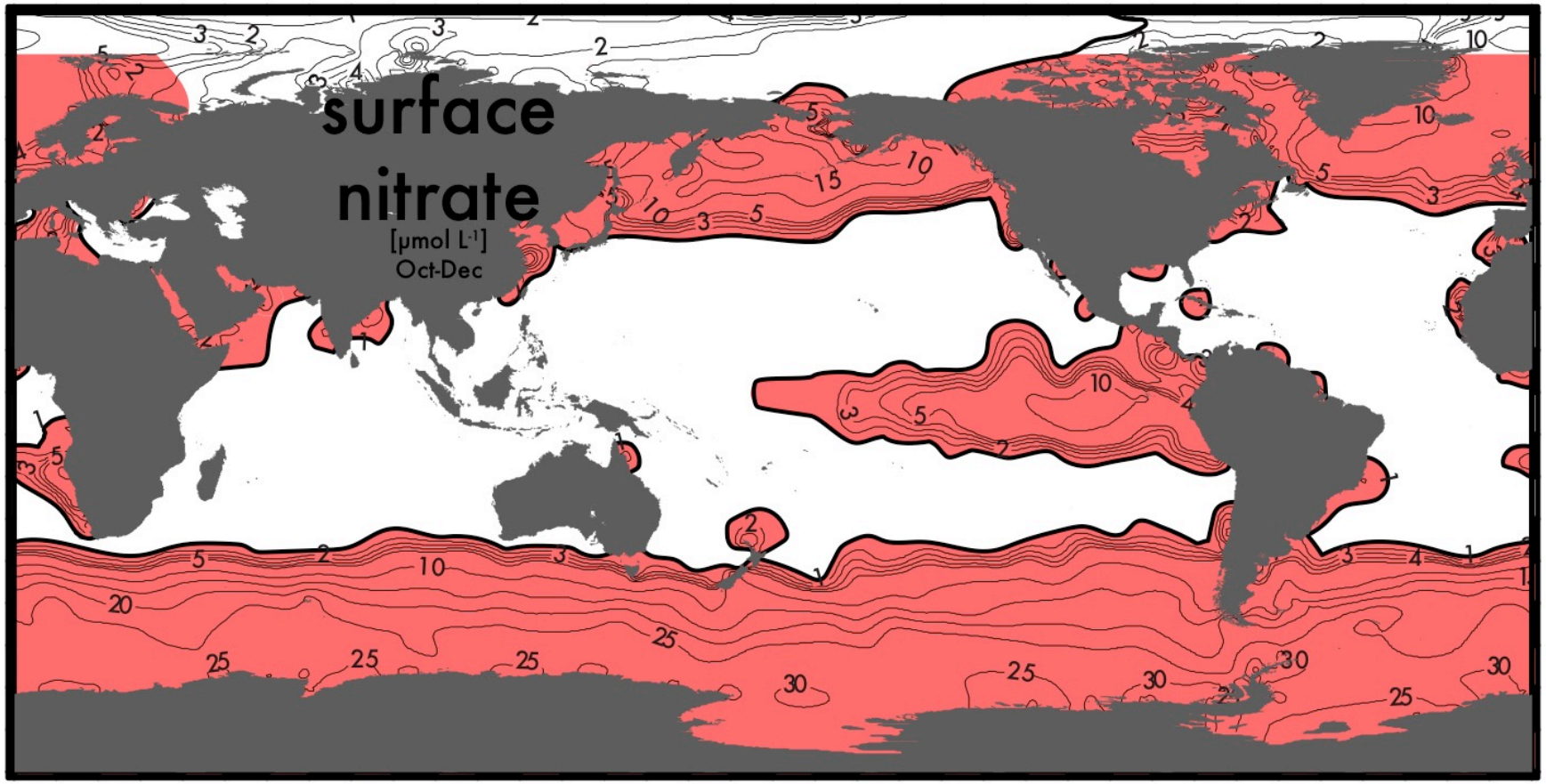
The general thesis of this talk is synthesizing paleo- and modern oceanographic findings w.r.t. variability of nitrate consumption in High Nutrient-Low Chlorophyll regions (nitrate rich, iron-limited waters)



