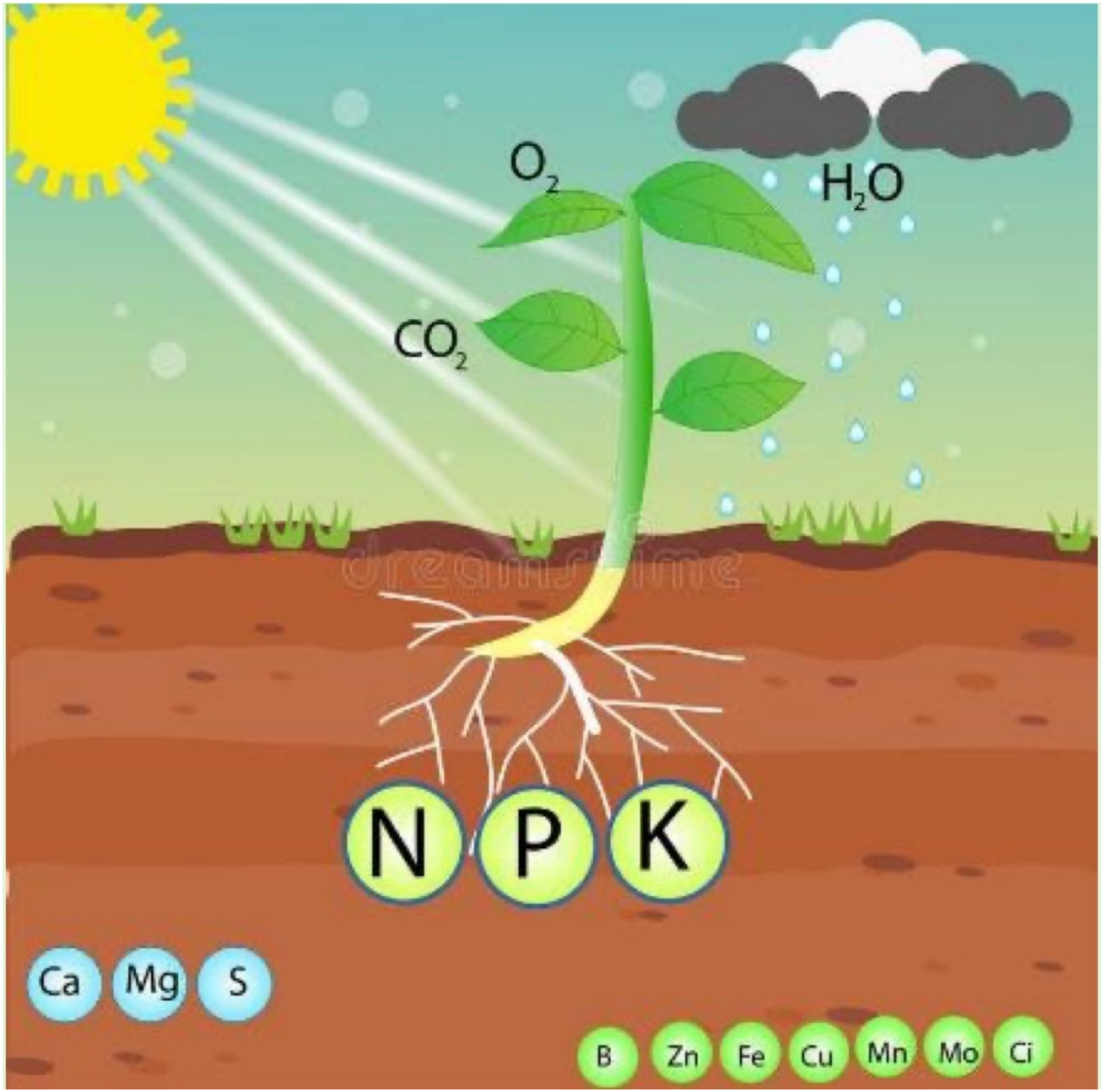
High School level concept of photosynthesis

$$2\,H_2O + 2\,NADP^+ + 3\,ADP + 3\,P_i + light \rightarrow 2\,NADPH + 2\,H^+ + 3\,ATP + O_2$$









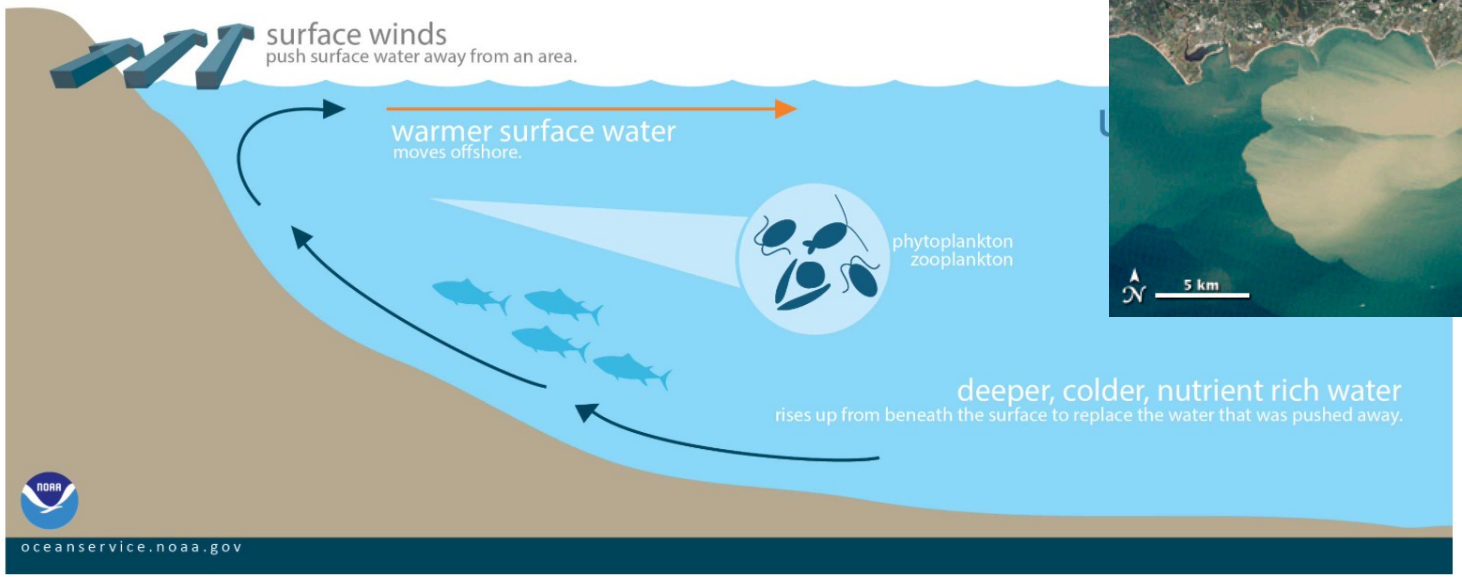
Plants obtain their nutrients from the soil

And yet all the simplistic pictures of photosynthesis portray
terrestrial plants

How do phytoplankton obtain their nutrients?

