IOCS Meeting, May 15th 2017

Photo:https://eol.jsc.nasa.gov/

Trichodesmium global distribution

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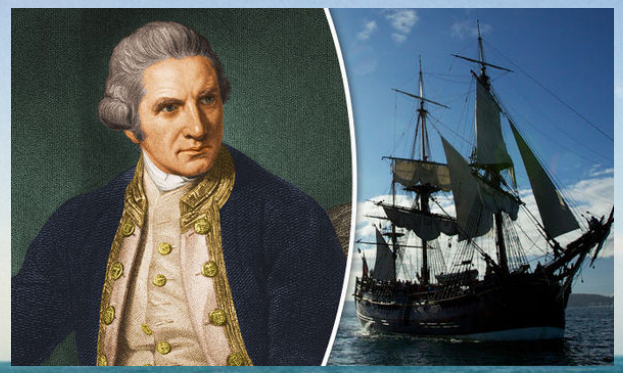
International Ocean Colour Science Meeting 2017

USC University of Southern California

OCB

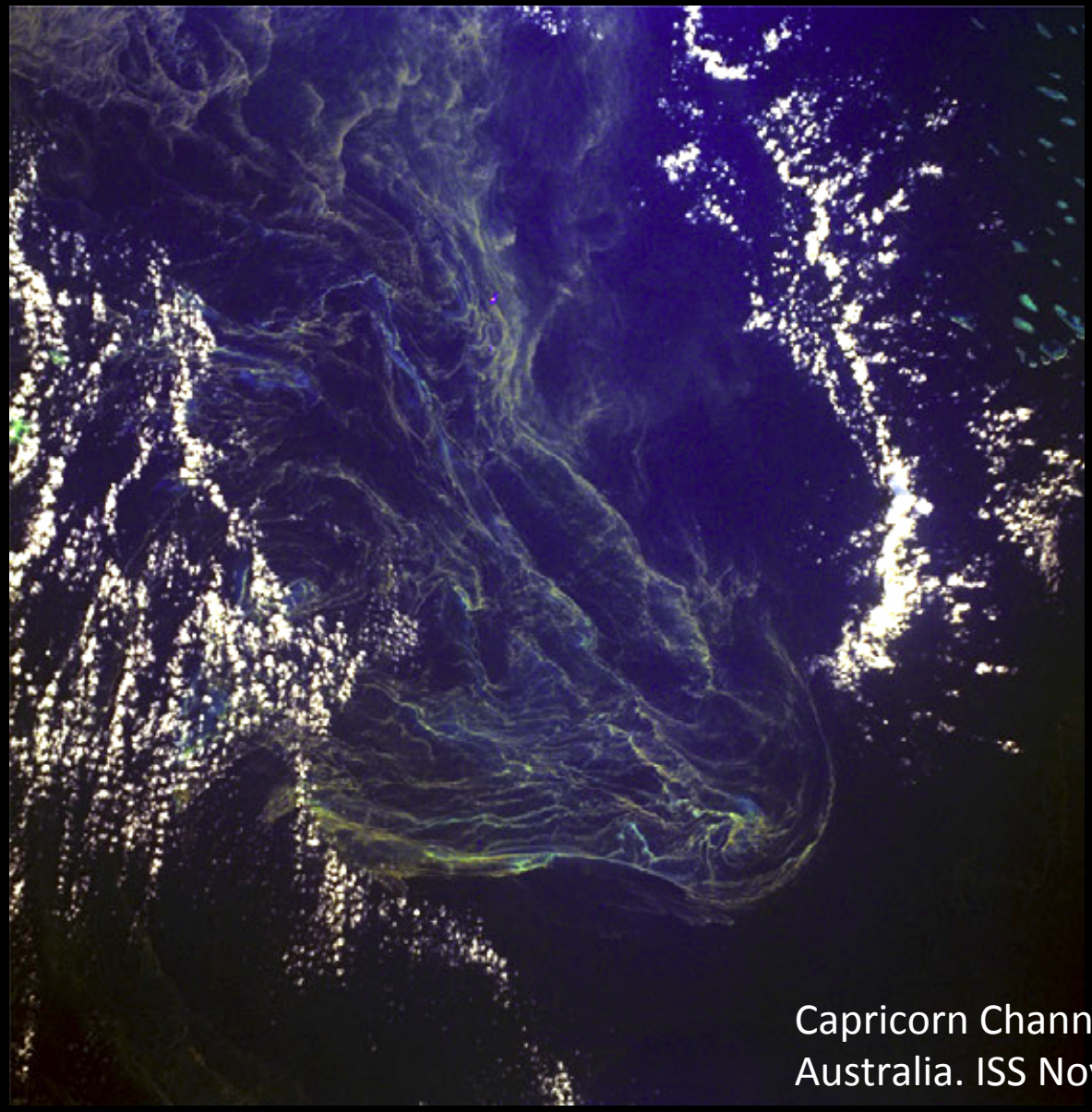


In In August 1770, Captain Cook wrote:
“The Sea in many places is her cover’d with a kind of a brown scum…”

sailors call it “Sea Sawdust”

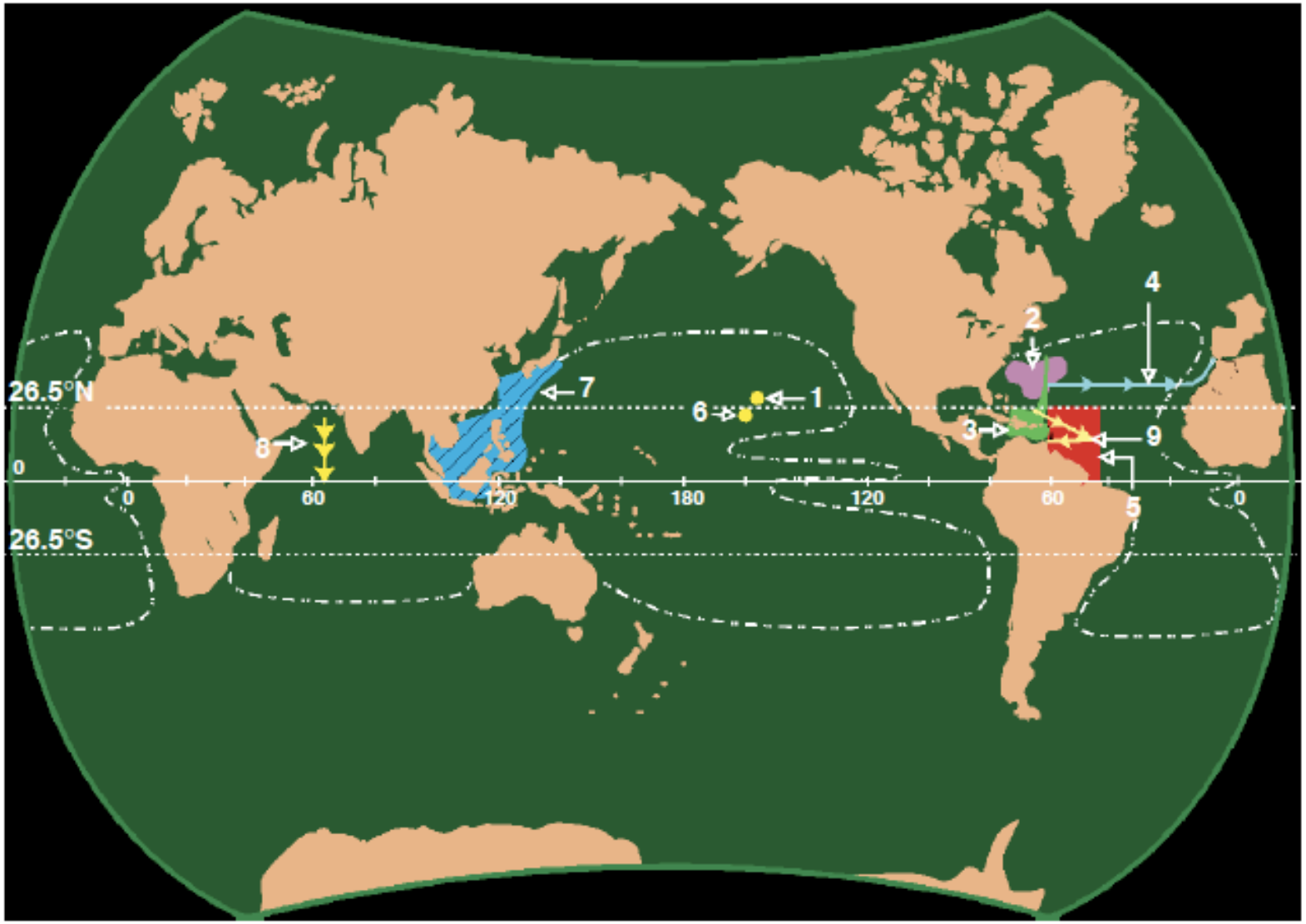
Key West, Florida. U.S. Coast Guard photo

First report from Space, Nov 1983



Capricorn Channel of the southern Great Barrier Reef, Australia. ISS Nov 1983 (Kuchler and Jupp, 1988)

Global compilation of in situ and satellite records



(Capone et al., Science 1997)

Global compilation of in situ and satellite records

a net sequestering of atmospheric CO_2 into

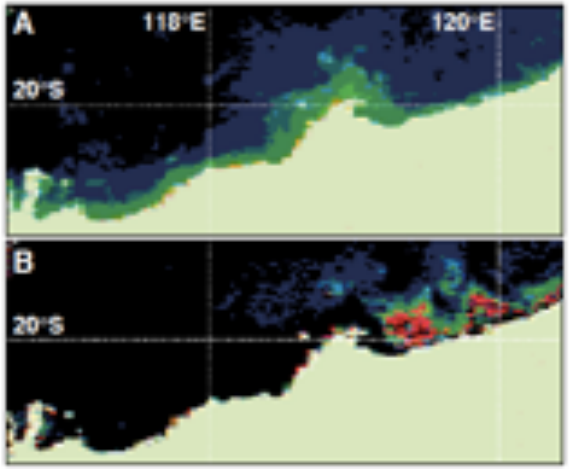
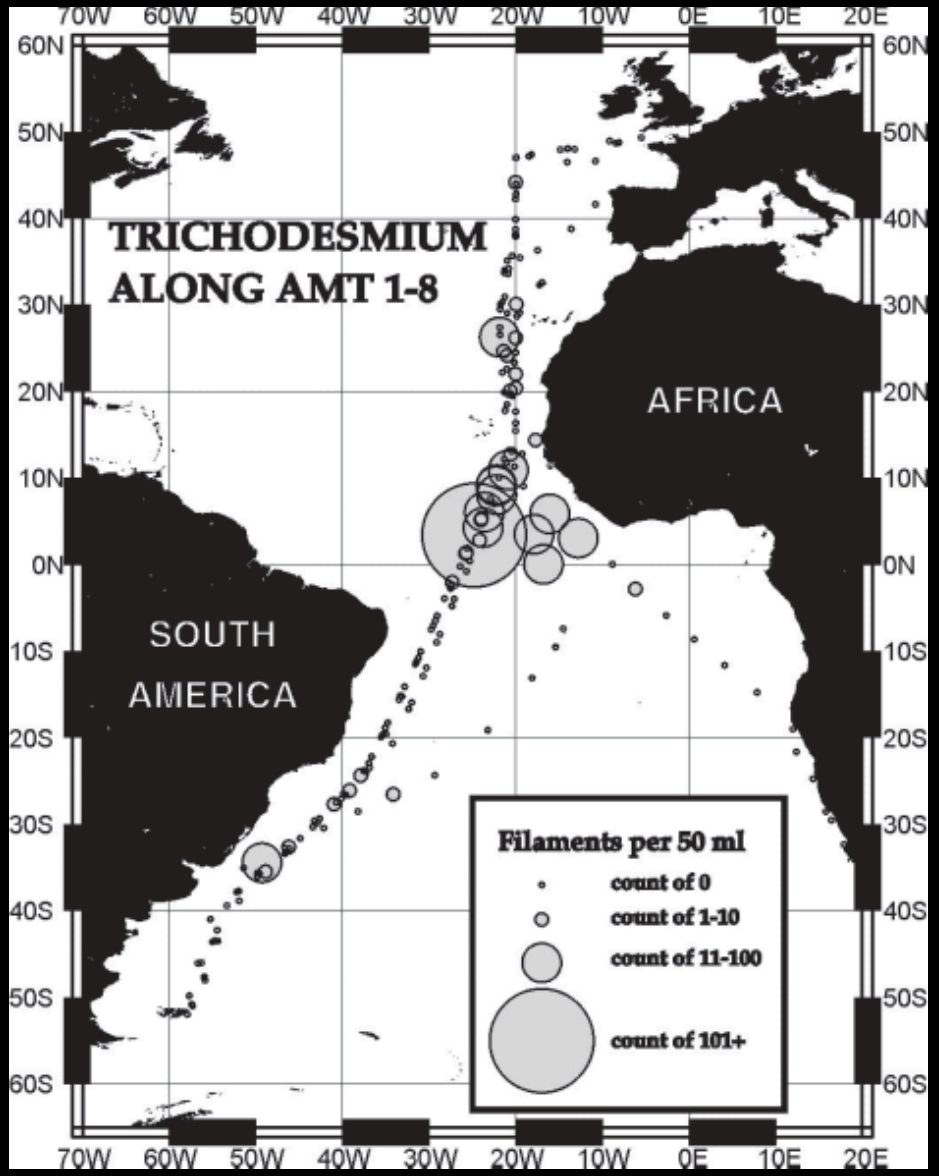


Fig. 5. (**A**) Image of chlorophyll and (**B**) relative *Trichodesmium* abundance derived from a coastal zone color scanner (CZCS) image of the northwestern coast of Australia in the vicinity of the Dampier Archipelago and confirmed by contemporaneous sea-truth data [adapted from (*42*)]. A protocol based on reflectivity and absorption at 550 nm was used. Chlorophyll is reported as detected by CZCS, with lowest to highest chlorophyll a concentrations ranging from purple (<0.05 mg m^{-3}) to red (>3.0 mg m^{-3}). For *Trichodesmium*, dark colors indicate its absence; lighter colors (light blue through orange) indicate its presence. Differences in color represent varying responses to the protocol, not necessarily differences in *Trichodesmium* concentration.