Rethinking iron fertilization & the marine biological pump on seasonal to ice age timescales

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UCI
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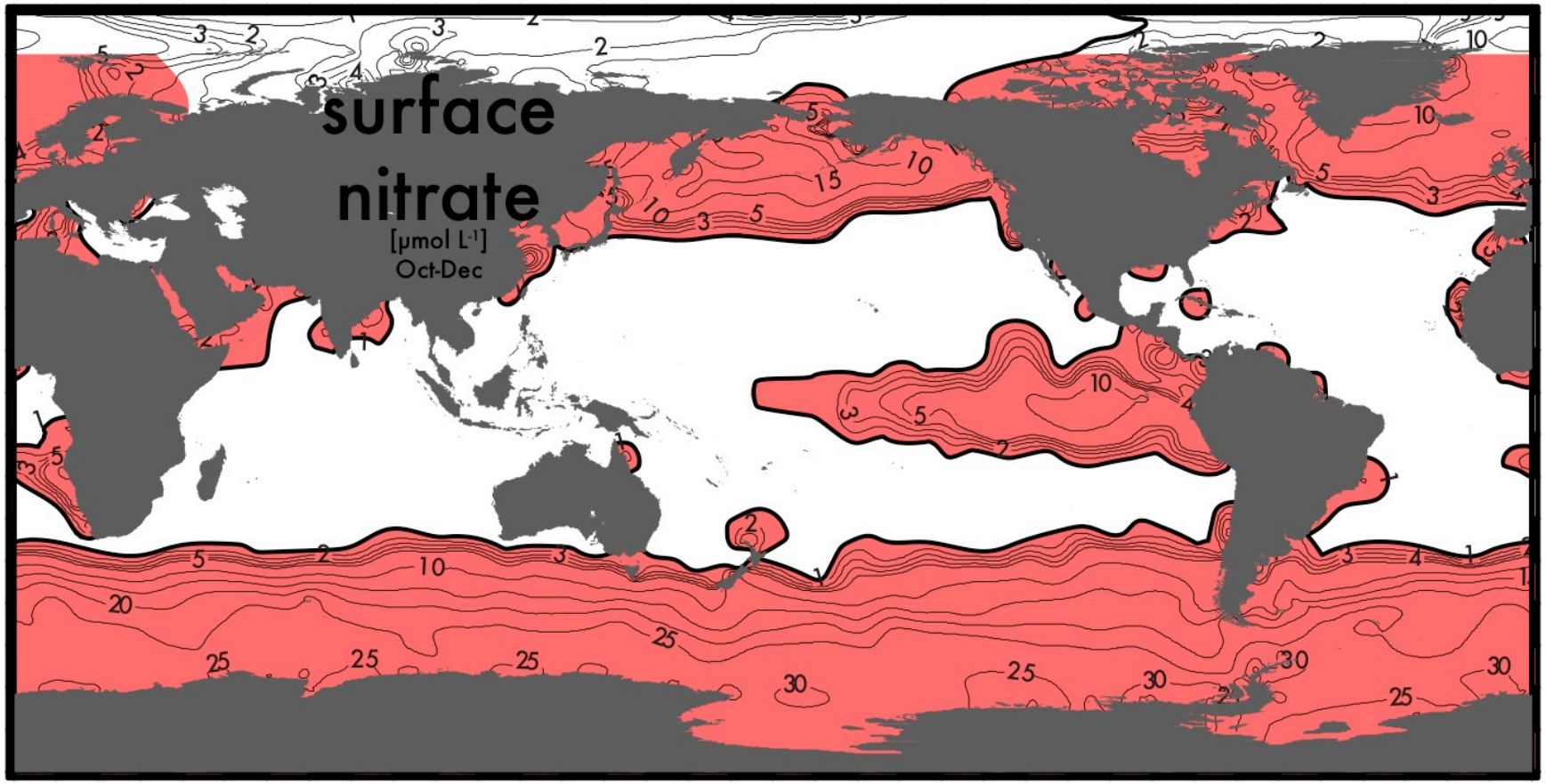
www.prafter.com
@OceanAndClimate