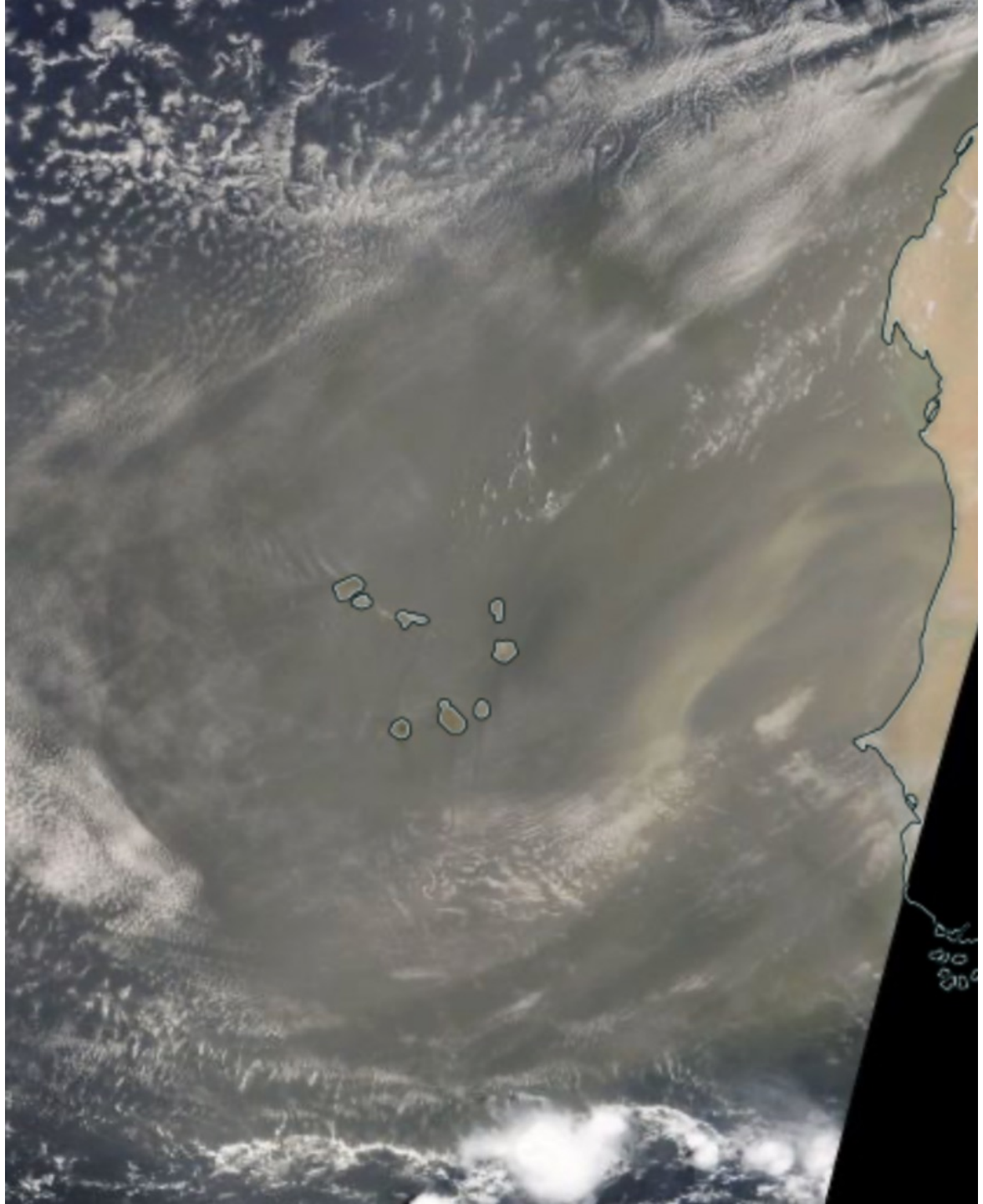
Sources of mineral nutrition for ocean phytoplankton?

- sediments in river runoff
- mixing on continental shelves
- upwelling from deep ocean



But what about the atmosphere

as a source for mineral nutrition for phytoplankton?

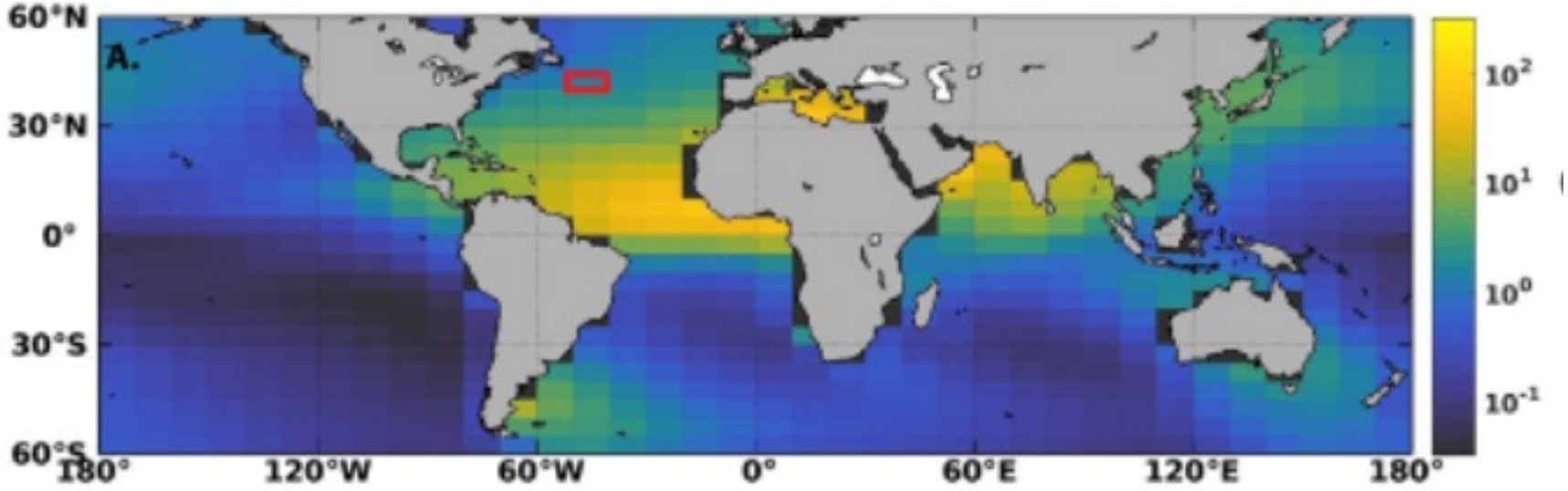


But what about the atmosphere as a source for mineral nutrition for phytoplankton?

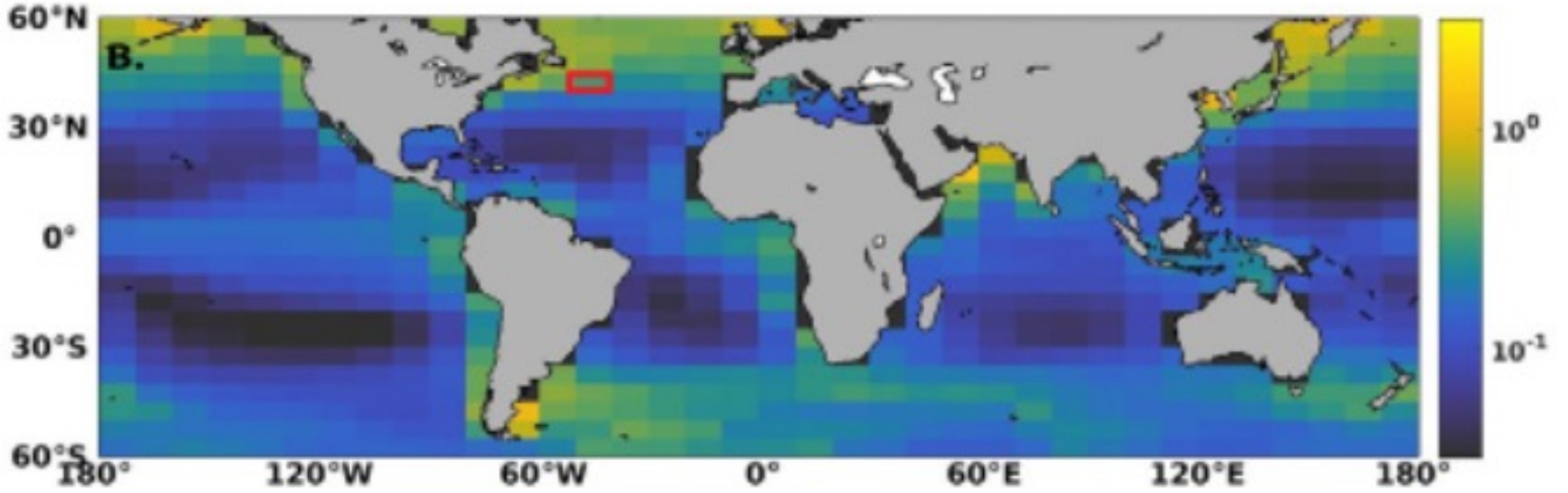
Is there a relationship between airborne mineral aerosol and phytoplankton on global scales?