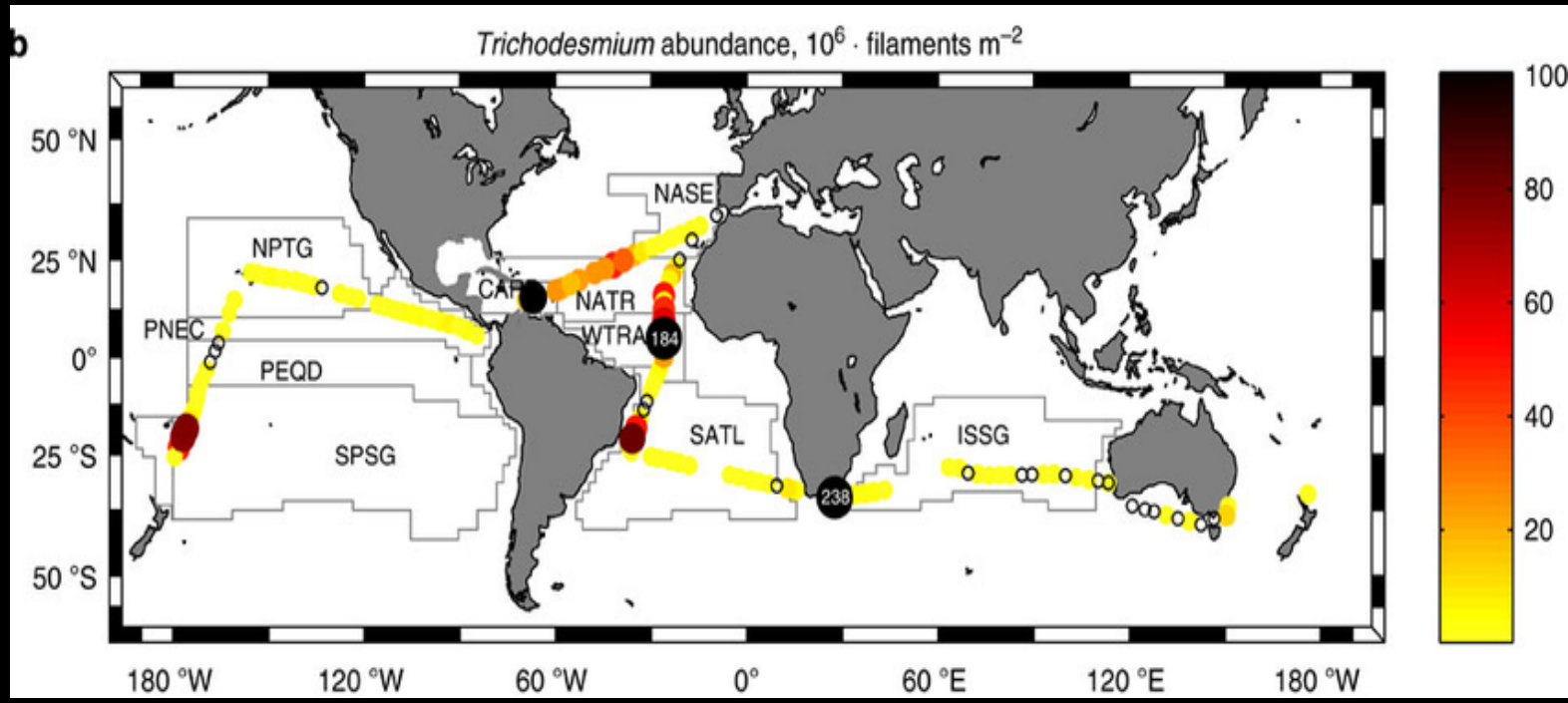
Table 1. Summary of direct areal estimates of N_2 fixation, as originally reported or as derived. Studies based on C_2H_2 reduction determinations of N_2 fixation used a 3:1 conversion from C_2H_2 reduced to N_2 fixed, unless otherwise noted. *N*, number of discrete observations.

Location	Areal estimates: Date	Areal estimates: Average ± SE (μmol N m^{-2} day^{-1})	Areal estimates: *N*	Map code	Reference
Subtropical					
28°N, 155°W (North Pacific)	Aug 73	33	1	1	(95)
27° to 34°N (NW Sargasso Sea)	Sep–Oct 73	1.4* ± 0.47	9	2	(93)
22° to 36°N (Sargasso Sea)	Aug 74	6.2* ± 4.0	7	3	(92)
22° to 23°N (Caribbean passages)	Feb–Mar 74, Aug 74	4.2* ± 4.0	10	3	(92)
30°N (Atlantic transect)	May–Jun 75	0.29* ± 0.13	5	4	(94)
Tropical					
0° to 24°N, 45° to 66°W (SW North Atlantic)	Fall 64	41† ± 7.6	19	5	(65)
	Spring 65	106† ± 24	15	5	(65)
21°N, 159°W (North Pacific)	Oct, Dec 72	134	2	6a	(62)
12° to 22°N (Caribbean)	Feb–Mar 74, Aug 74	77* ± 9.7	12	3	(92)
10° to 25°N (SE East China Sea)	Summer 77	126	32	7	(63)
23°N, 158°W (North Pacific)	Jun 90, Feb 91	85	2	6b	(89)
7° to 10°N (Arabian Sea)	May 95	35 ± 7.4	9	8	(81)
14° to 22°N (SW North Atlantic)	May 94	73 ± 22	12	9	(64)
NE Caribbean	May 94	278 ± 129	3	9	(64)
Tropical, grand average		106 ± 24			

*Data as originally presented using a 6.3:1 conversion ratio. †Data based on direct $^{15}N_2$ uptake. Average rates from 0 and 15 m are assumed over the top 20 m and have been increased by 50% to account for activity below 20 m, on the basis of data for the region from Fig. 4 and (*64*).



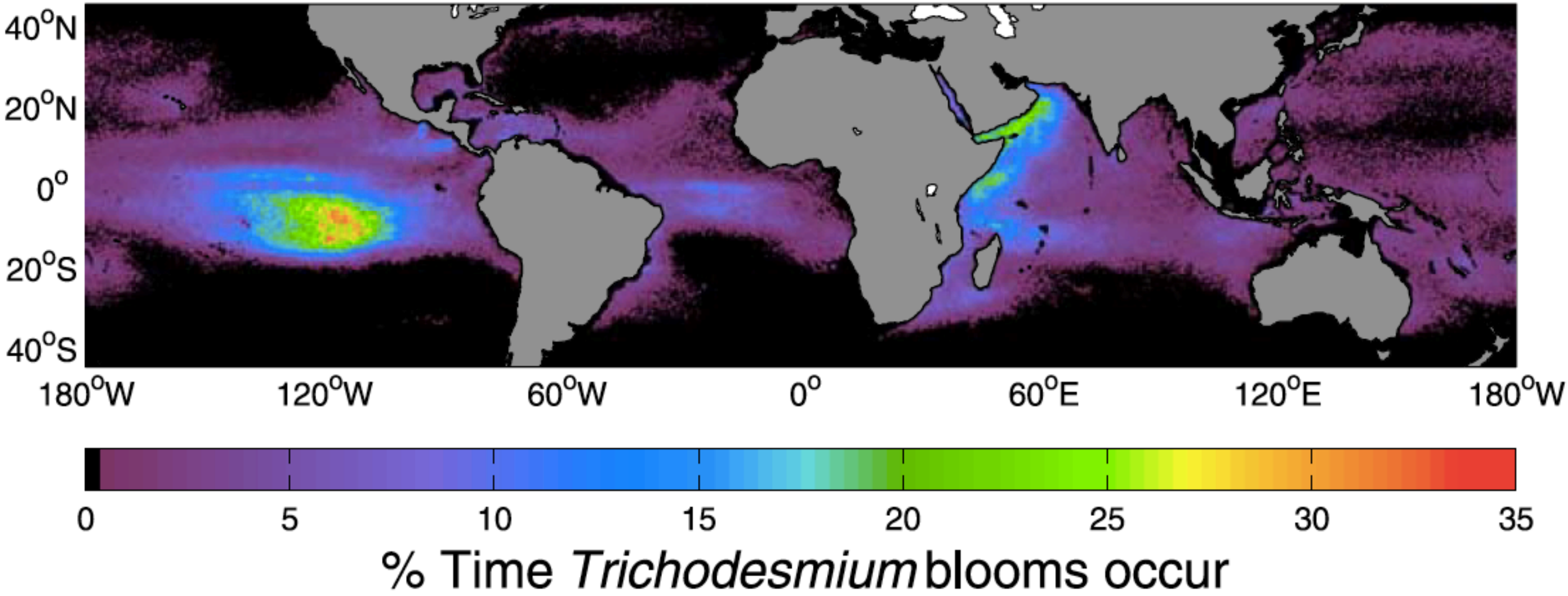
< Tyrrell et al 1990's-10 cruises between about 50S and 50N in the Atlantic.



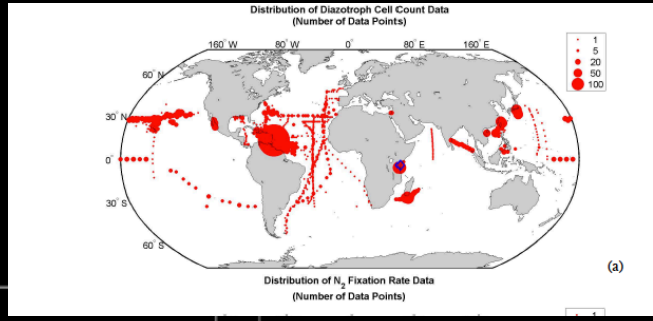
^ Malaspina Expedition 2010-2011
Fernandez-Castro et al, 2015 Nature Comm.

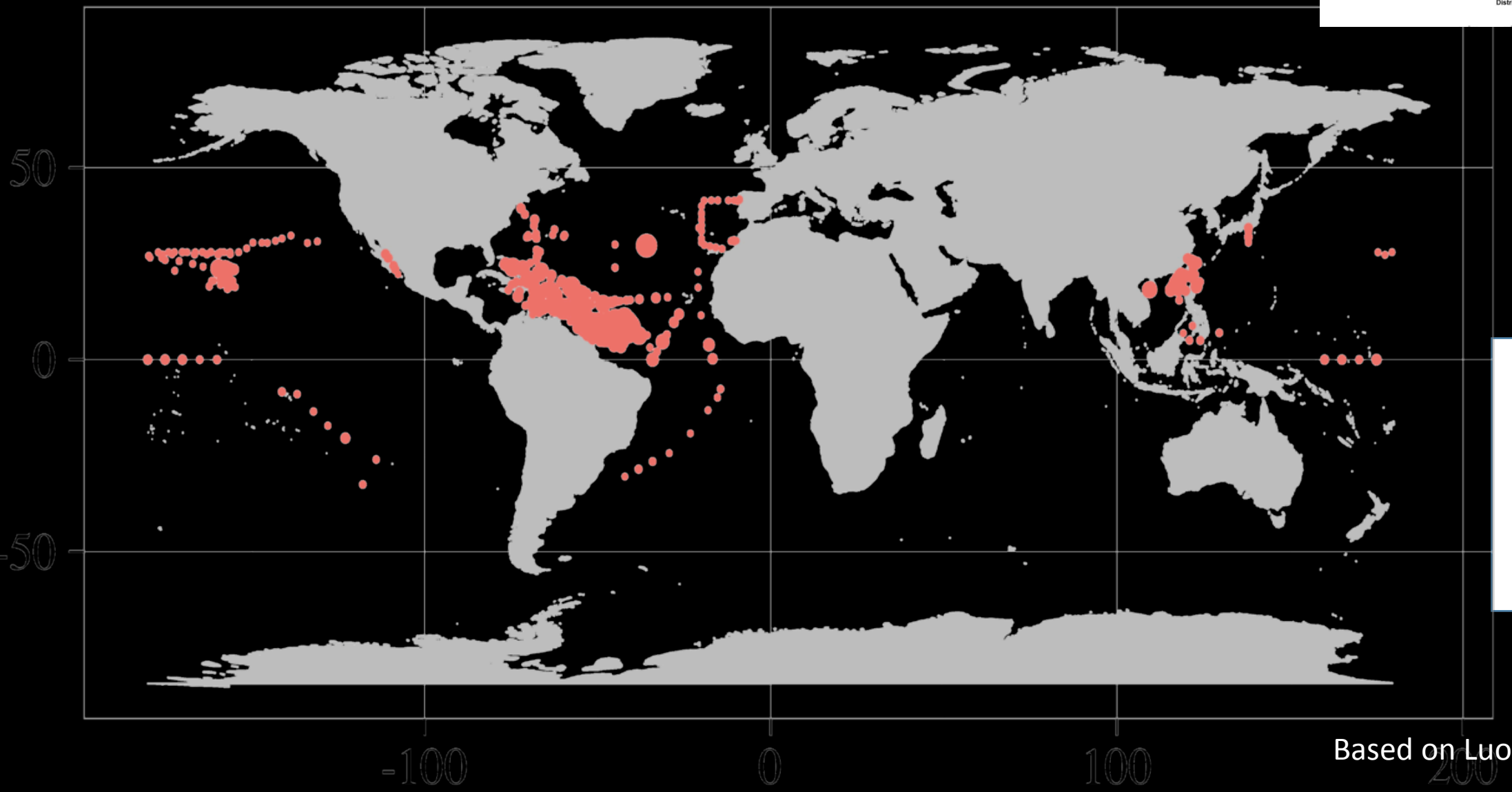
First Satellite-derived Global Bloom Occurrence

Westberry & Siegel 2006. GBC.

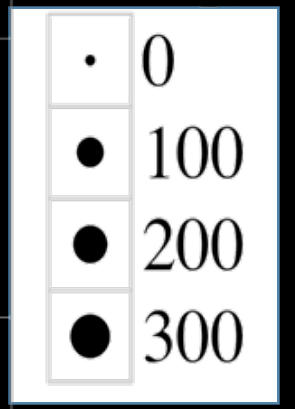


A global database effort: MAREDAT





Trichodesmium Counts*$10^6/m^2$



Based on Luo et al 2012

Methods

- Light Microscopy
- Flow cytometry
- Video Camera Recorder (VCR)
- Molecular: nifH genes
- DNA: clade specific qPCR
- Pigments (PUB,PEB, PC)
- Optics: Backscattering +Absorption