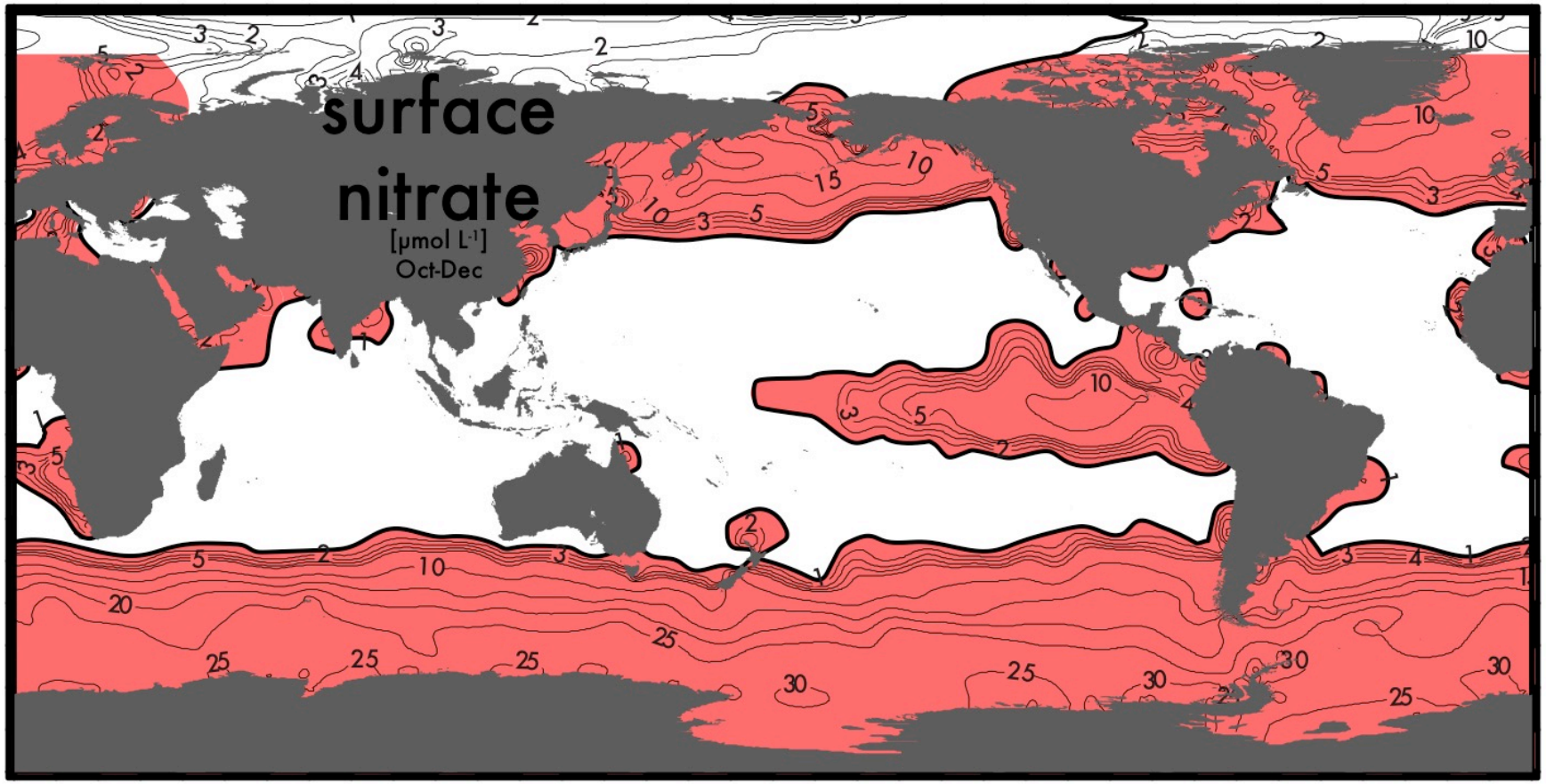


add iron and…

increase nitrate consumption

strengthen biological pump