Can we see a response from space?

No global correlation between dust and chlorophyll concentration



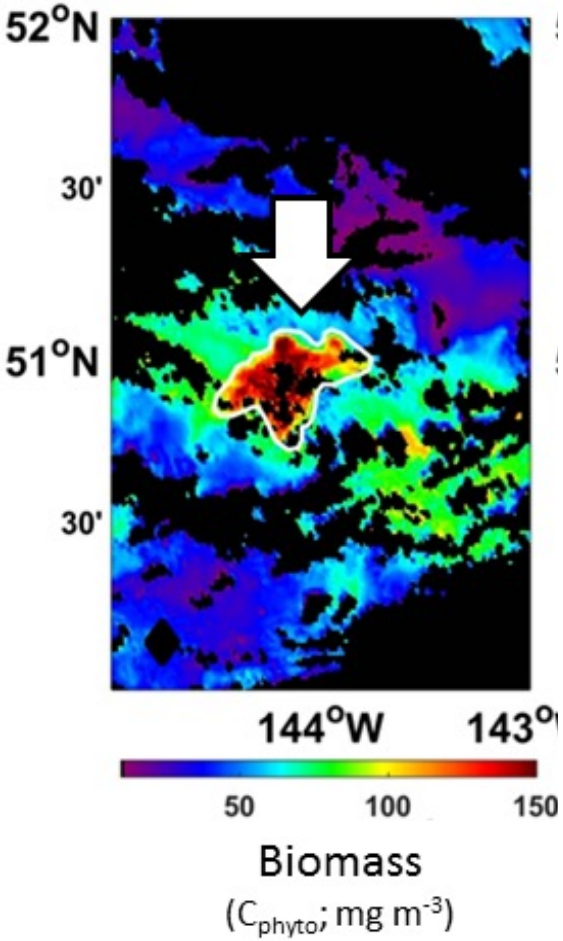
GEOS model dust deposition rates



Average chlorophyll concentration

Westberry et al. (2023)

And yet,

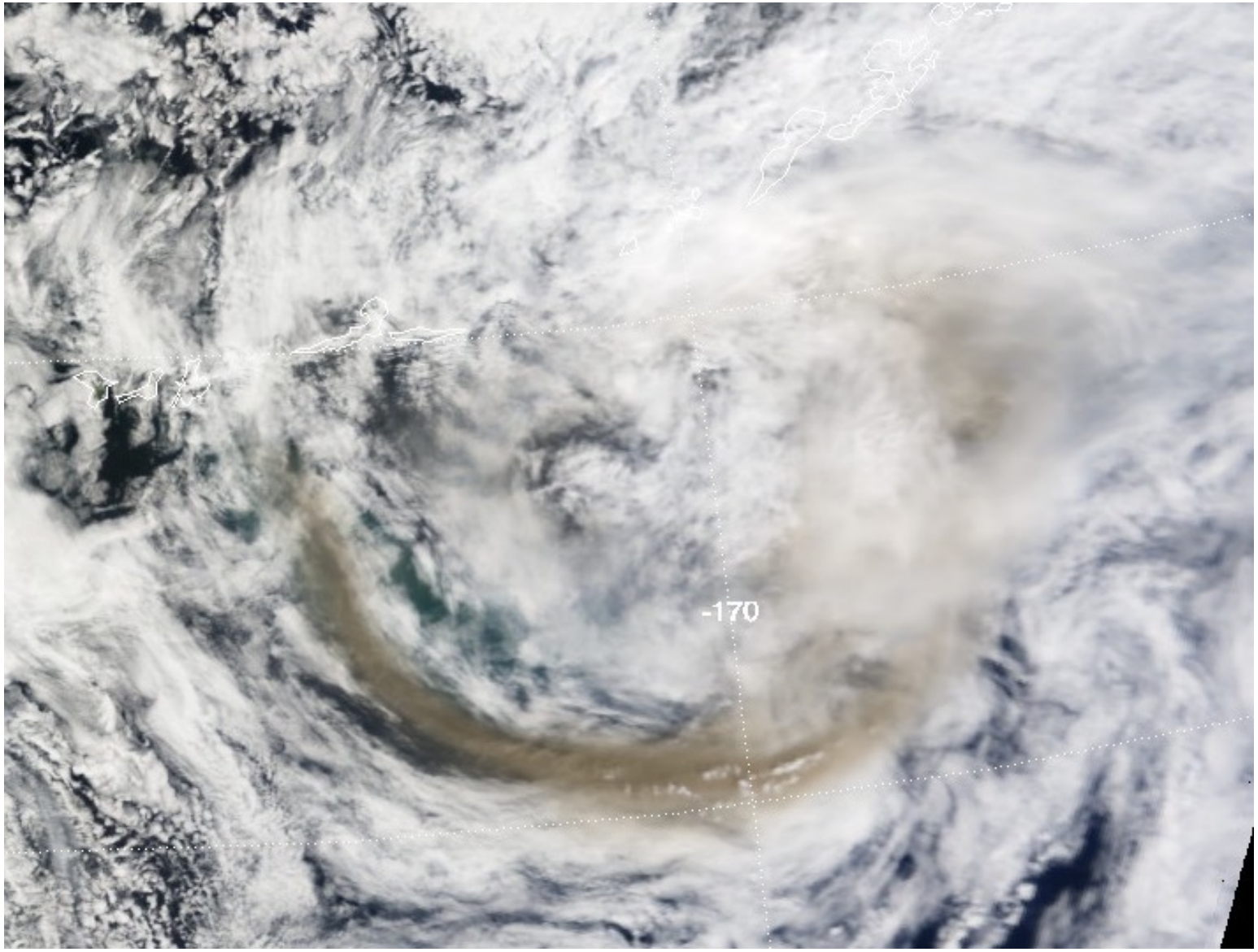


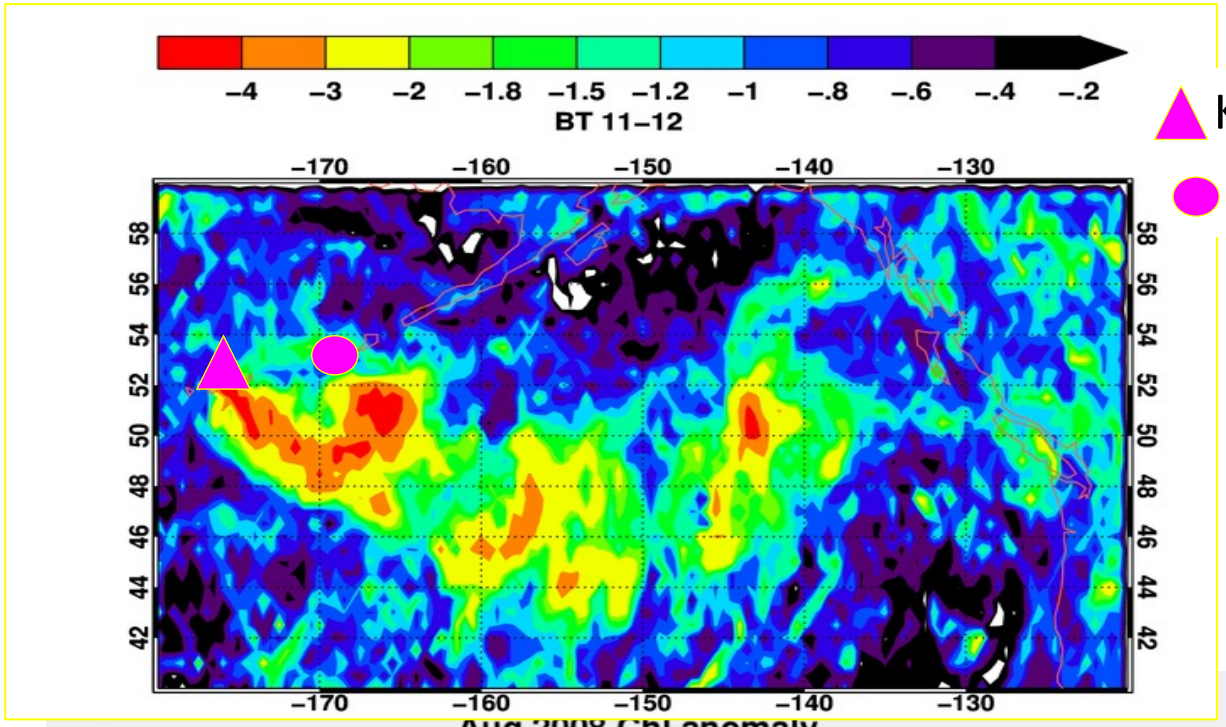
When you dissolve iron and dump it over the side of a ship you see an increase of phytoplankton biomass.