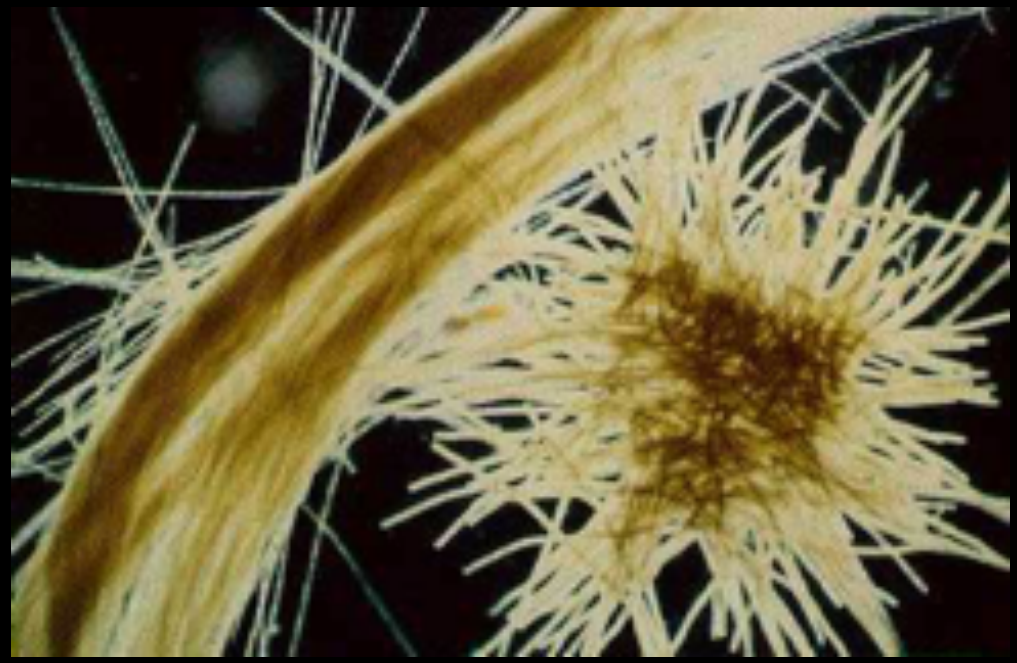
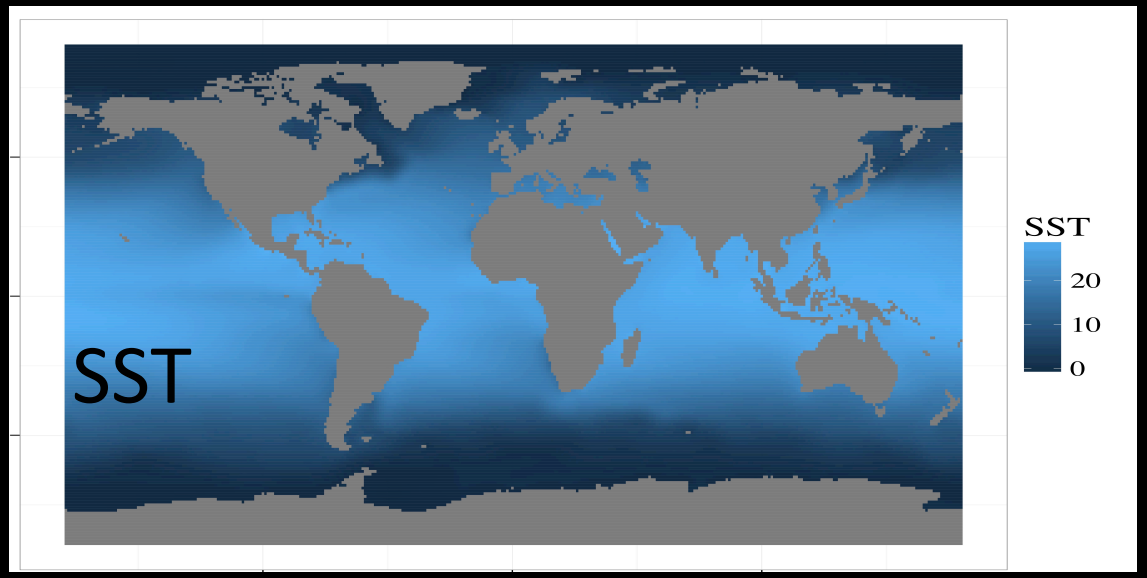
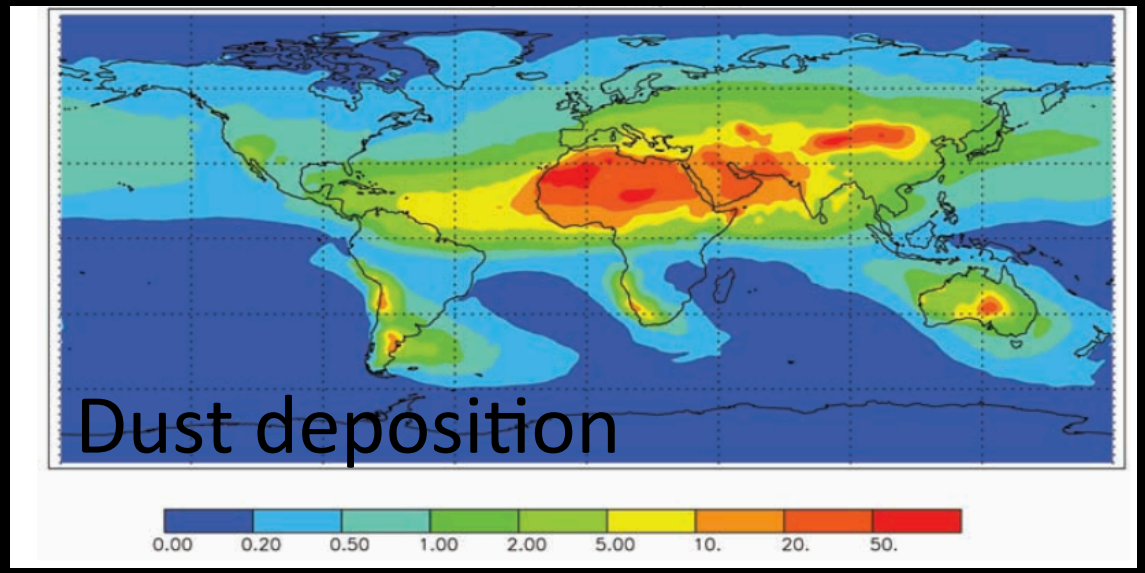