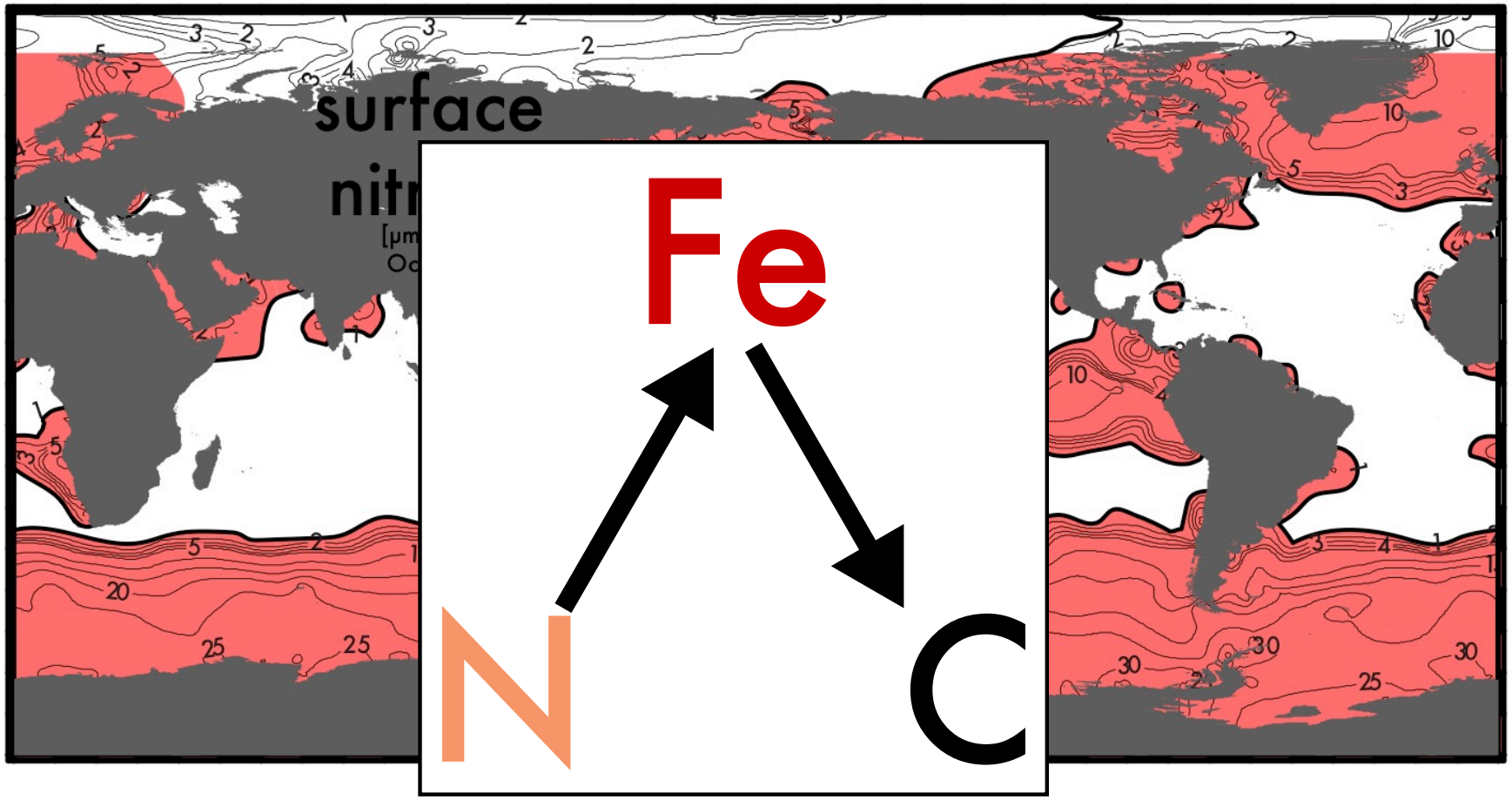
[Dugdale & Goering, 1967; Martin, 1990; Coale et al. 1996; others]