And you can see it from space

Westberry et al. (2013)

Kasatochi eruption 7-8 Aug 2008

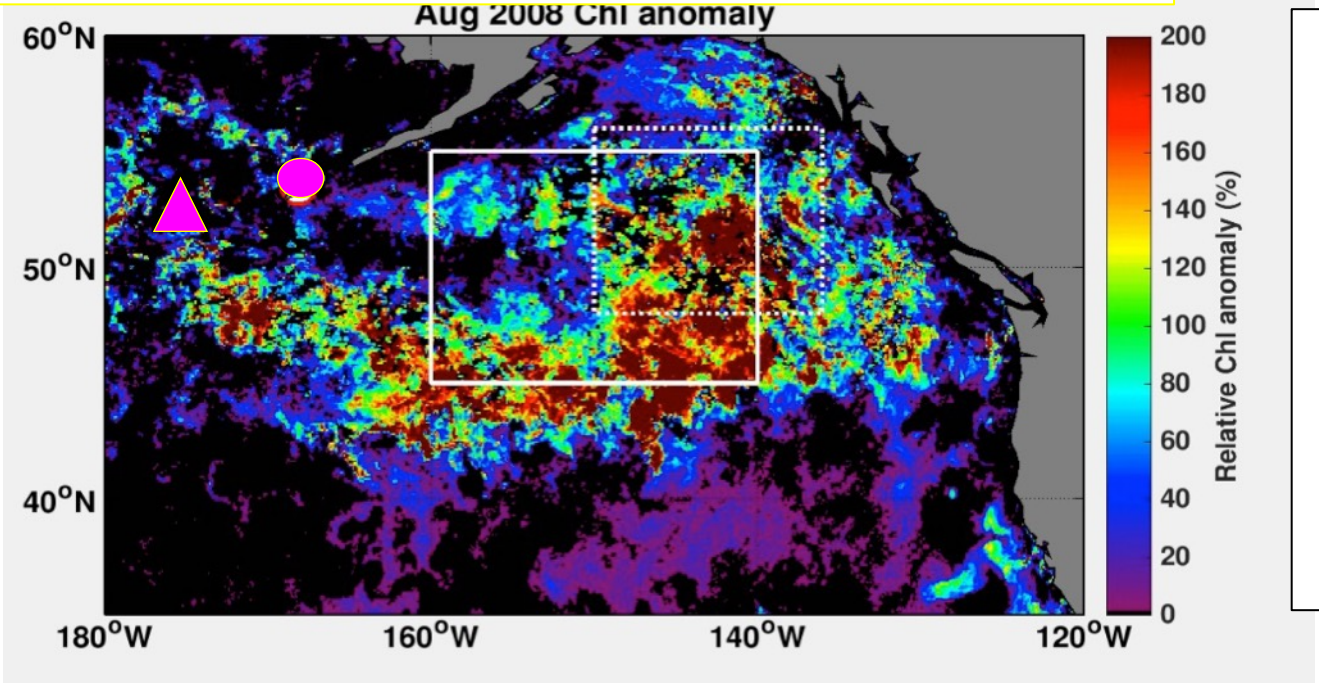




▲ Kasatochi eruption 7-8 Aug 2008

● Okmok: 22 Jul to 18 Aug 2008

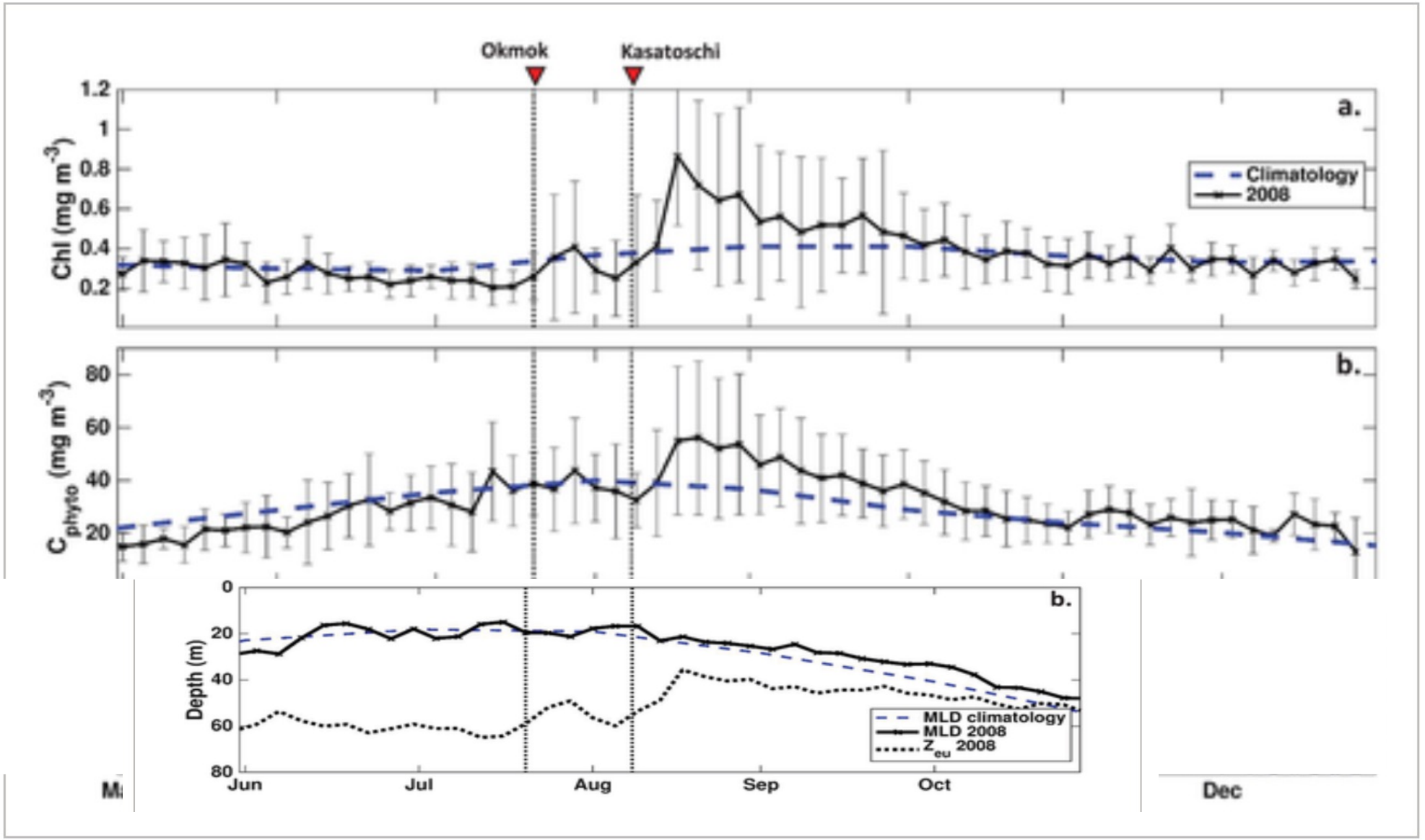
Atmosphere
Volcanic ash plumes
Composite BT 11-12
8-12 August 2008
(Yingxi Shi)



Ocean
Chl Aug 2008
anomaly

Monthly mean, but heavily influenced by latter half of the month.
(Toby Westberry)