Photo Credit: Bergman

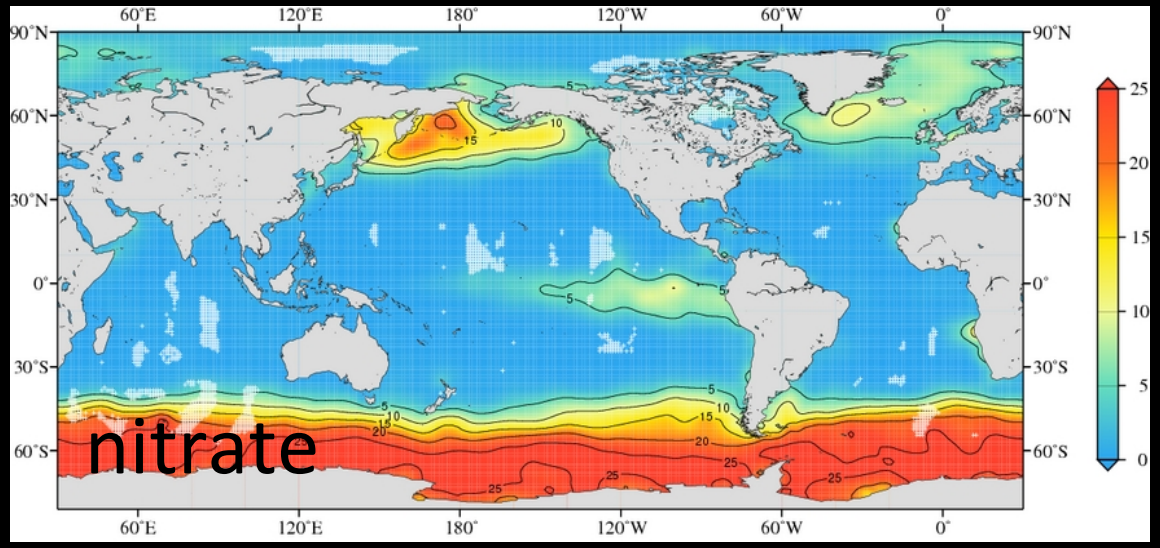
Environmental limitations

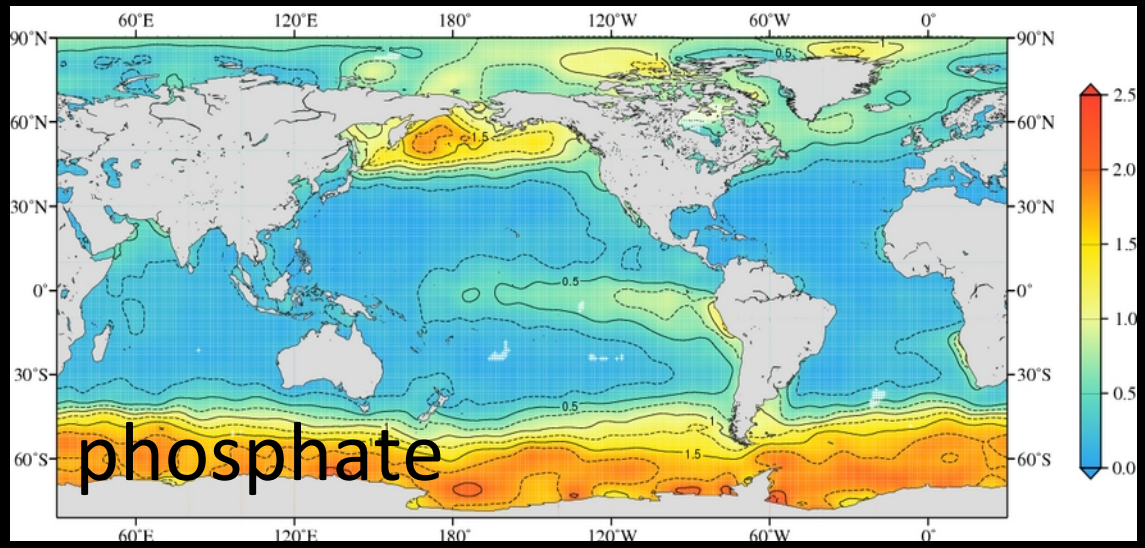


Levitus, 2005

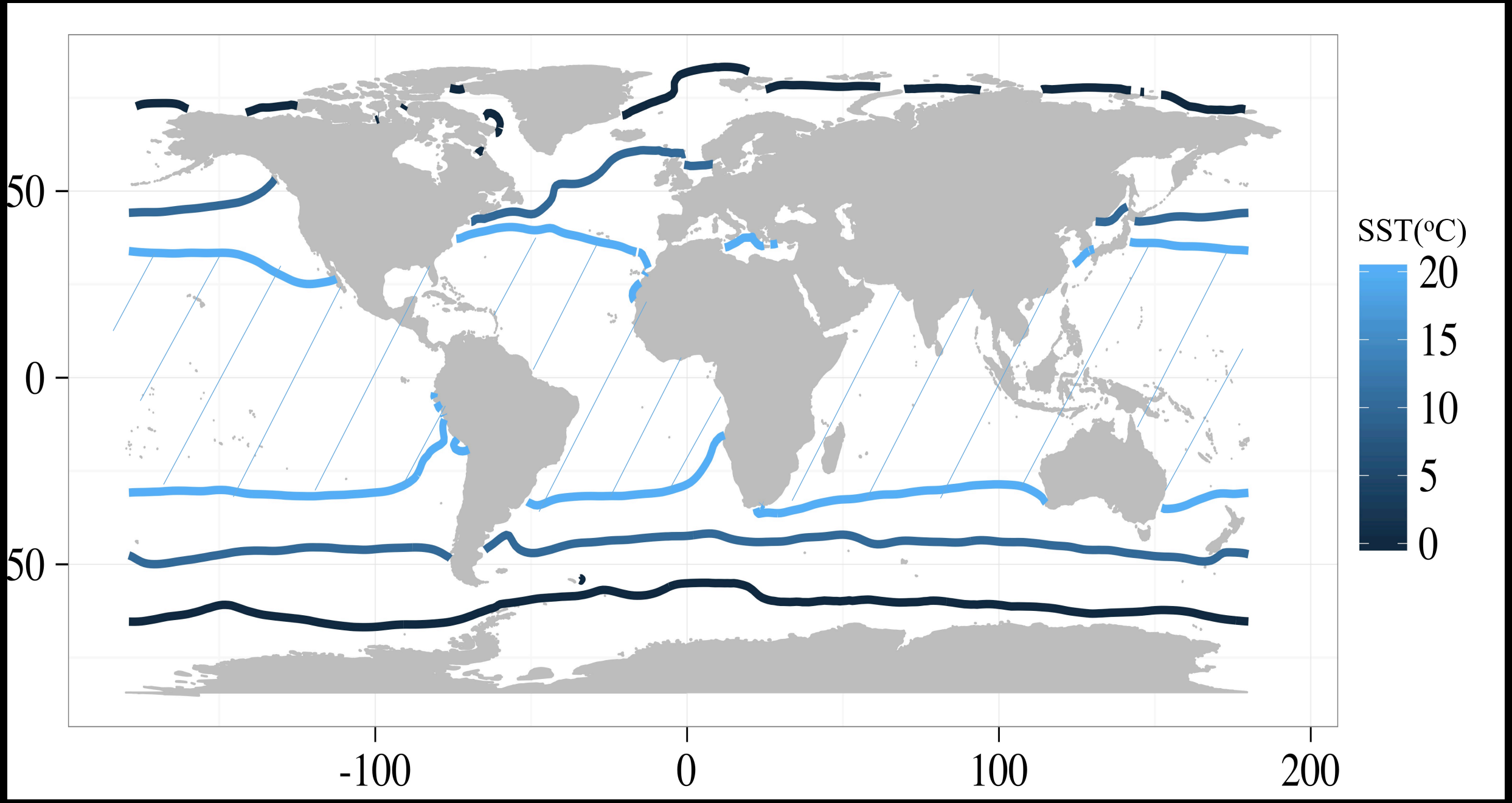


Jickells et al., Science, 2005





https://www.nodc.noaa.gov/OC5/woa13fv2/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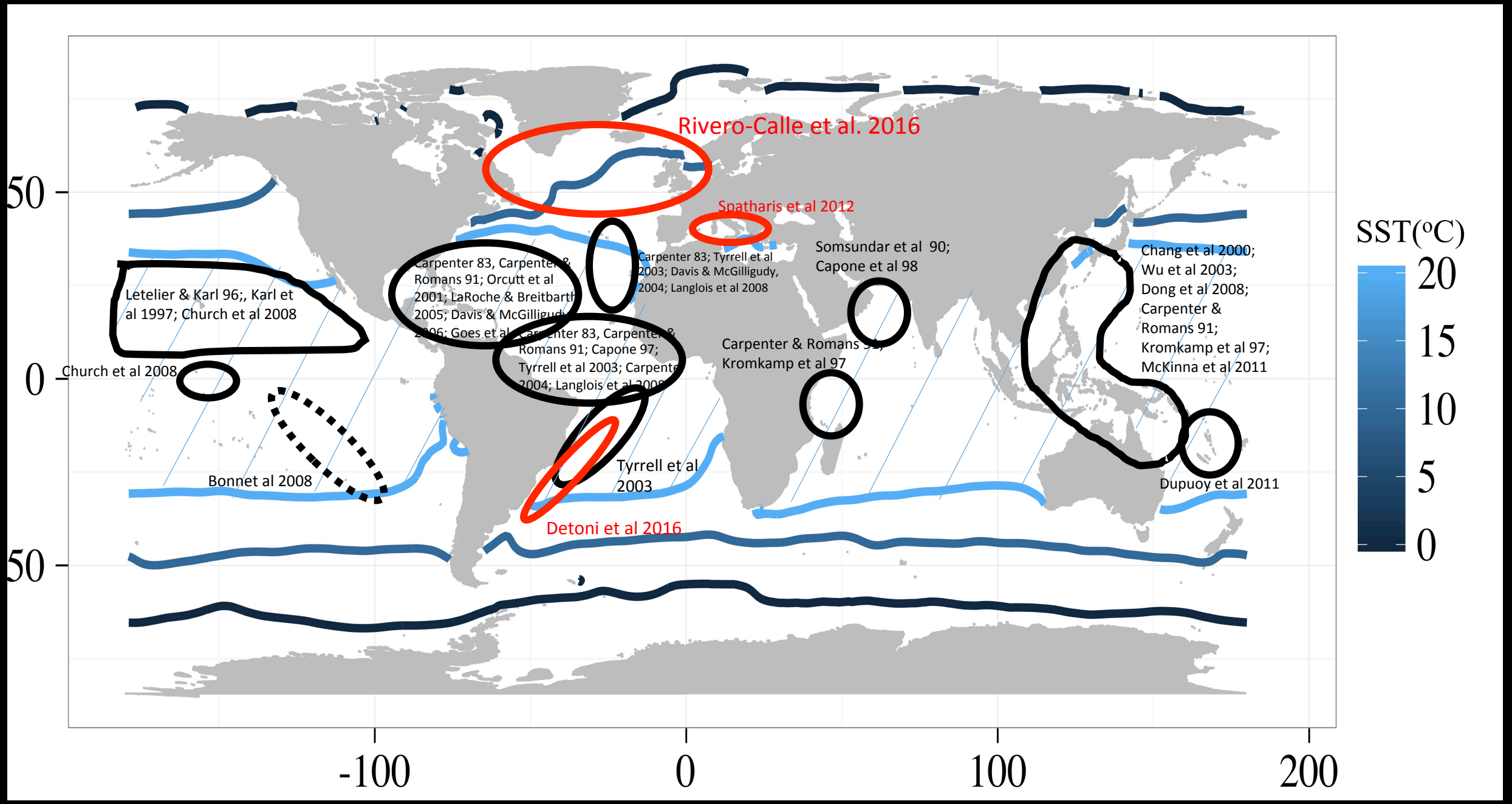
Rivero-Calle et al. 2016
Spatharis et al 2012
Carpenter 83; Tyrrell et al 2003; Davis & McGilligudy, 2004; Langlois et al 2008
Somsundar et al 90; Capone et al 98
Carpenter 83, Carpenter & Romans 91; Orcutt et al 2001; LaRoche & Breitbarth 2005; Davis & McGilligudy
Letelier & Karl 96;, Karl et al 1997; Church et al 2008
Carpenter 83, Carpenter & Romans 91; Capone 97; Tyrrell et al 2003; Carpente 2004; Langlois et al 2008
Carpenter & Romans 91; Kromkamp et al 97
Chang et al 2000; Wu et al 2003; Dong et al 2008; Carpenter & Romans 91; Kromkamp et al 97; McKinna et al 2011
Church et al 2008
Bonnet al 2008
Tyrrell et al 2003
Dupuoy et al 2011
Detoni et al 2016
SST(°C)
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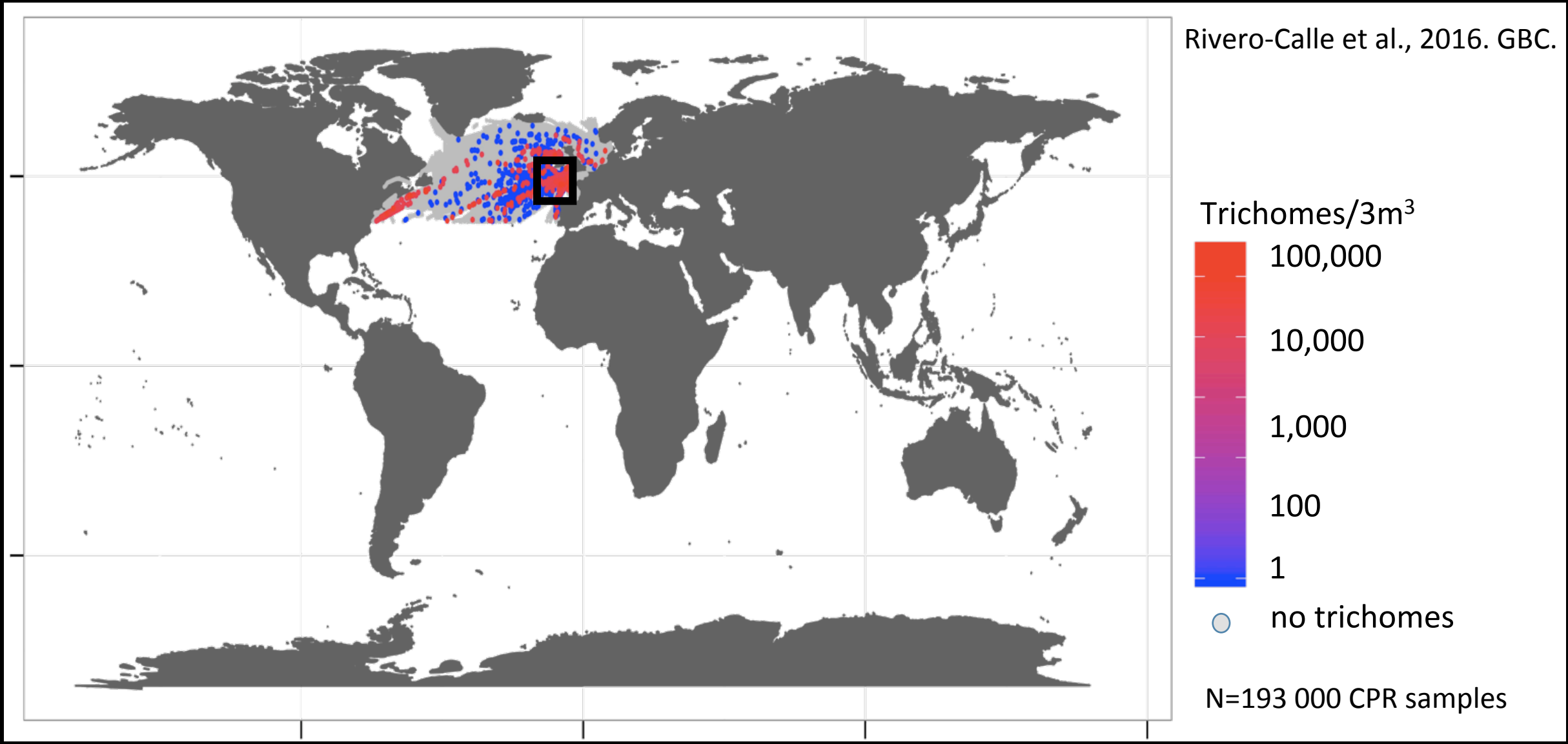
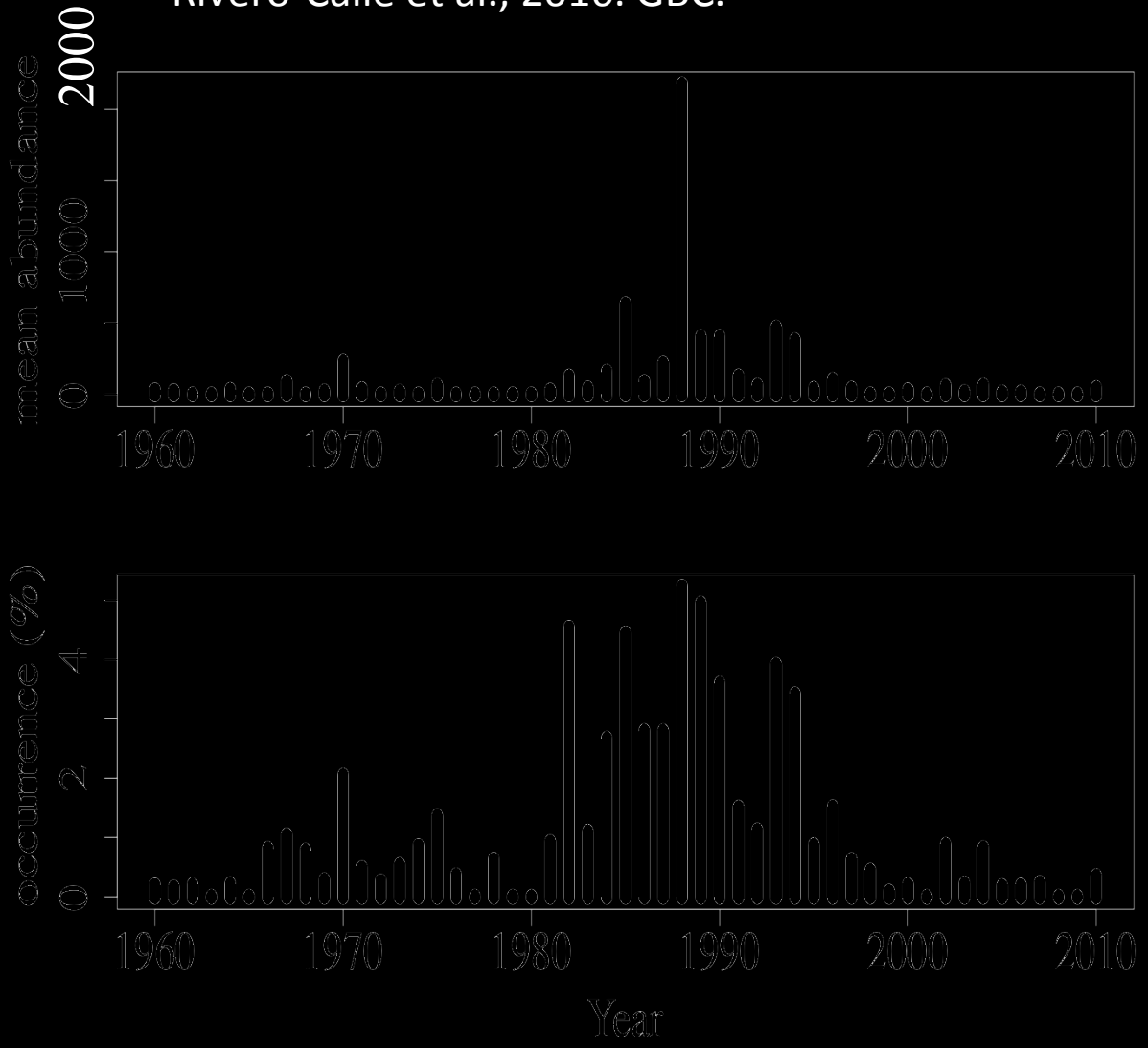
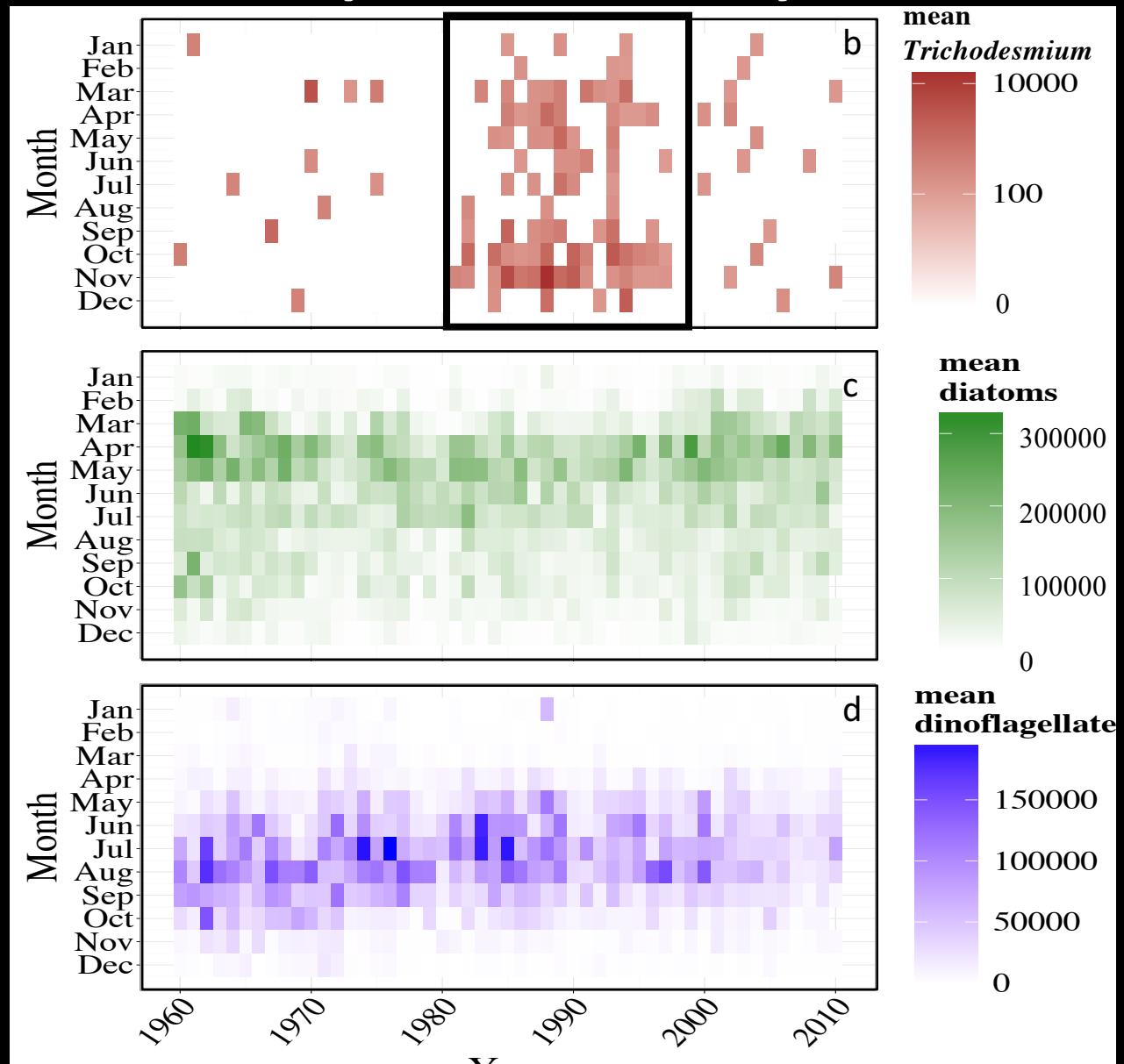
50 years of Trichodesmium records in the North Atlantic



Biscay interannual and monthly variability

Rivero-Calle et al., 2016. GBC.





Conclusions, challenges, future work

- Disagreement among methods
- Reports often clump diazotrophs together
- Specificity of techniques
- Matchups – groundtruthing
- Hard to predict blooms
- Rare + ephemerous blooms
- Sub-bloom concentrations
- Patchiness
- Vertical migration
- Subsurface distribution
- Resolution: Spectral +Spatial + Temporal
- Quantitative algorithms
- Nutrients, temperature assumptions often bias sampling areas
- Clades/ strains/ species differences

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- Advisors: Carlos Del Castillo, Anand Gnanadesikan, Naomi Levine
- Co-authors: Amin Dezfuli, Ben Zaitchik, David Johns
- Funding: APL graduate fellowship, EPS, EPS summer research funding, SAHFOS external researcher fund, Student travel Awards
- USC Postdoctoral Scholar Travel and Training Award, Ocean Carbon and Biogeochemistry Travel scholarship and the Trichodesmium Breakout session organizers

Thank you!!