nitrate consumption → “new” production

→ biological carbon pump efficiency

[Dugdale and Goering 1967; Eppley and Peterson 1979]

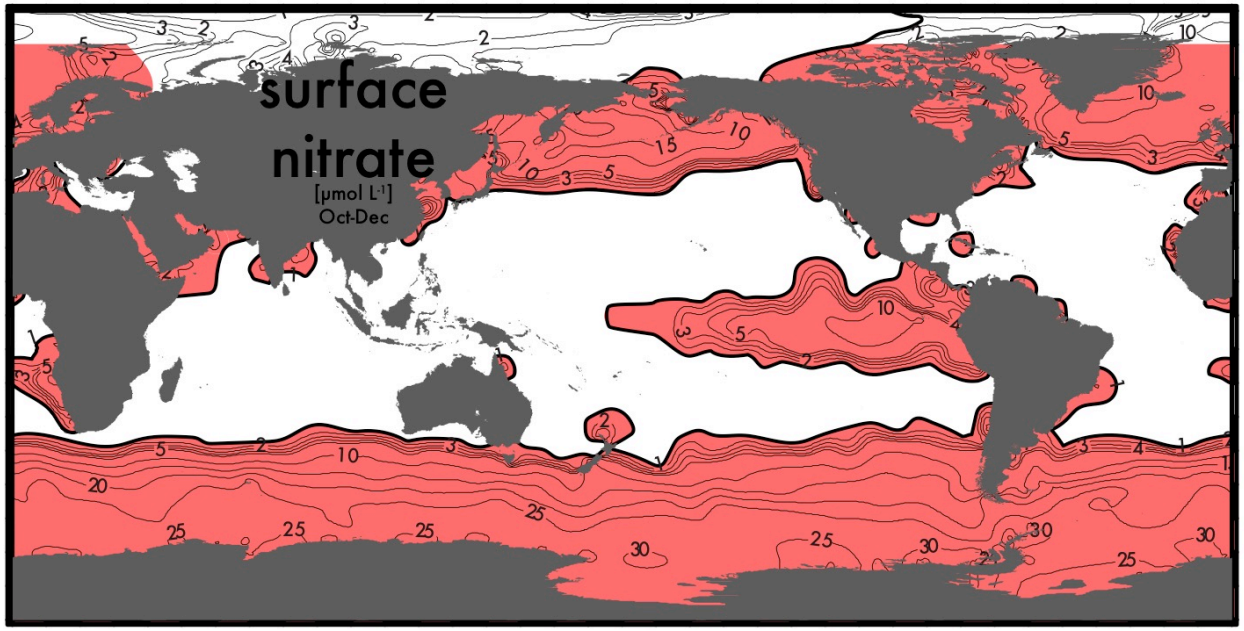


nitrate consumption → “new” production

→ biological carbon pump efficiency

[Dugdale and Goering 1967; Eppley and Peterson 1979]