Westberry et al. 2019

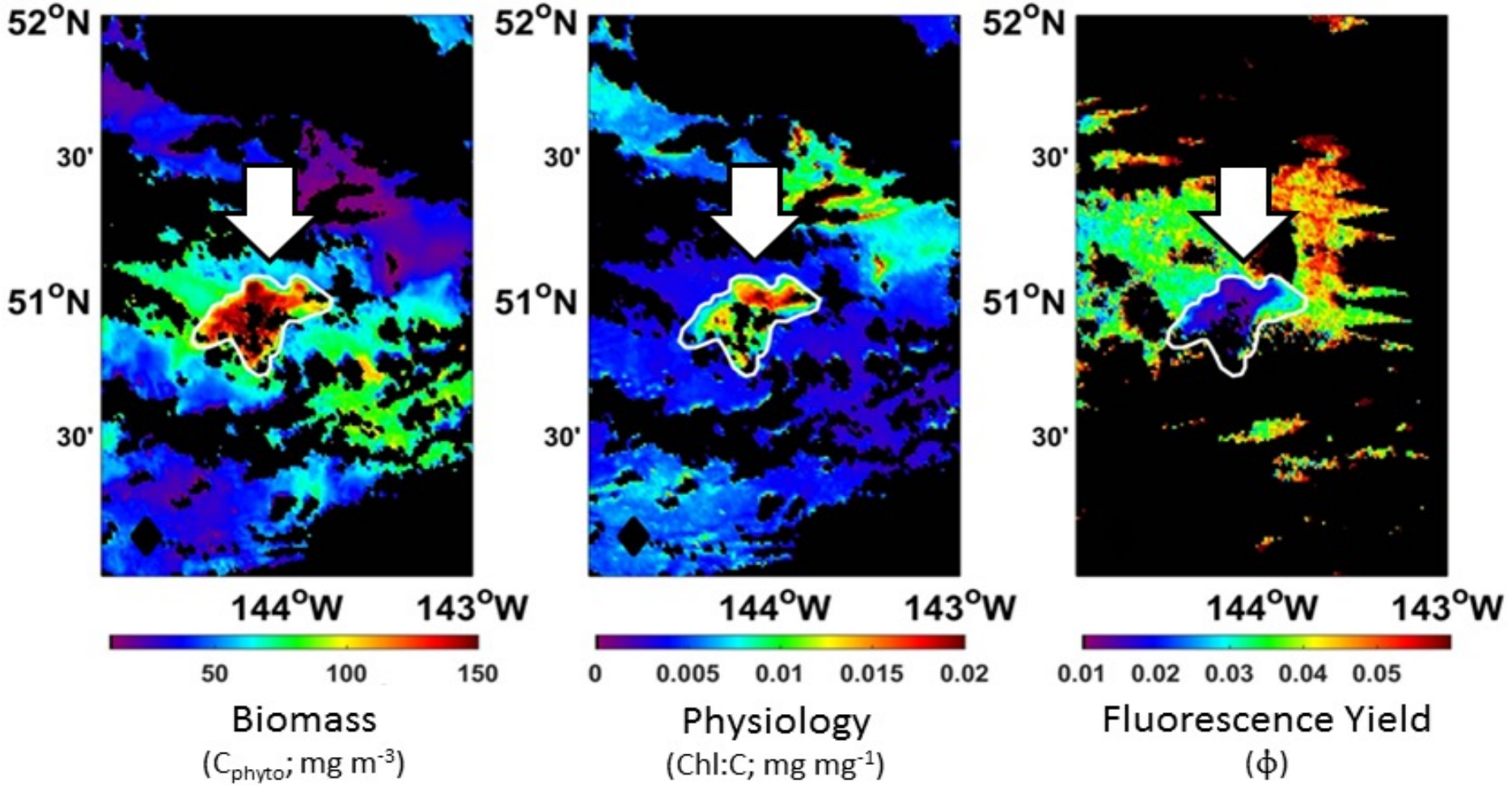


Westberry et al. 2019

Evidence exists that phytoplankton do respond from a deposition of minerals into the ocean

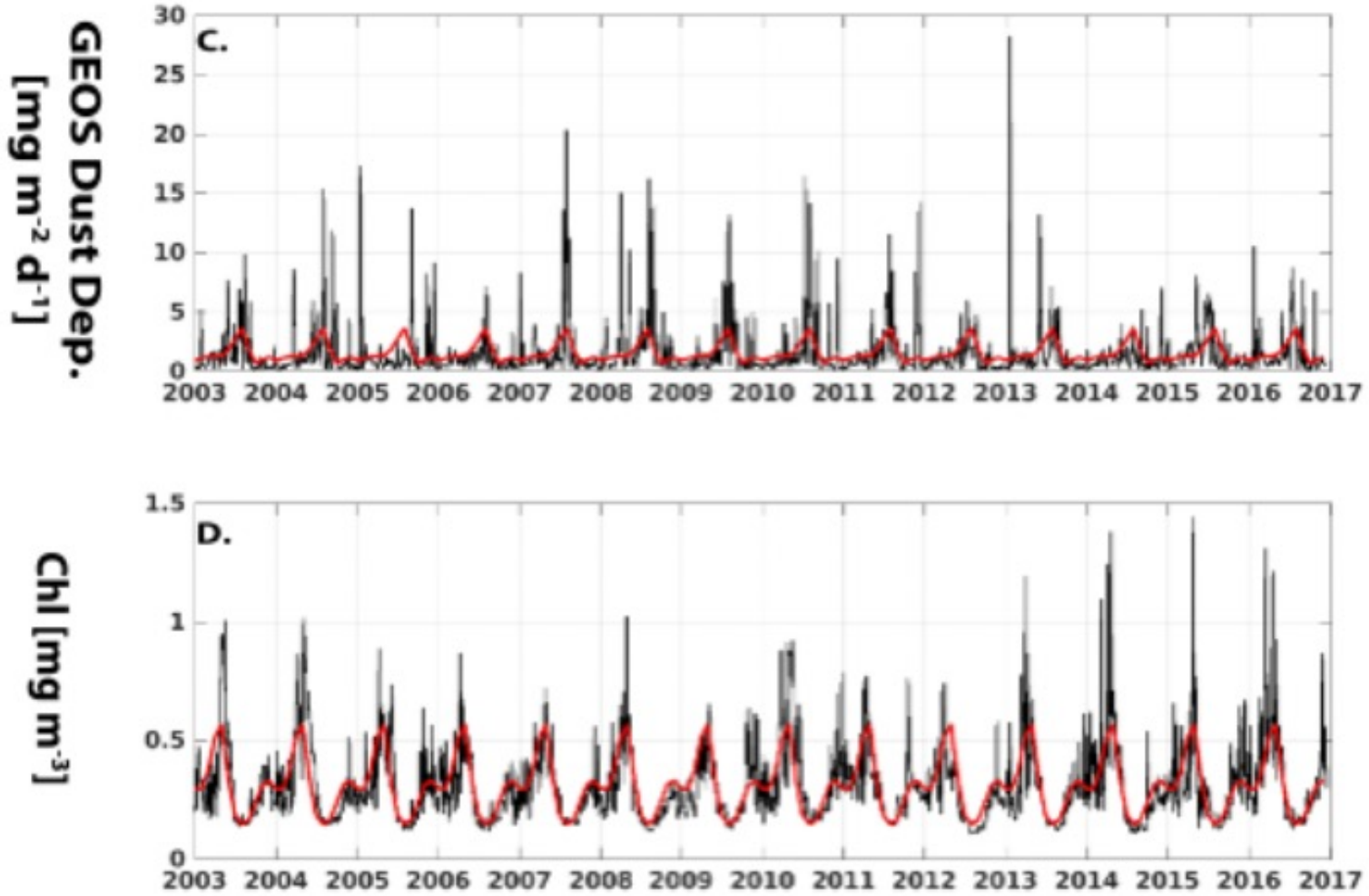
And that we can see this response from space

But, keep in mind, there is NO statistical correlation on a large-scale basis



Westberry et al. (2013)

Time series of 4 –day dust deposition from GEOS5 and 4-day mean chlorophyll concentration from MODIS Aqua for a specific 5^{o} by 10^{o} grid square in the north Atlantic