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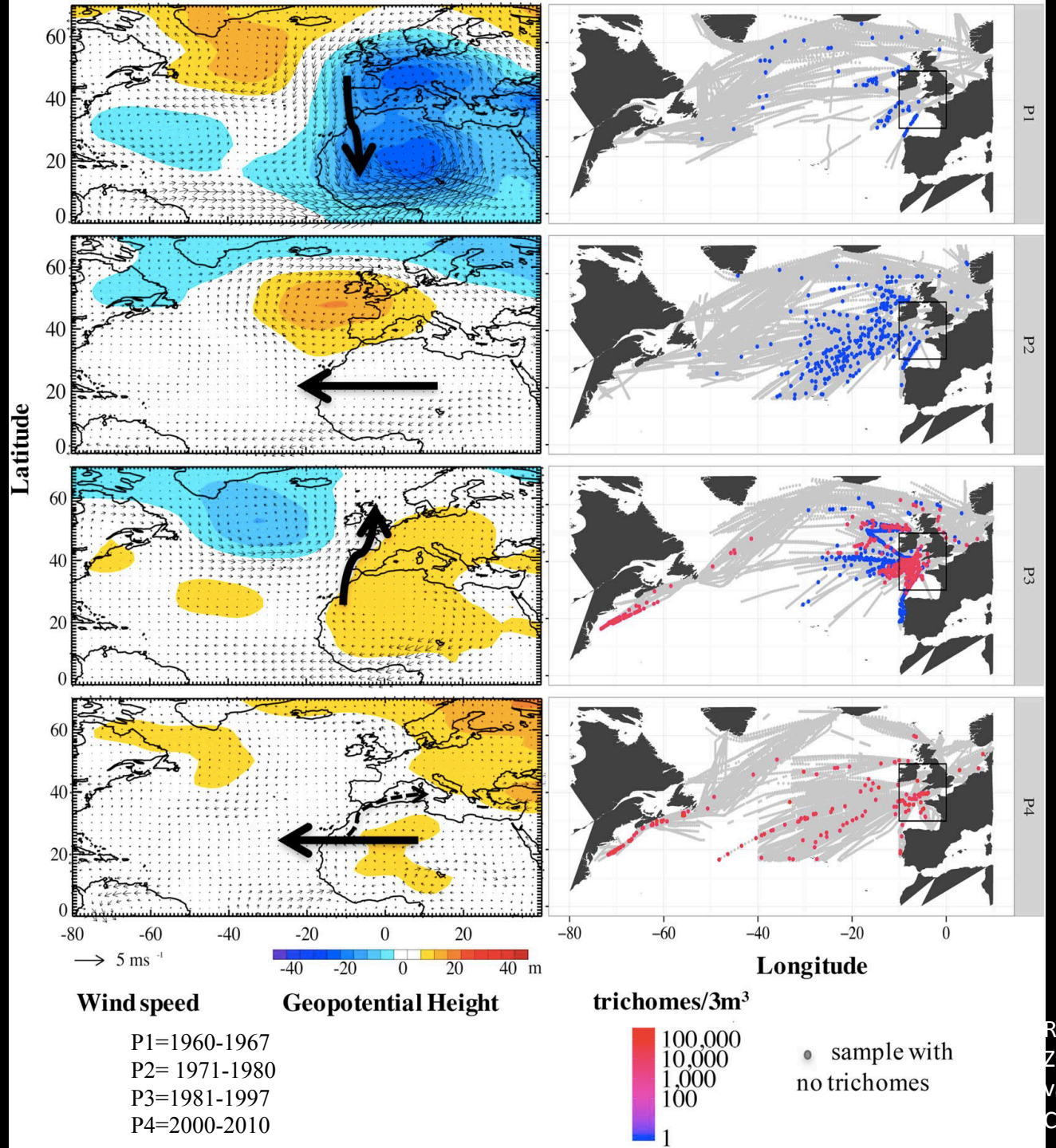
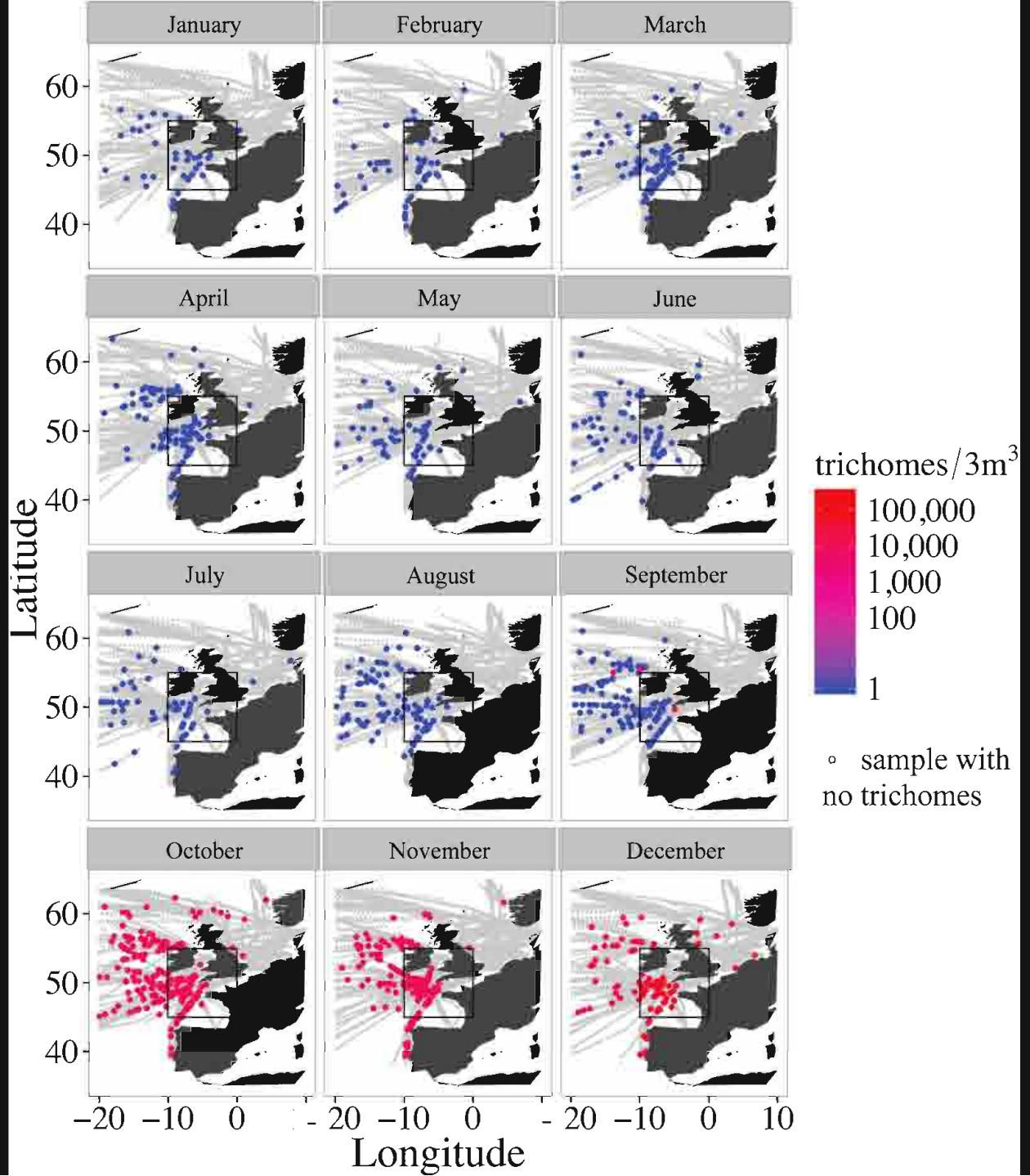
USC University of Southern California | JOHNS HOPKINS UNIVERSITY | APL The Johns Hopkins University APPLIED PHYSICS LABORATORY | NASA | CONTINUOUS PLANKTON RECORDER SURVEY SAHFOS | OCB Ocean Carbon & Biogeochemistry | International Ocean Colour Science Meeting 2017



Rivero-Calle, S., C. E. Del Castillo, A.Gnanadesikan, A. Dezfuli, B. Zaitchik, and D. G. Johns (2016), Interdecadal Trichodesmium variability in cold North Atlantic waters, Global Biogeochem. Cycles, 30. doi:10.1002/2015GB005361.


January
February
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November
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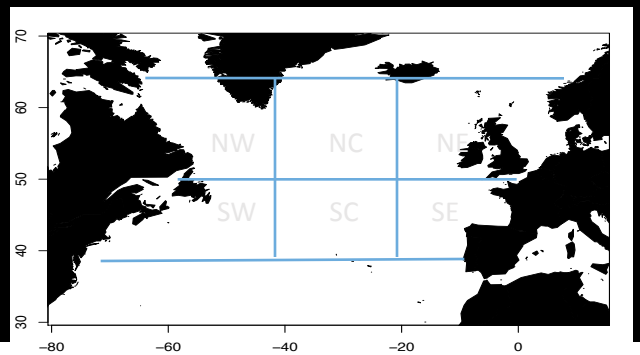
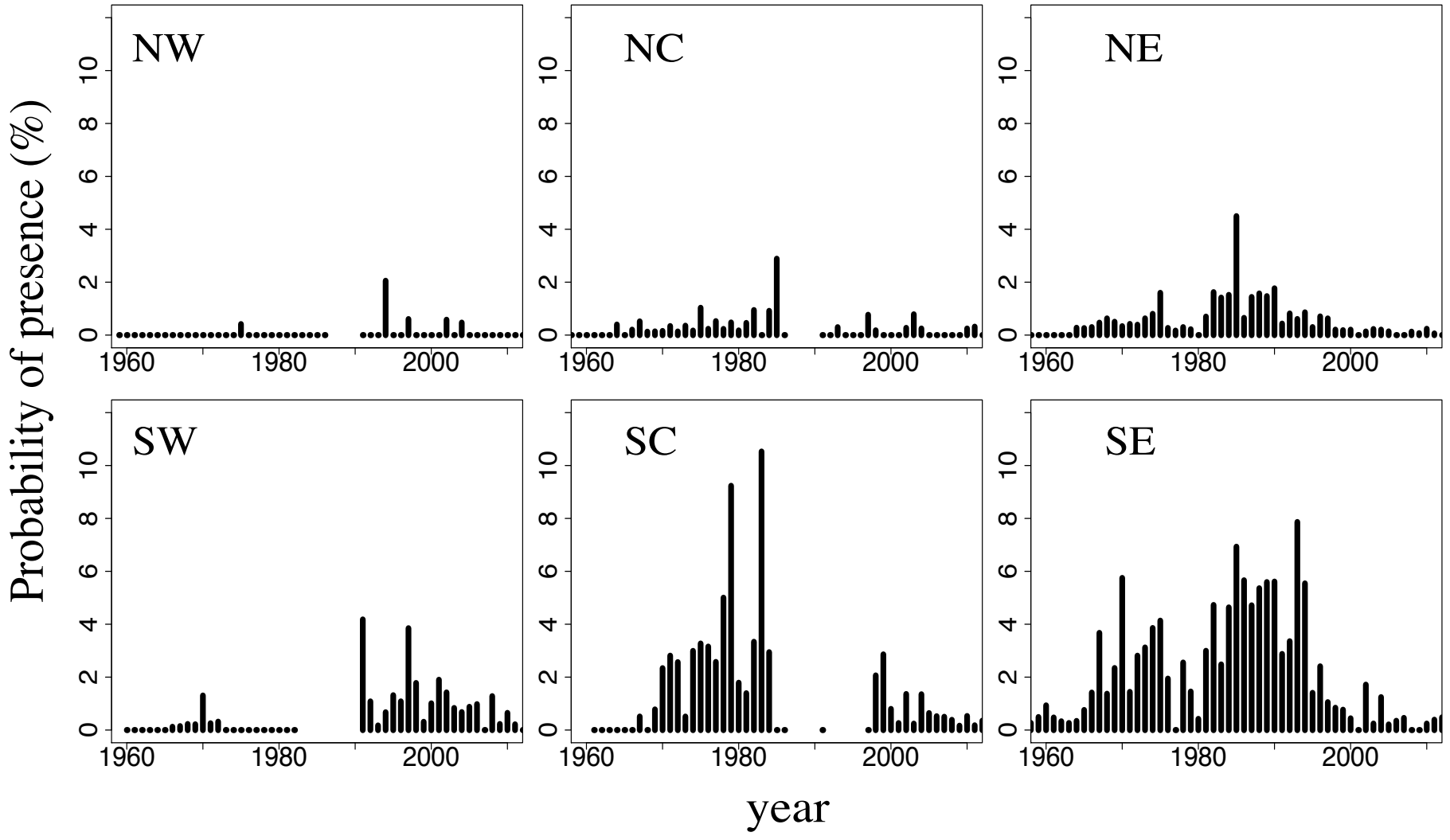
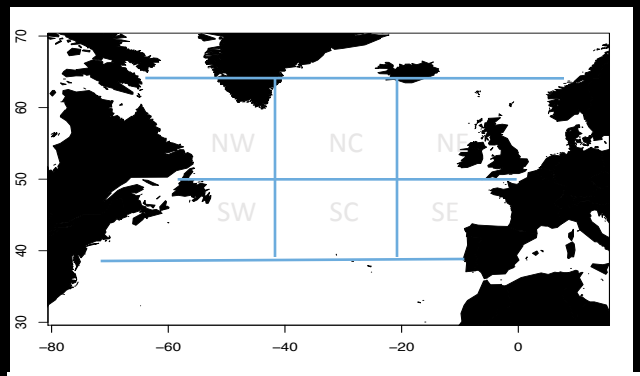
Longitude
trichomes/3m3
100,000
10,000
1,000
100
1
sample with no trichomes