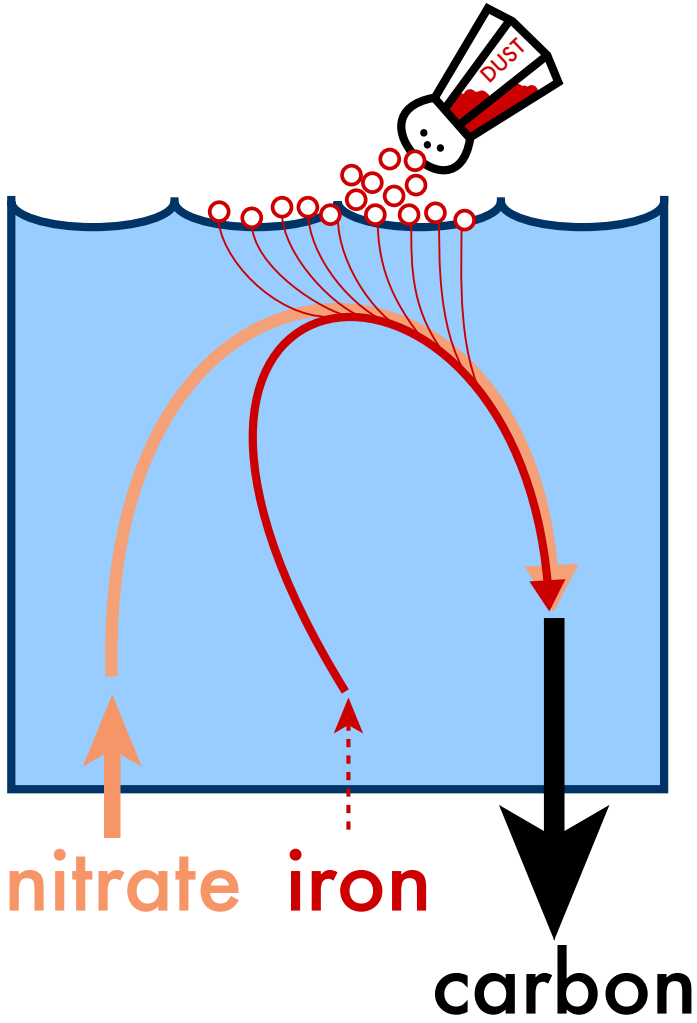
how to get nitrate consumption variability?



1. change iron / nitrate of source water (Altabet 2001)

2. change dust supply (John Martin 1990)

the "Iron Hypothesis"



2. change dust supply (John Martin 1990)