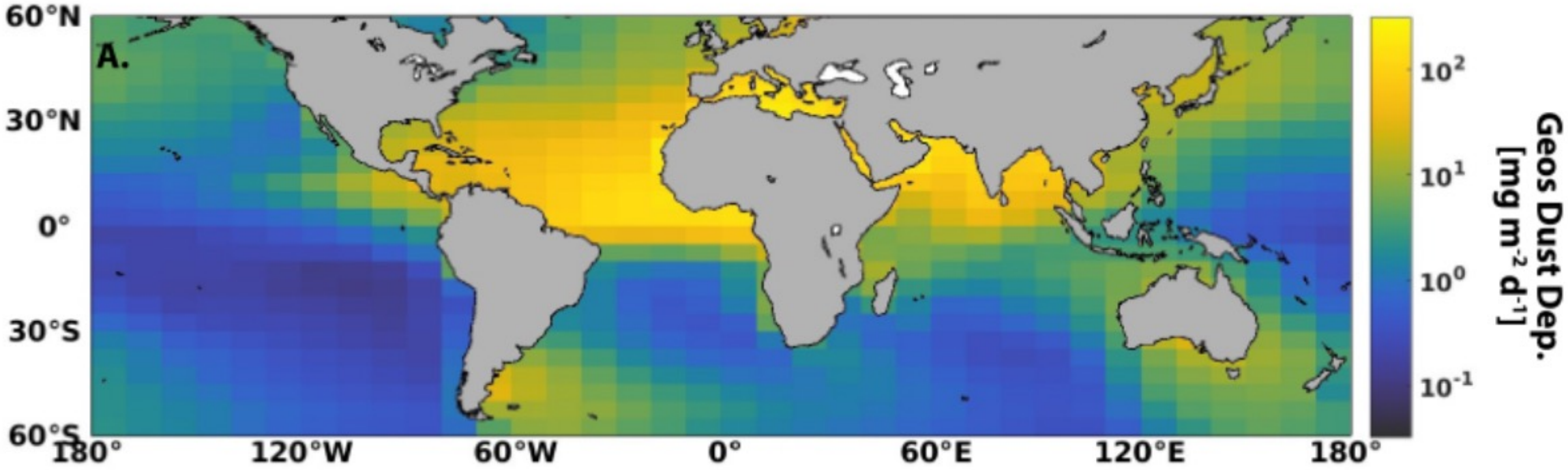


Red line is climatological mean annual cycle

An event is defined as the top 10% of 4-day depositions of the time series

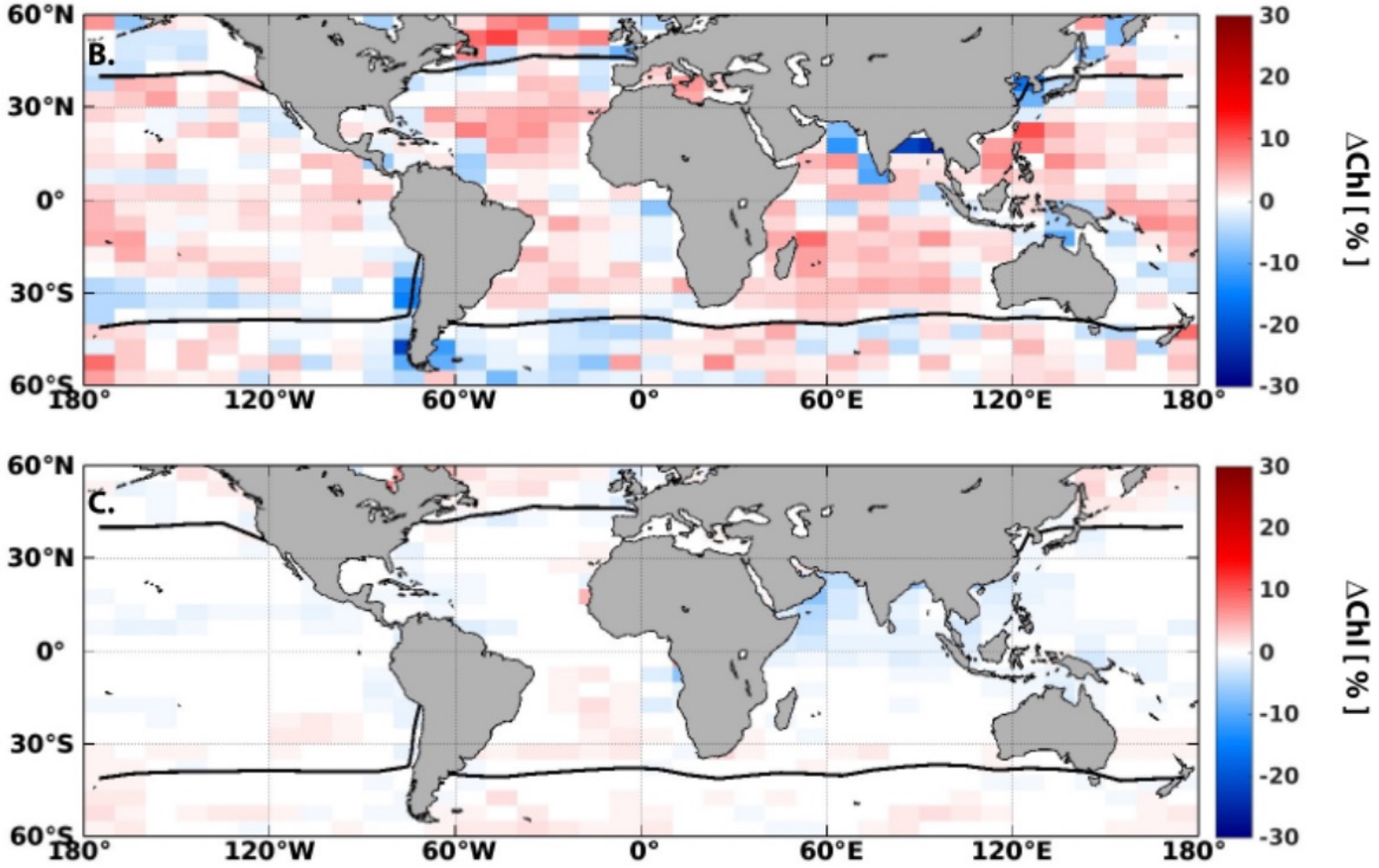
Westberry et al. 2023

GEOS 5 average dust deposition rate (mg m^{-2} d^{-1}) during the top 10% of the record (2003-2016)



Westberry et al., 2023

Change in chlorophyll in the tetrad following a dust deposition event versus the tetrad before the event