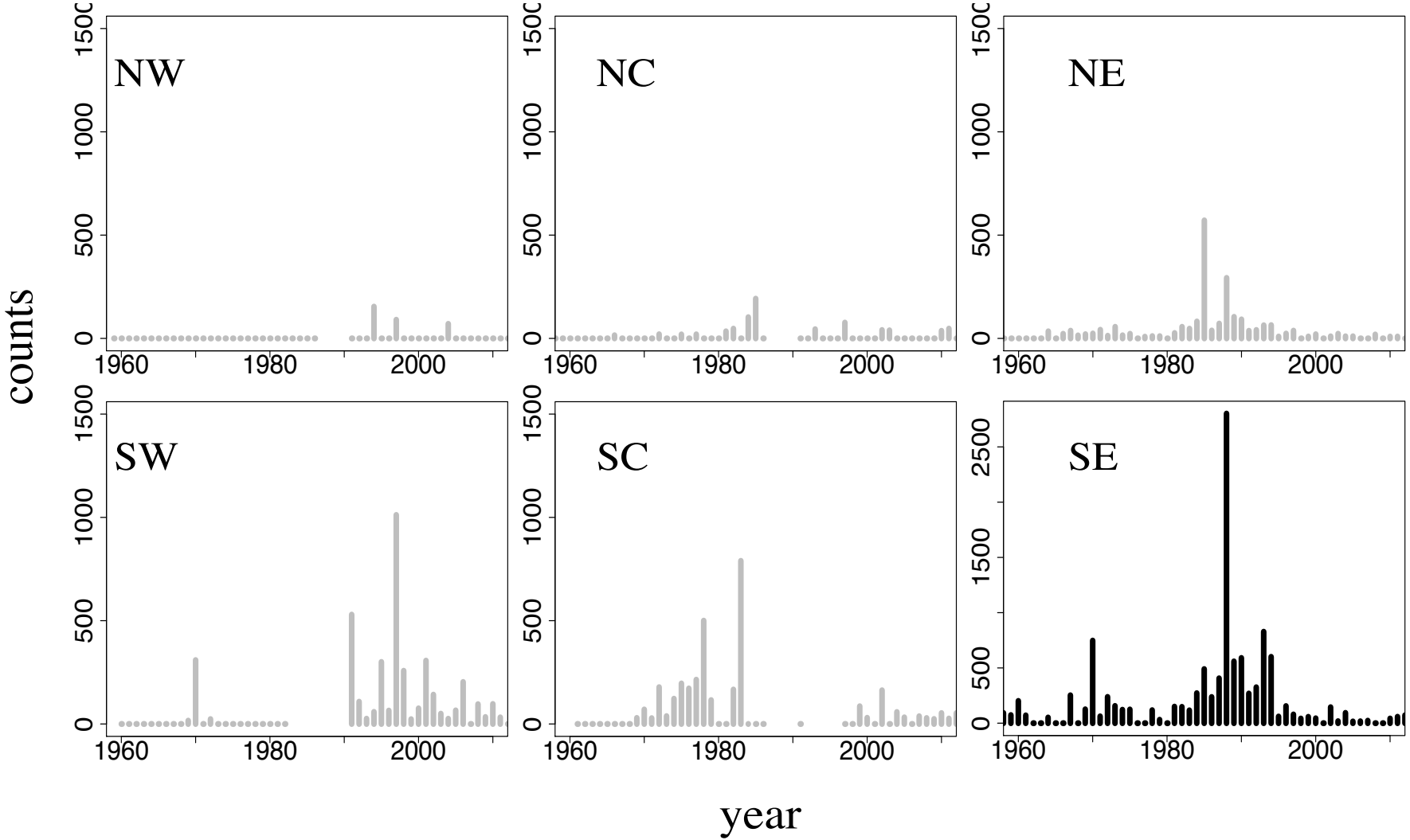


Annual *Trichodesmium* occurrence per region

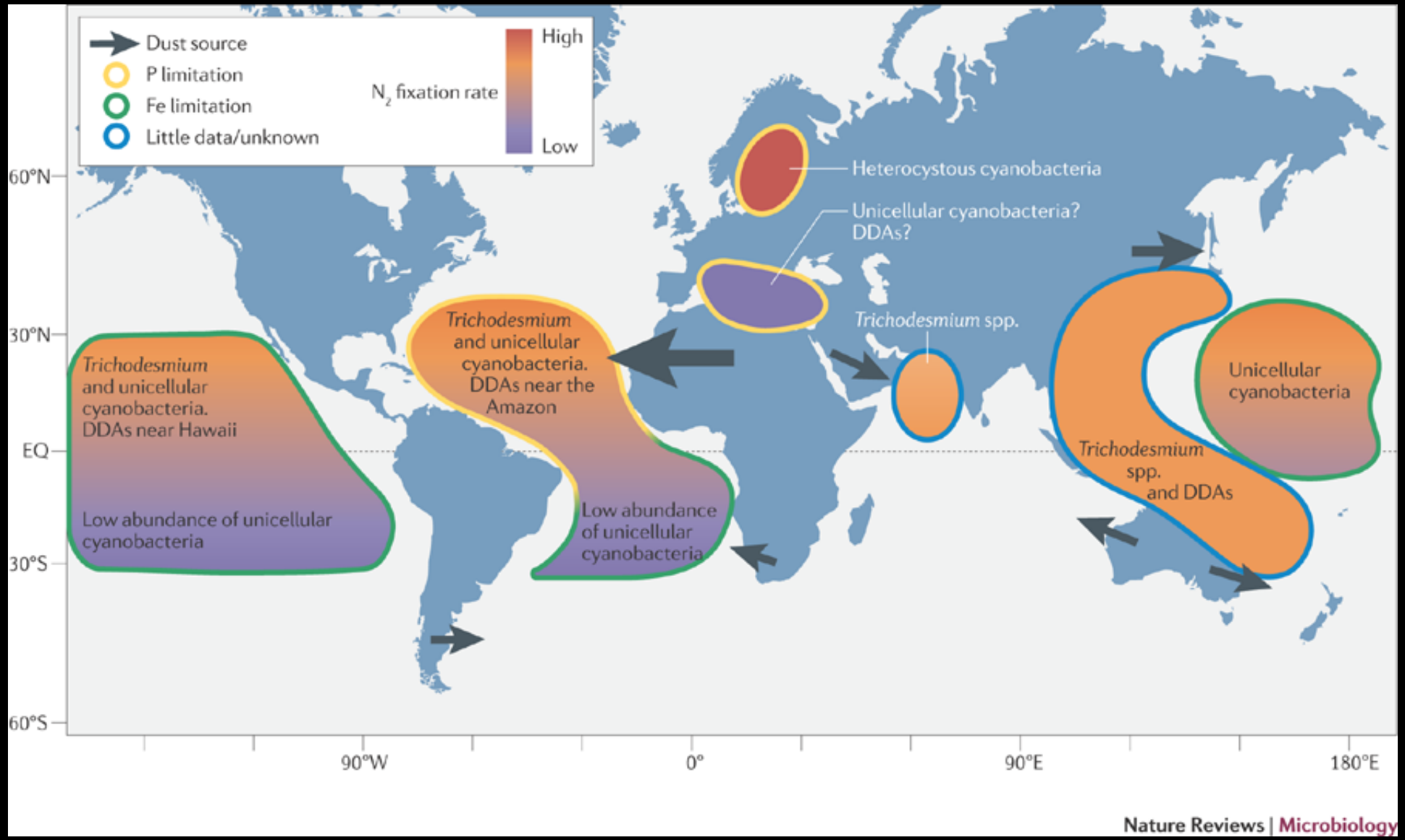




Mean annual *Trichodesmium* counts per region



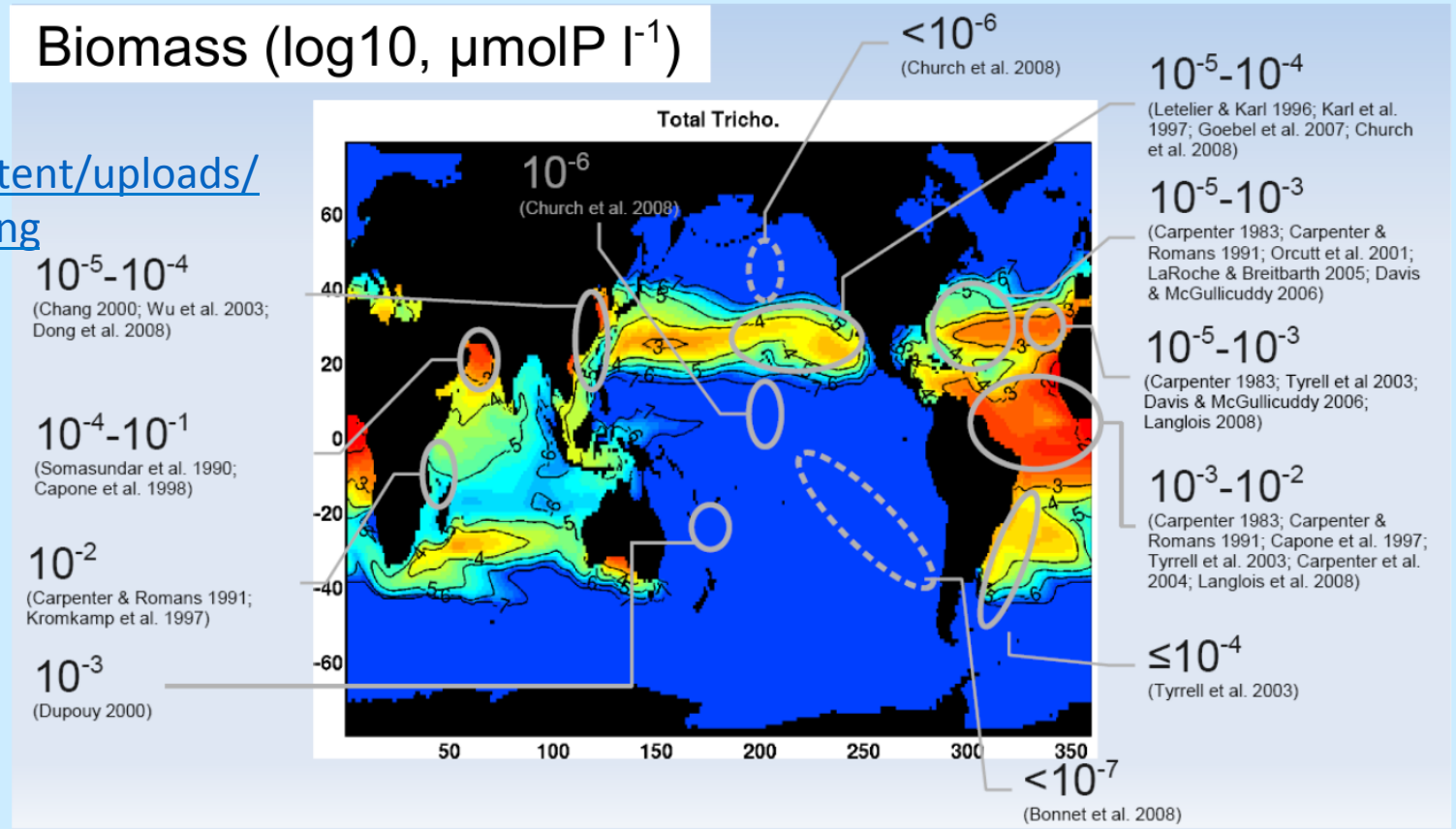
Element limitation P, FE , little data



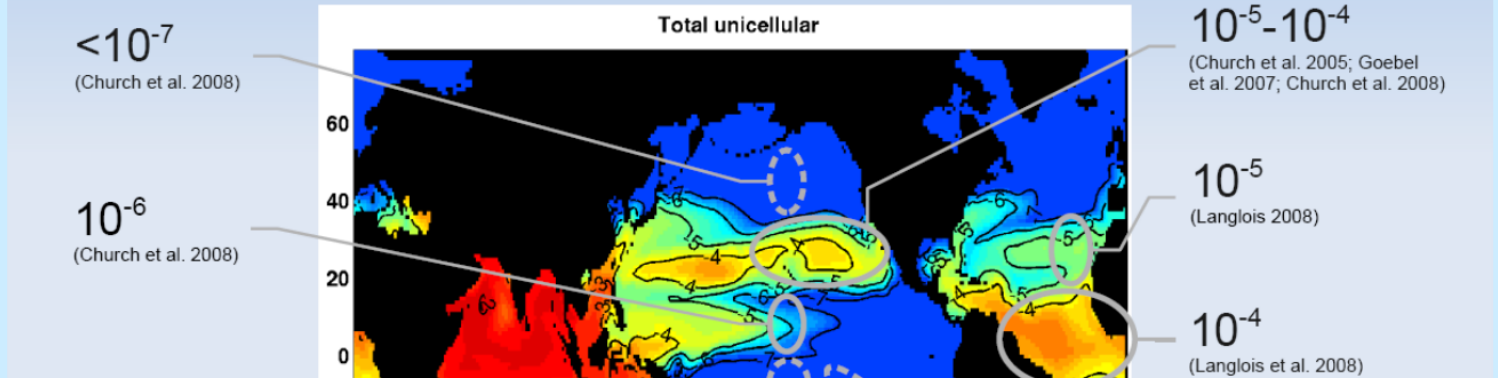
MIT

http://mitgcm.org/wordpress/wp-content/uploads/2009/06/comparisontobservations1.png

Distributions and comparison to observations



Trichode
analogs



Unicellul

Mail Online

Brazil's darkest hour: National

Sand-ageddon! Britain is covered in layer of dust after African storms carry in sand from the SAHARA desert 2,000 miles away (and even Cameron's car got hit)

- Unusual atmospheric conditions have blown up sandstorm from Africa
- Thin layer of dust seen today in areas including Cornwall and London
- 10/10 air pollution forecast for London for tomorrow and Wednesday
- Temperatures hit 20.9C yesterday and today is expected to be as hot

By MARK DUELL

PUBLISHED: 07:41 EST, 31 March 2014 | **UPDATED:** 12:21 EST, 31 March 2014

Methods

- Sampling and filtering-microscopy
- Flow cytometry
- HPLC Pigments (PE, PB)
- Video Camera Recorder (VCR)
- Molecular: Nifh genes
- DNA: clade specific qPCR
- Inferred from N fixation
- Optics: Backscattering +Absorption

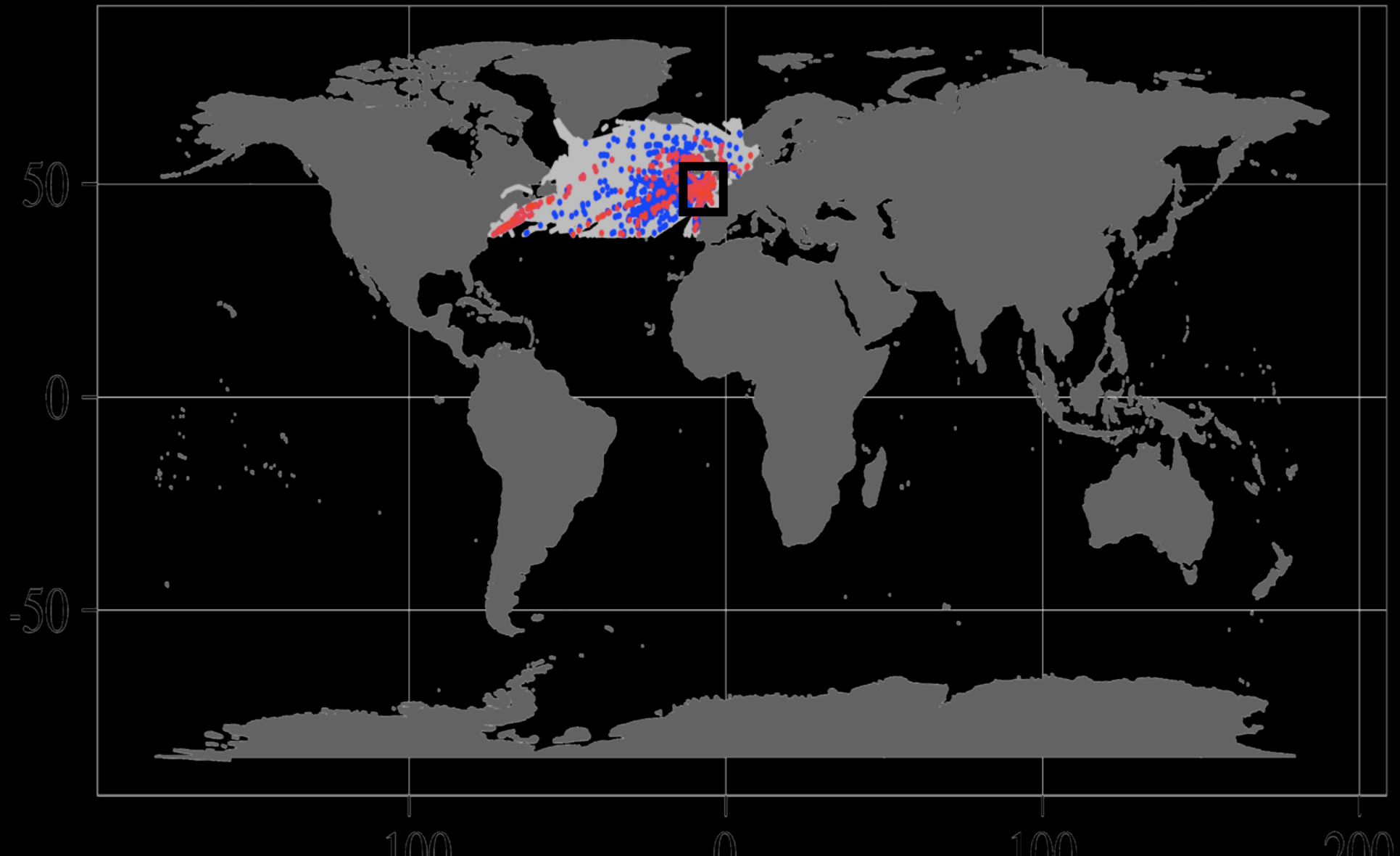
Challenges

- Agreement among methods
- Reports often clump diazotrophs together
- Specificity of techniques
- Matchups – groundtruthing
- Predicting blooms
- subbloom concentrations
- ephymerous blooms
- Patchiness
- Vertical migration
- Subsurface distribution
- Resolution: Spectral +Spatial + Temporal
- Quantitative algorithms
- Nutrients, temperature assumptions
- previous knowledge as sampling bias
- Clades/ strains/ species differences

Challenges mapping global distribution

- Sampling and filtering – microscopy –time consuming
- Vertical distribution- how far down? Vertical migration
- Flow citometry
- Pigments HPLC- specific tricho pigment
- Video
- Nif h genes- not exclusive to trichodesmium
- Inferred from N fixation
- Backscattering- vesicle, depth
- Absorption- need the right bands
- Sub-bloom concentrations
- DNA-clades

50 years of Trichodesmium records in the North Atlantic



N=193 000 samples

Trichomes/3m^3

100,000

10,000

1,000

100

1

no trichomes

Rivero-Calle et al., 2016. GBC.

Global map attempts

http://mitgcm.org/wordpress/wp-content/uploads/2009/06/comparisontobservations1.png
The first report in the literature of a direct observation of Trichodesmium is the photograph taken from the Space Shuttle of a massive bloom of this organism in the Capricorn Channel (Kuchler and Jupp, 1988).

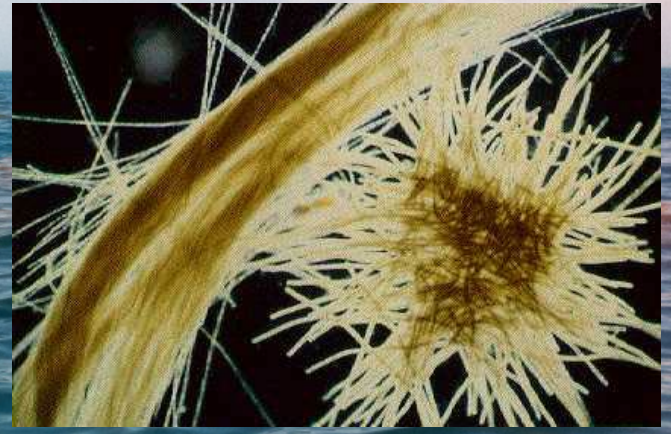
Phycoerythin and phycocyanin
Luo
Westberry- temp mask
Capone-science
Rouco
Detoni 2016
Monteiro, F. M., M. J. Follows, and S. Dutkiewicz (2010), Distribution of diverse nitrogen fixers in the global ocean, Global Biogeochem. Cycles, 24, GB3017, doi:10.1029/2009GB003731.
Dupuoy 2011
subraniam

- Rouco, M., Haley, S. T., Alexander, H., Wilson, S. T., Karl, D. M. and Dyhrman, S. T. (2016), Variable depth distribution of Trichodesmium clades in the North Pacific Ocean. Environmental Microbiology Reports, 8: 1058–1066. doi:10.1111/1758-2229.12488
- Detoni, A. M. S., Á. M. Ciotti, P. H. R. Calil,V. M. Tavano, and J. S. Yunes (2016),Trichodesmium latitudinal distributionon the shelf break in the southwestern Atlantic Ocean during spring and autumn, Global Biogeochem. Cycles, 30,1738–1753, doi: 10.1002/2016GB005431.
- The depth-distribution of nitrogen fixation by *Trichodesmium* spp. colonies in the tropical–subtropical North Atlantic

Trichodesmium

In In August 1770, Captain Cook wrote:
"The Sea in many places is her cover'd with a kind of a brown scum…"

sailors call it "Sea Sawdust"



1. The most significant primary producer in tropical oligotrophic waters
2. Responsible for ~1/2 of the ocean N fixation
3. Comparable to the amount of new nitrate from upwelling processes

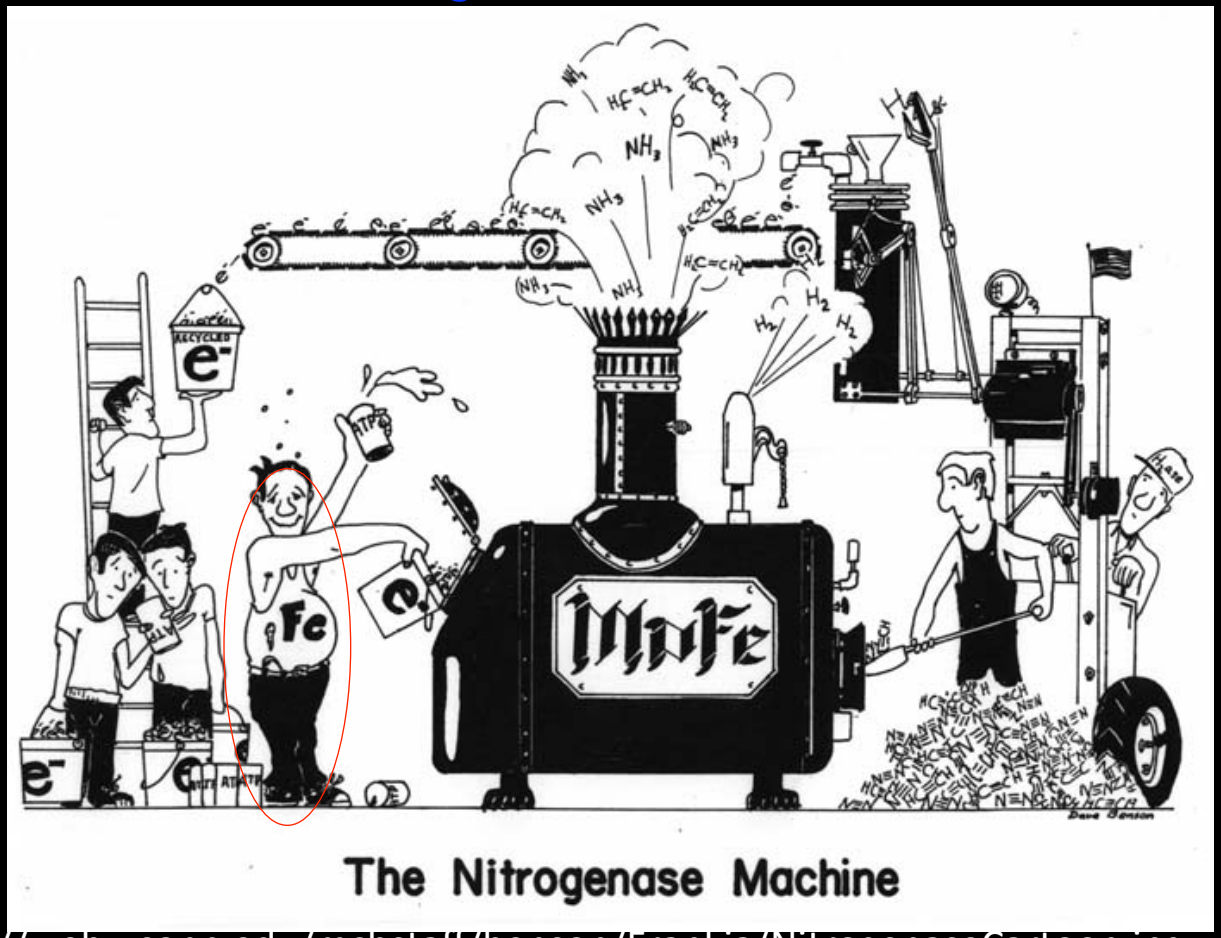
Key West, Florida. U.S. Coast Guard photo

Nitrogenase

N_2 NH_3

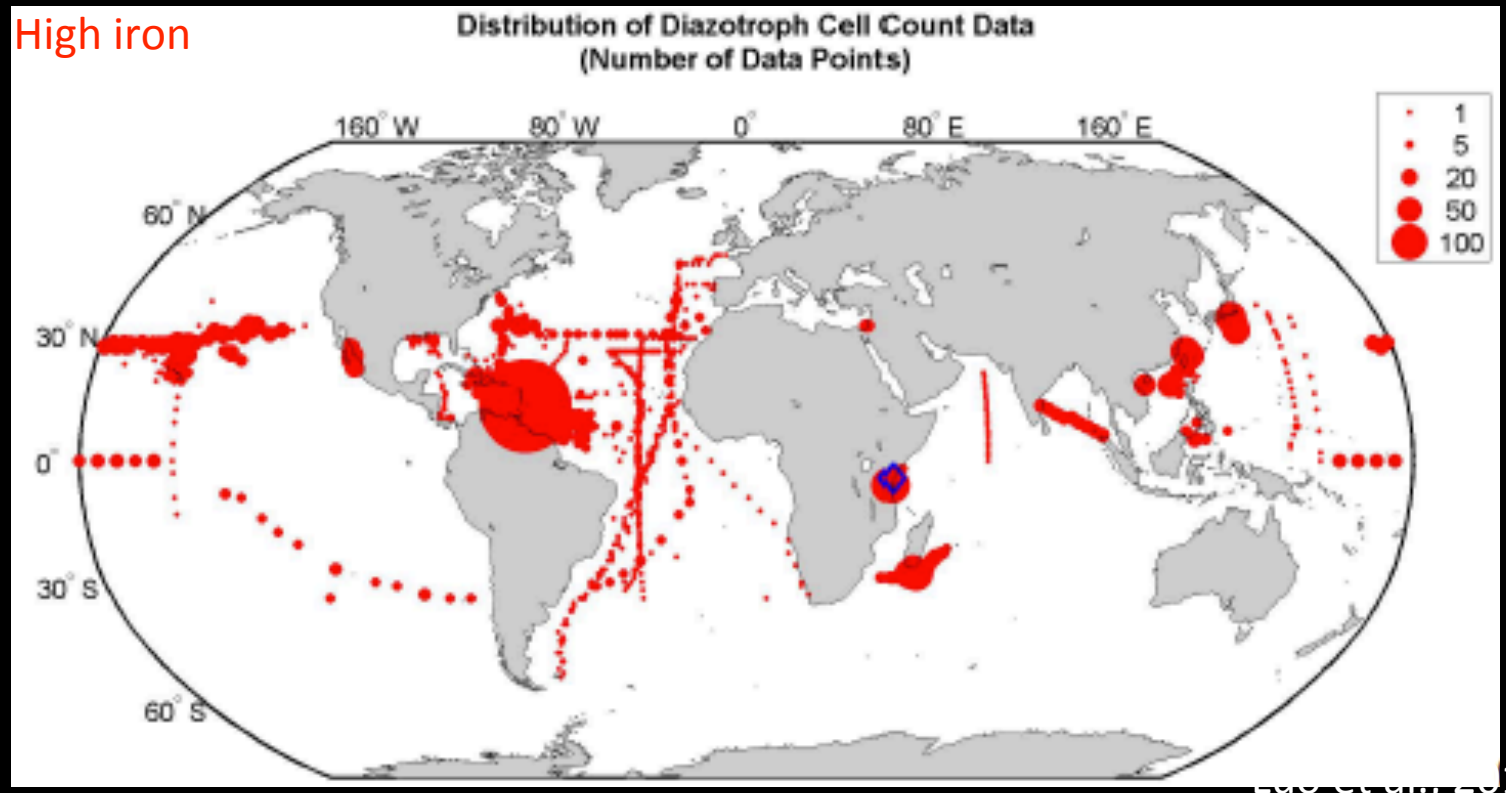
- High Iron

Tropical and subtropical



http://web.uconn.edu/mcbstaff/benson/Frankia/NitrogenaseCartoon.jpg

- Distribution of N_2-fixers is patchy in time and space
- Lack of global long-term variability
- Most studies focus on tropical +subtropical regions
- Distribution assumptions
  - Temperature >20°C
  - High iron

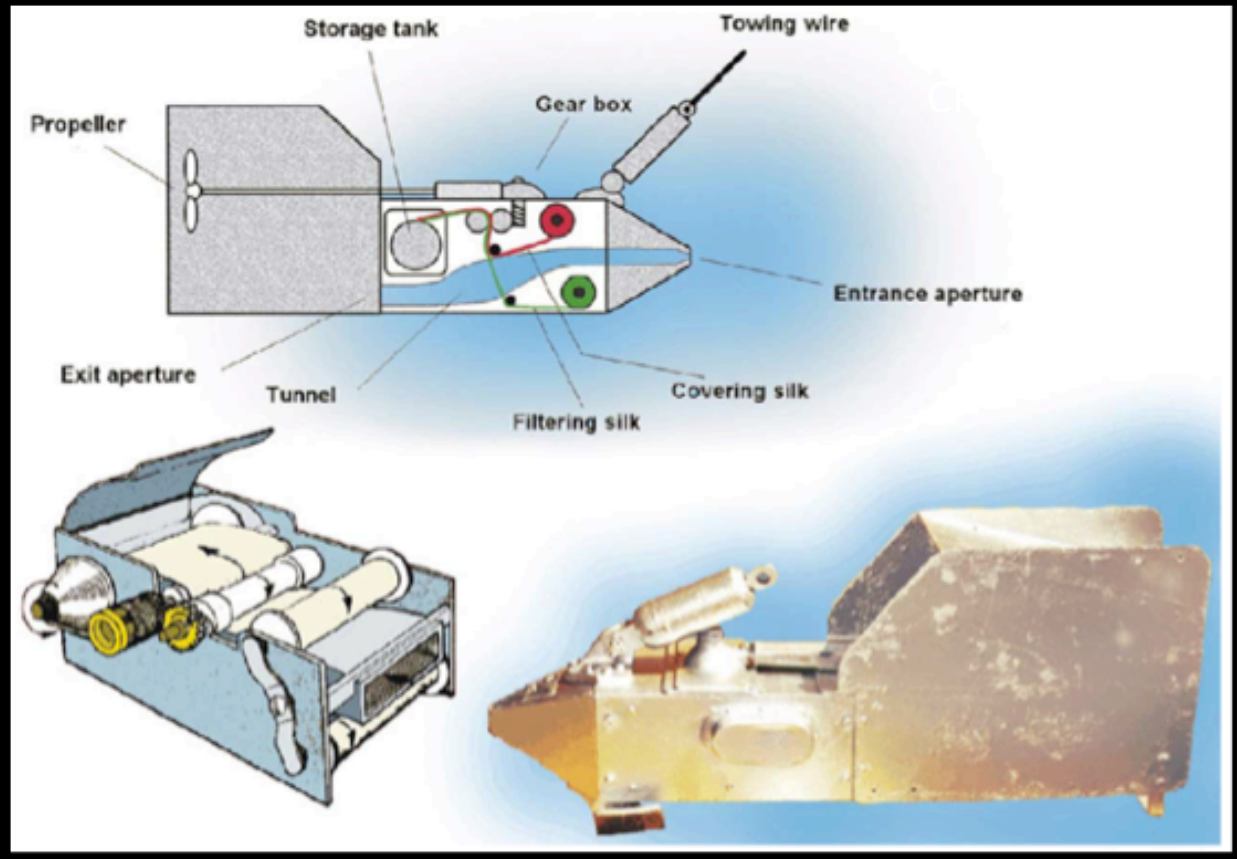


Luo et al., 2012

Continuous Plankton Recorder (CPR)