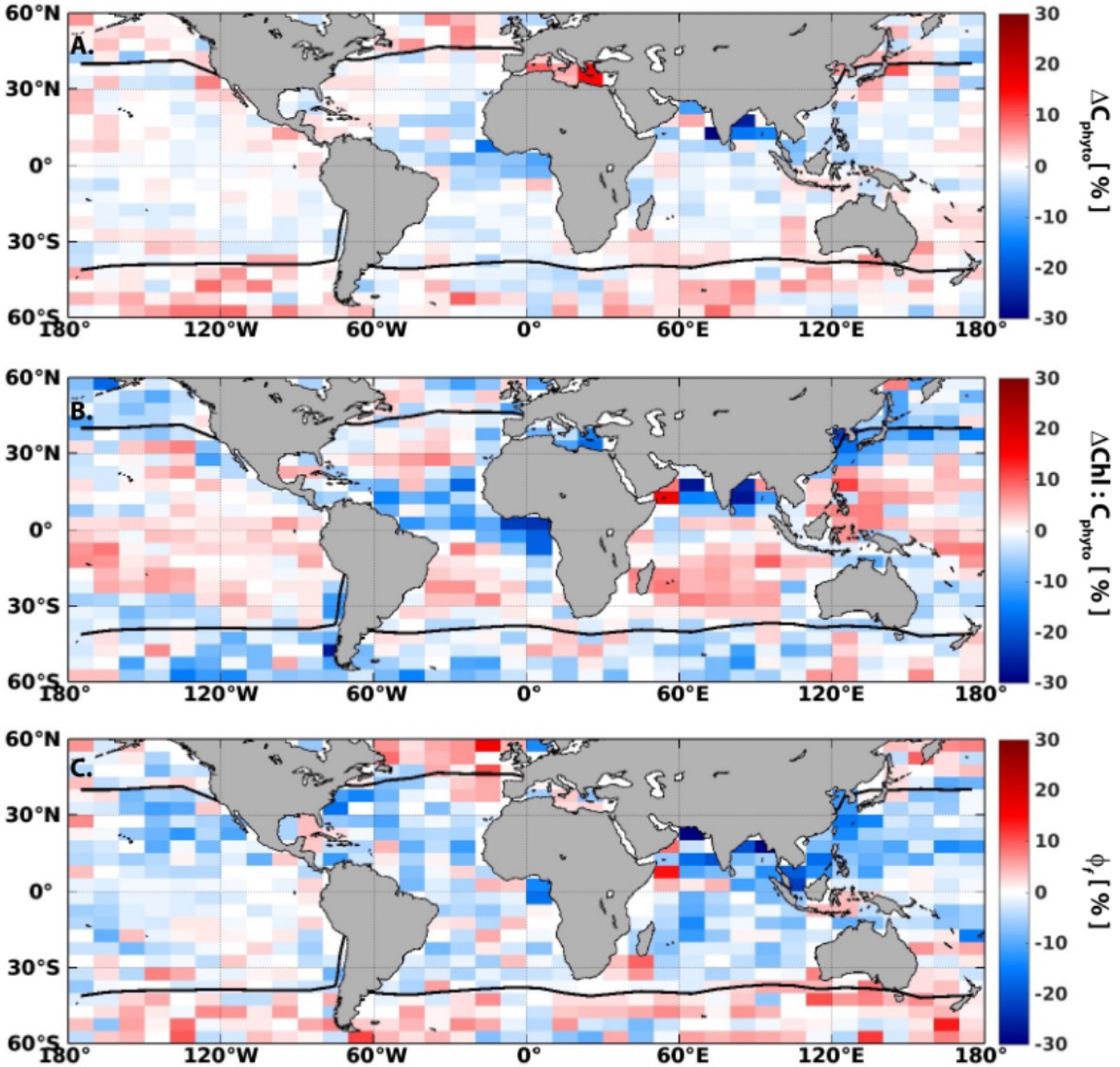
The black lines separate regions permanently stratified within photic layer from deep seasonal mixing regions

The same before and after analysis of a randomly selected 10% of events

The *first observationally-based study* presenting evidence of a phytoplankton response to atmospheric nourishment *at global scales*

Westberry et al., 2023

The first study to show the nature of this response (i.e., health, biomass, or both) varies regionally.



Biomass response

Physiological response

Fluorescence

Westberry et al. 2023

So what did we learn?

1. The atmosphere is a source of nutrition for global ocean phytoplankton
2. Even modest amounts of added minerals will trigger a response
3. We can see this from space
4. The story is no longer iron-focused
5. Finding signal requires an event-by-event analysis
6. Fluorescence is a powerful indicator of response
7. Stratified and mixed oceans respond differently
8. Interdisciplinary science rocks!

Consequences of this study

The atmosphere is a natural and normal contributor to ocean ecosystem health.

As the planet warms, atmospheric circulations and aerosol sources change, what will be the consequences to ocean biology?

Open questions

What about differences in mineralogy or sources or chemical transformation in transit?

Has deposition/response changed over the satellite time series?

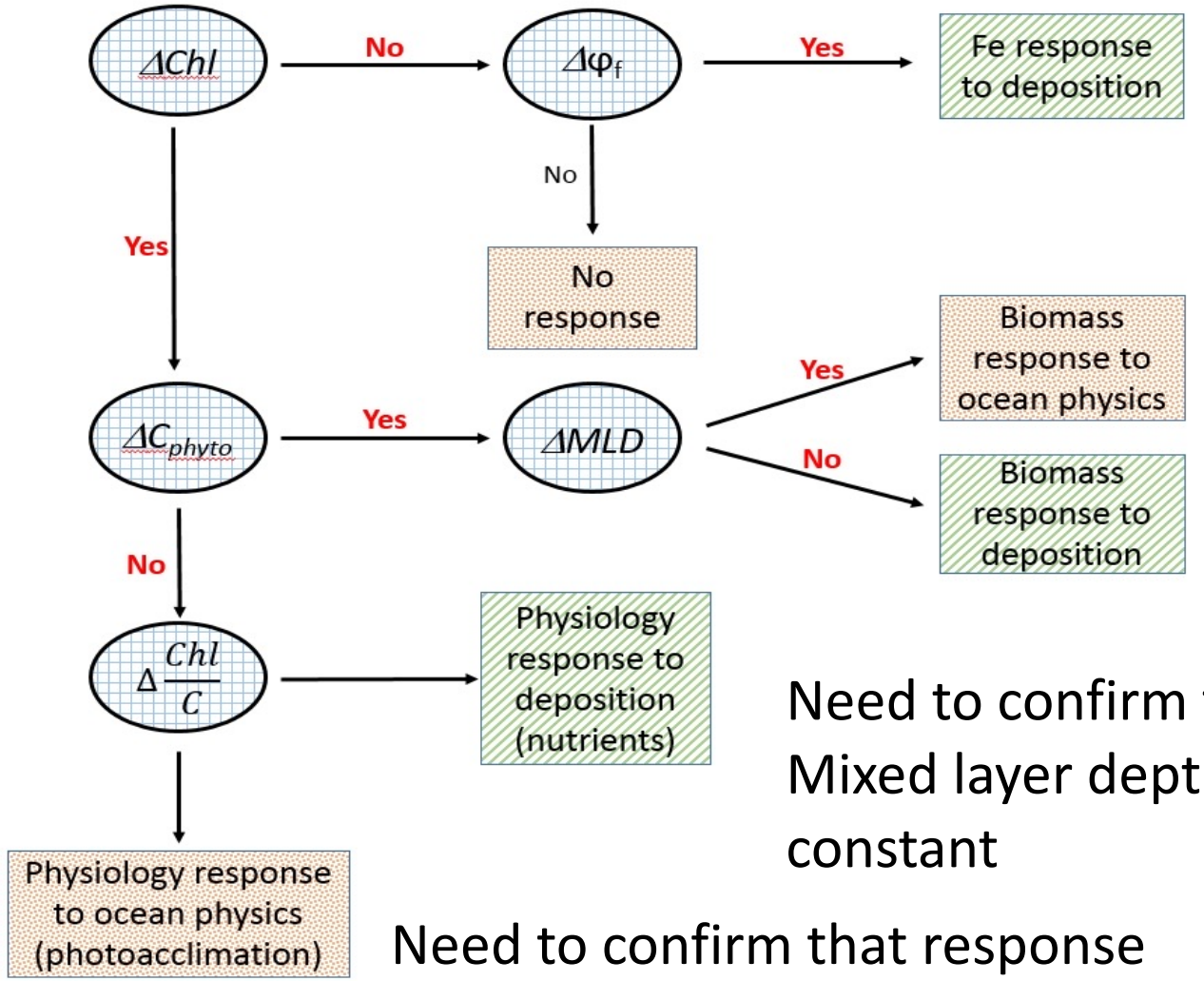
What role does smoke aerosol play?

BACK UP

Let's discuss "response". What are we looking for?

1. ΔChl (more photosynthetic activity)
2. Cell division making more phytoplankton?
3. Or healthier phytoplankton?

How do we measure health?
More Chl per Carbon (physiology)
Or a DECREASE of **fluorescence**



Need to confirm that Mixed layer depth is constant

Need to confirm that response exceeds photoacclimation model

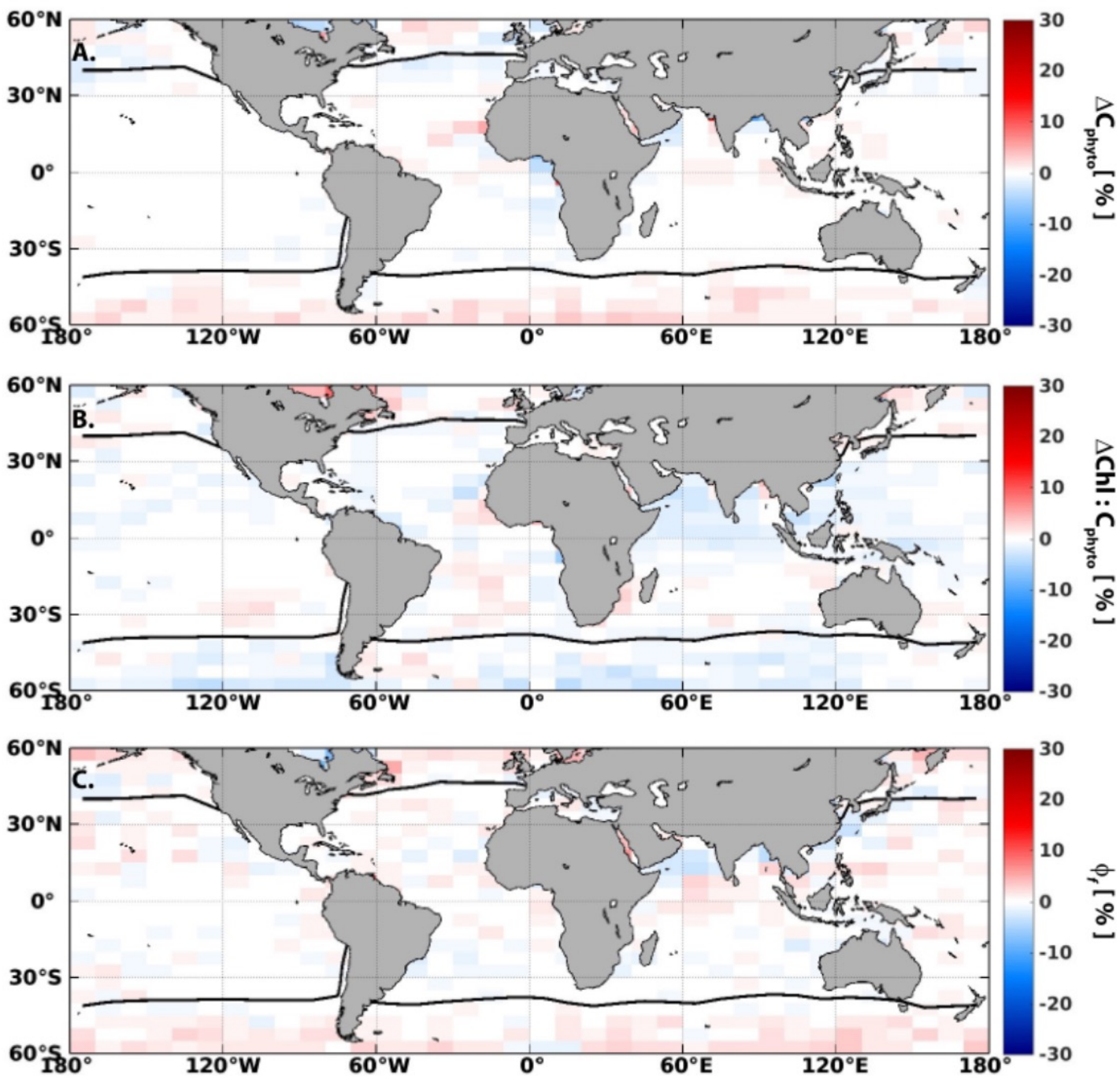
Chlorophyll fluorescence is light re-emitted by chlorophyll by molecules during return from excited to non-excited states. (Wikipedia)

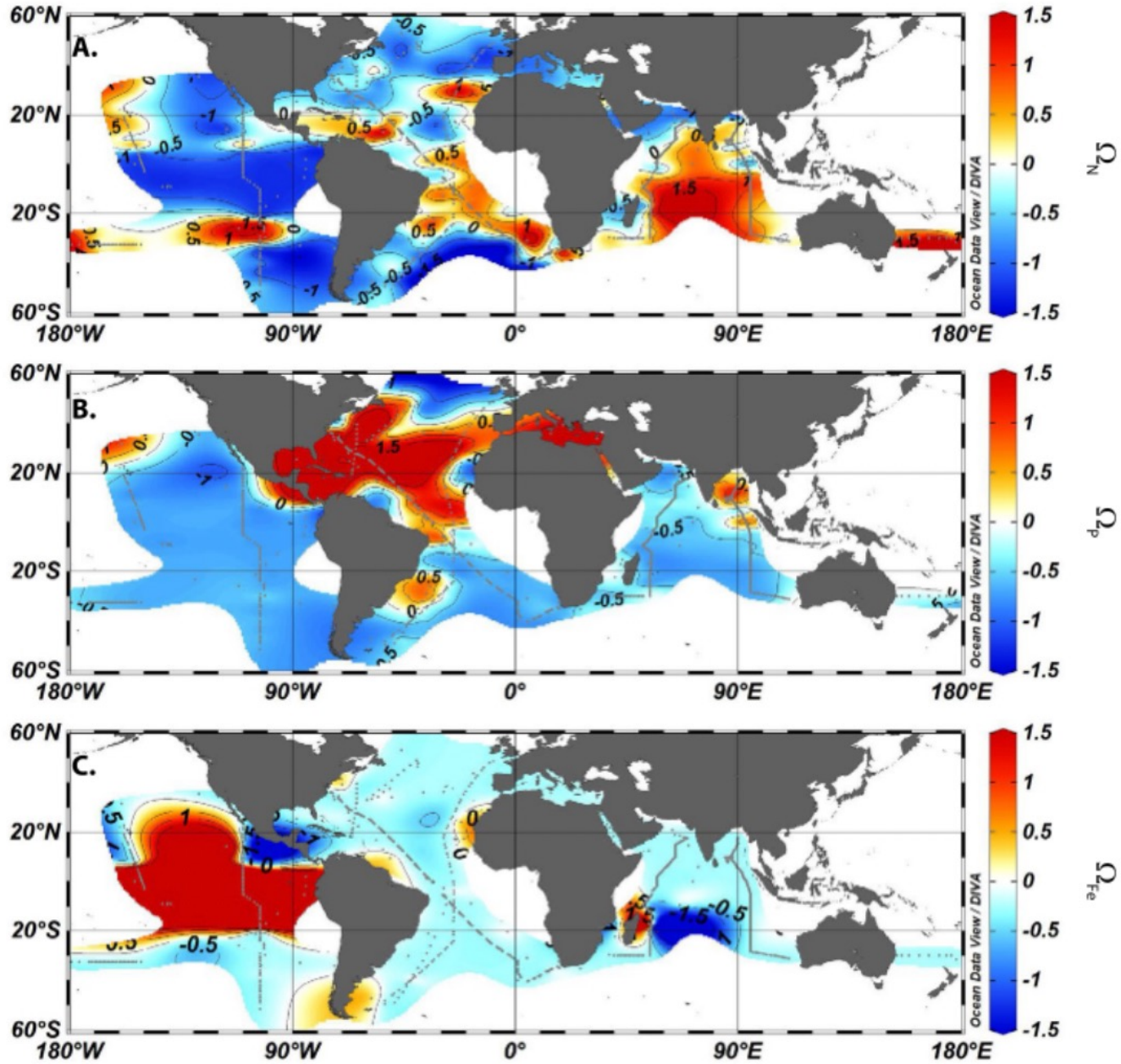
Phytoplankton can dissipate absorbed sunlight by

a. Using it in photosynthesis (chemical transformations)
b. Dissipating as heat
c. Emitting as fluorescence

If under stress, the normal pathway (a) is turned off and (c) increases. High fluorescence yield means stress.

If stress is mitigated, fluorescence DECREASES


A.
B.
C.
60°N
30°N
0°
30°S
60°S
180°
120°W
60°W
0°
60°E
120°E
180°
30
20
10
0
-10
-20
-30
ΔC phyto [%]
ΔChl : C phyto [%]
ϕr [%]


A.
B.
C.
60°N
20°N
20°S
60°S
180°W
90°W
0°
90°E
180°E
1.5
1
0.5
0
-0.5
-1
-1.5
Ocean Data View / DIVA
Ω_N
Ω_P
Ω_Fe