- Samples with ships of opportunity
- Longest and most extensive plankton survey in the World
- >200,000 samples
- >400 taxa

Sir Alister Hardy with CPR

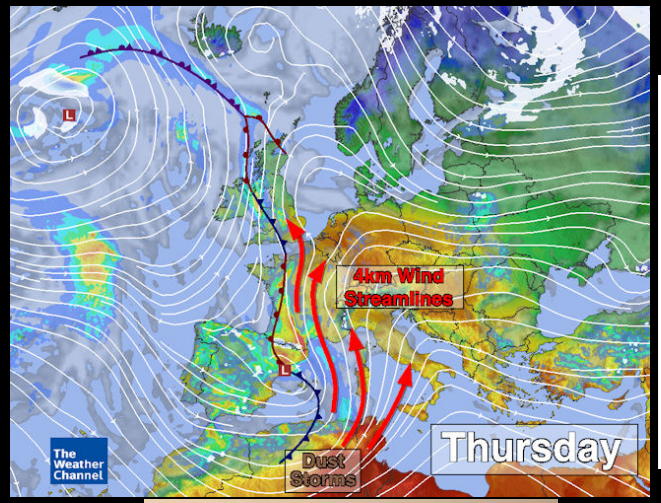


Richardson et al., 2006

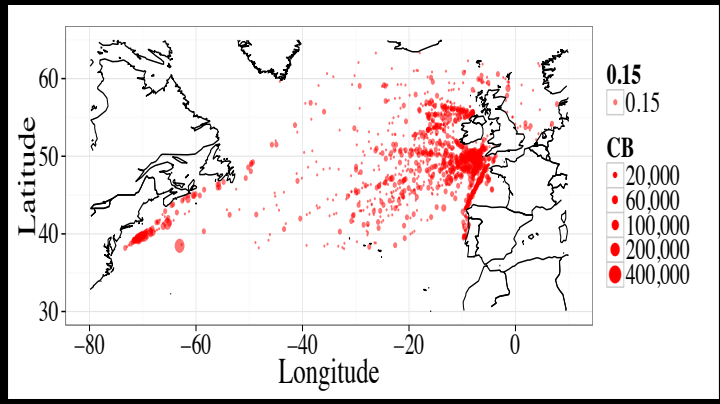
The Dust Hypothesis

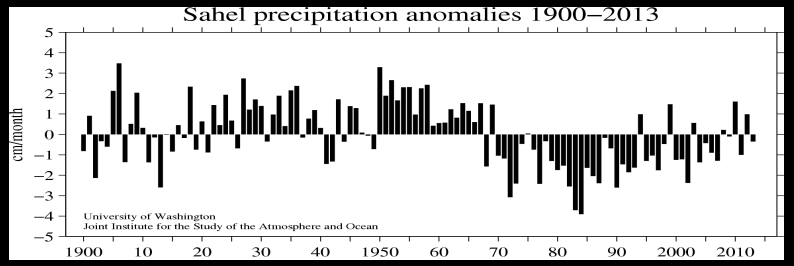
Source

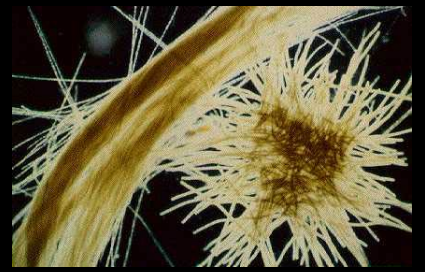
Pathway



Bloom







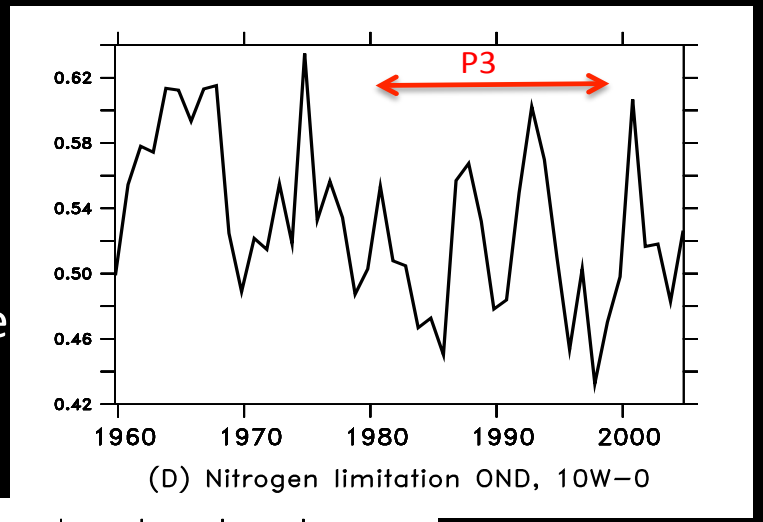
Conclusions and questions

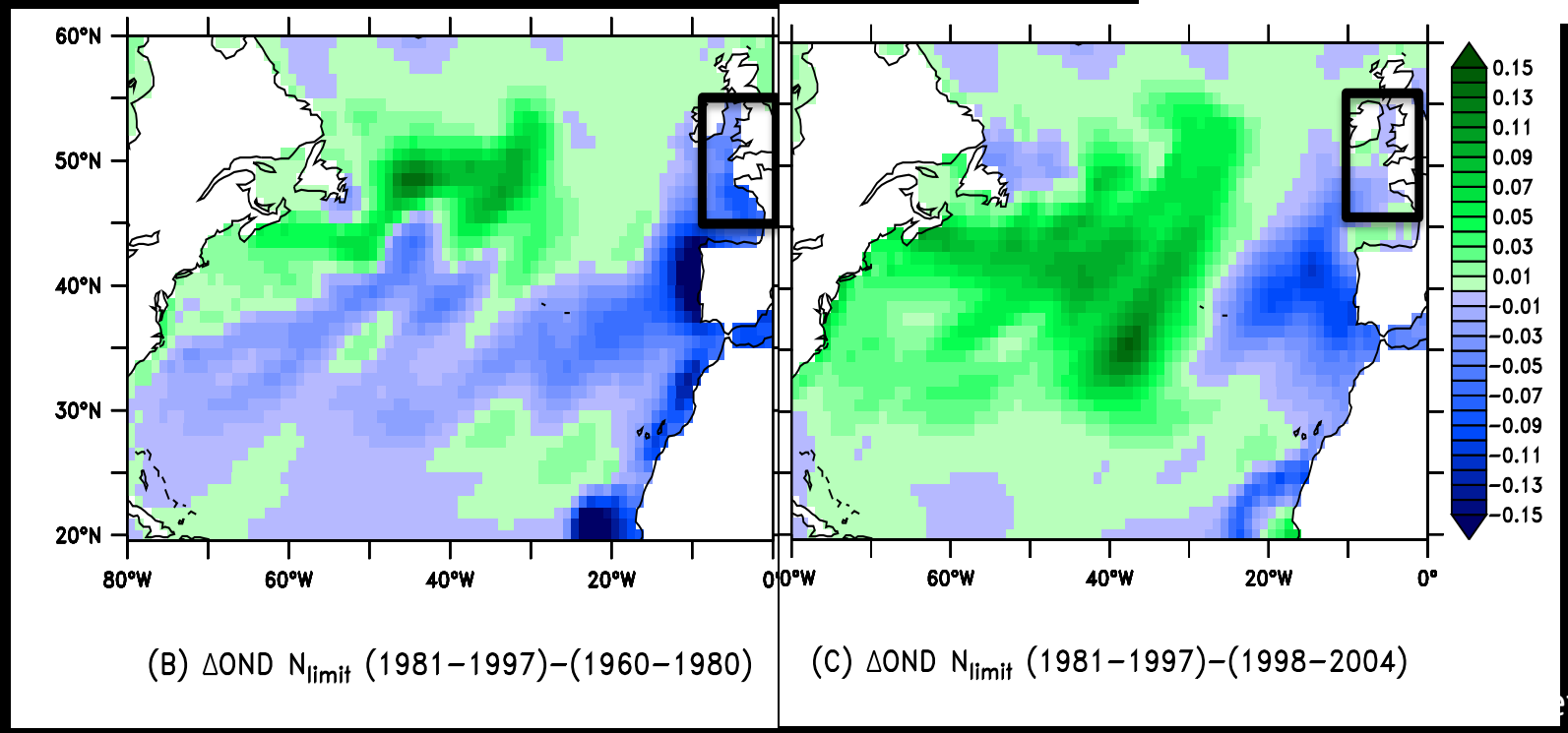
- *Trichodesmium* is present outside the tropics
- In temperate N Atlantic (40-65N): year round
- Temperature assumption needs to be revised (this study: 0-27^{o}C)
- Seasonal and interannual variability can be explained based on African dust variability.
- Most ESMs use historical dust climatologies, need for a dynamic dust component

- What will be the impacts from increasing global N deposition and CO_2 levels?
- What are the effects on N and C cycles? On higher trophic levels?

N fixation in Bay of Biscay?

- In absence of other forms of N, *Trichodesmium* can fix dissolved N_2.
- This requires large amounts of iron
- GFDL model runs suggests low N levels that in the 1980-1990s
- N fixation could be possible if enough iron.



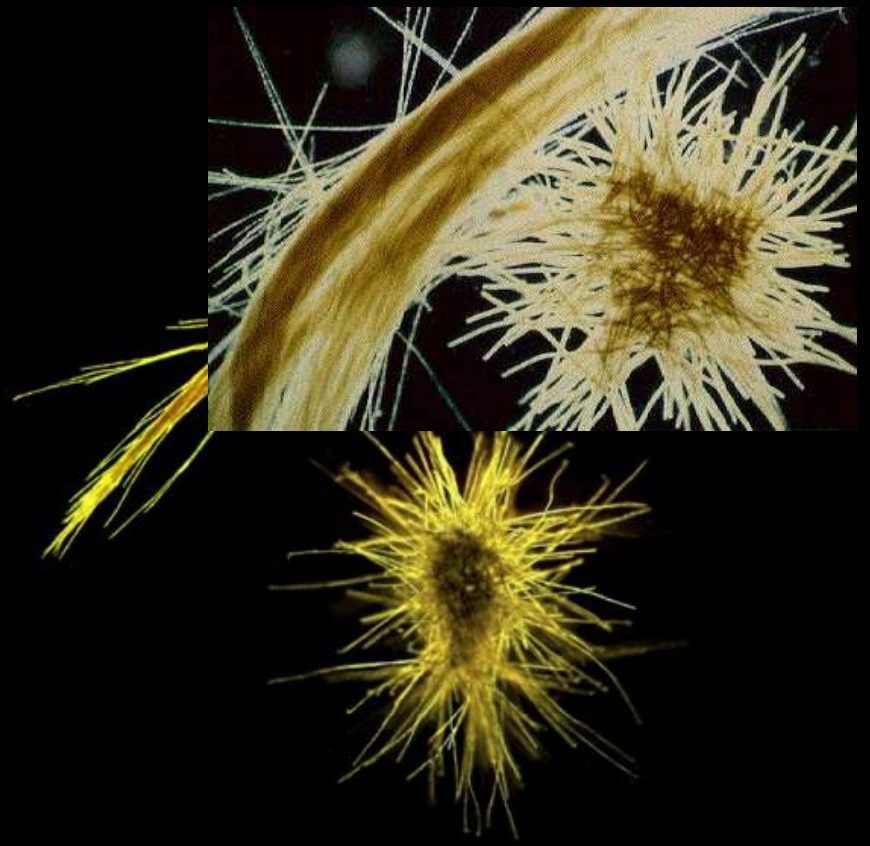


N available
N limited

et al 2015, submited

Trichodesmium spp.

- Tropical and subtropical
- Distribution limitations
  - Temperature >20^{o}C
  - iron
  - NO_3
  - PO_4
  - Dissolved O2



Anthropogenic Change vs. Natural Variability: Lessons Learned from the Continuous Plankton Recorder

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Dr. Carlos Del Castillo & Dr. Anand Gnanadesikan

December 11th, 2015

Luo et al 2014a, Biogeosciences. Envir marine N2 fixation

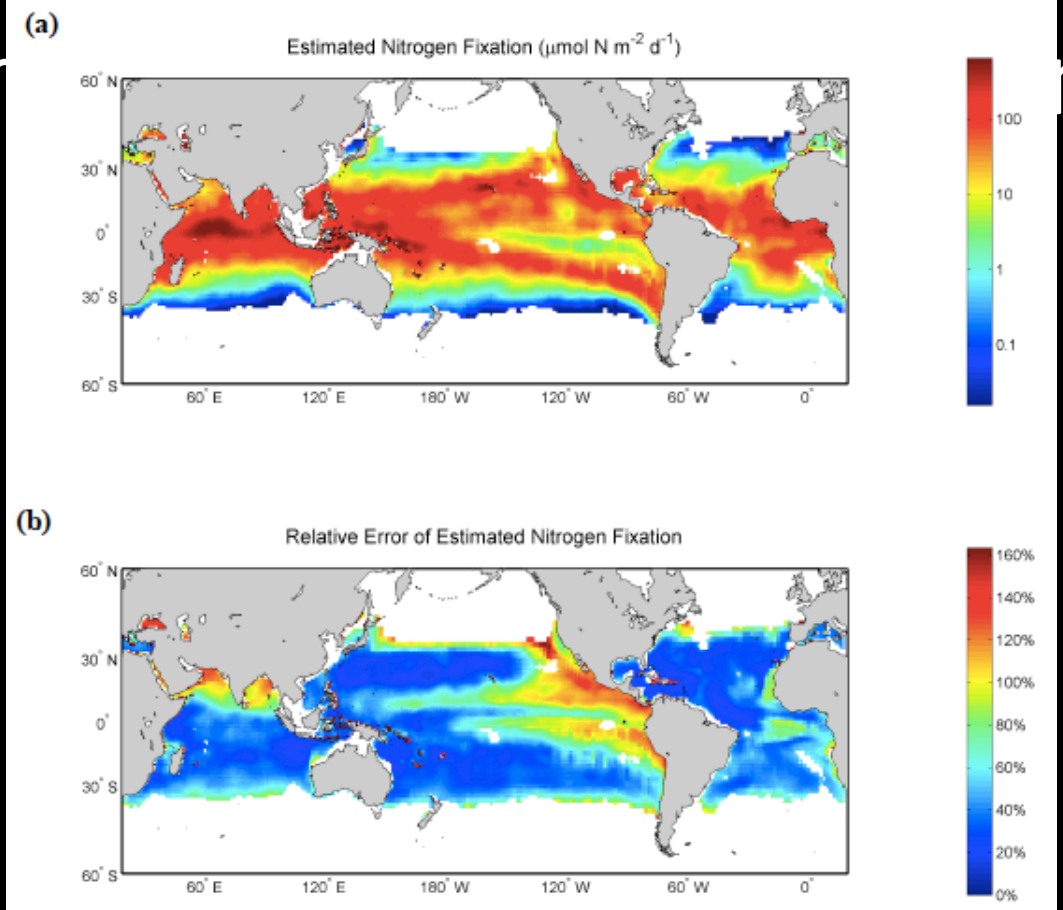

Fig. 6. (**a**) Map of estimated annual-mean, depth-integrated marine N_2 fixation using equation derived from the multiple linear regression (MLR) and (**b**) the relative errors of the estimates. White areas were outside the limits of the environmental parameter(s) used in the regression or were less than 250 m depth in coastal zones.