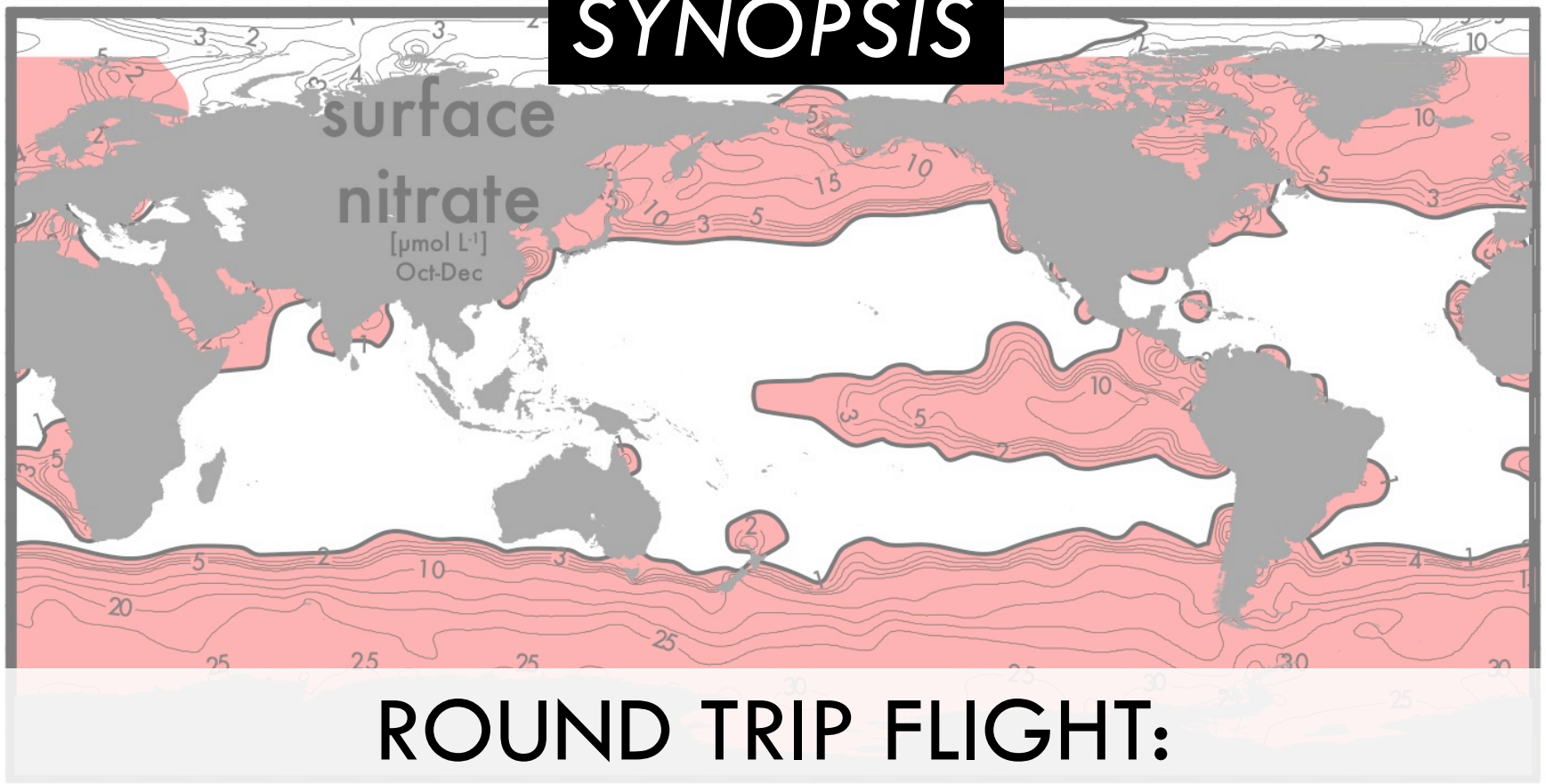
cracks in the "Iron Hypothesis"

no / little influence on glacial equatorial Pacific nitrate consumption (Rafter and Charles 2012; Costa et al. 2016; Winckler et al. 2016)

increased Southern Ocean nitrate consumption without increased dust (Studer 2015)

2. change dust supply (John Martin 1990)

SYNOPSIS



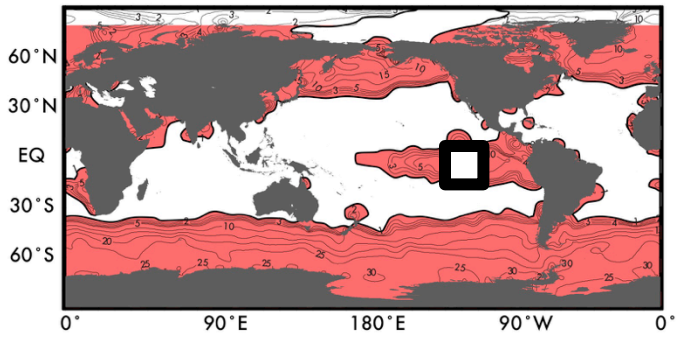
ROUND TRIP FLIGHT:

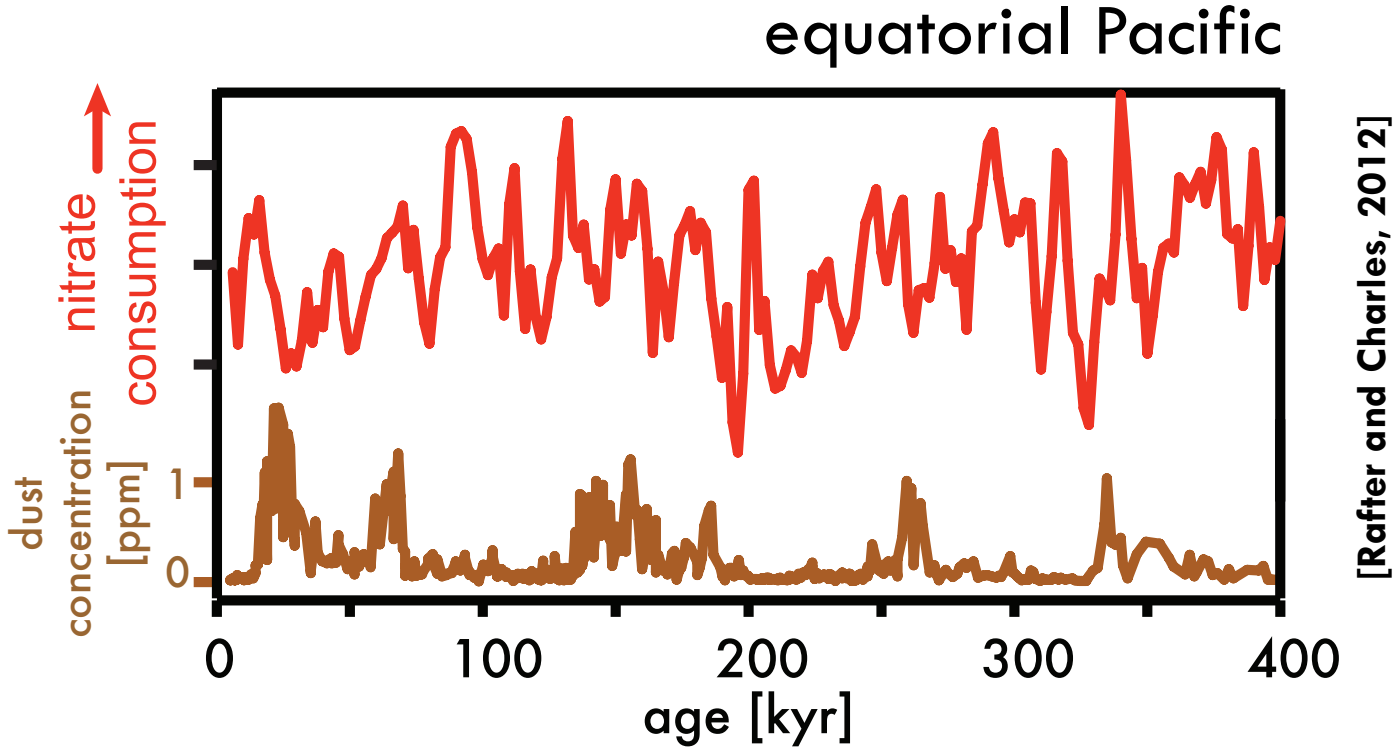
sediment proxy → surface biogeochemistry

&

biogeochemistry → sediment proxy

SYNOPSIS

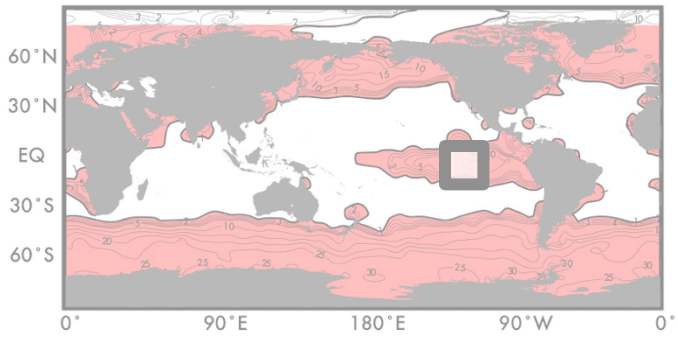

60°N
30°N
EQ
30°S
60°S
0°
90°E
180°E
90°W
0°

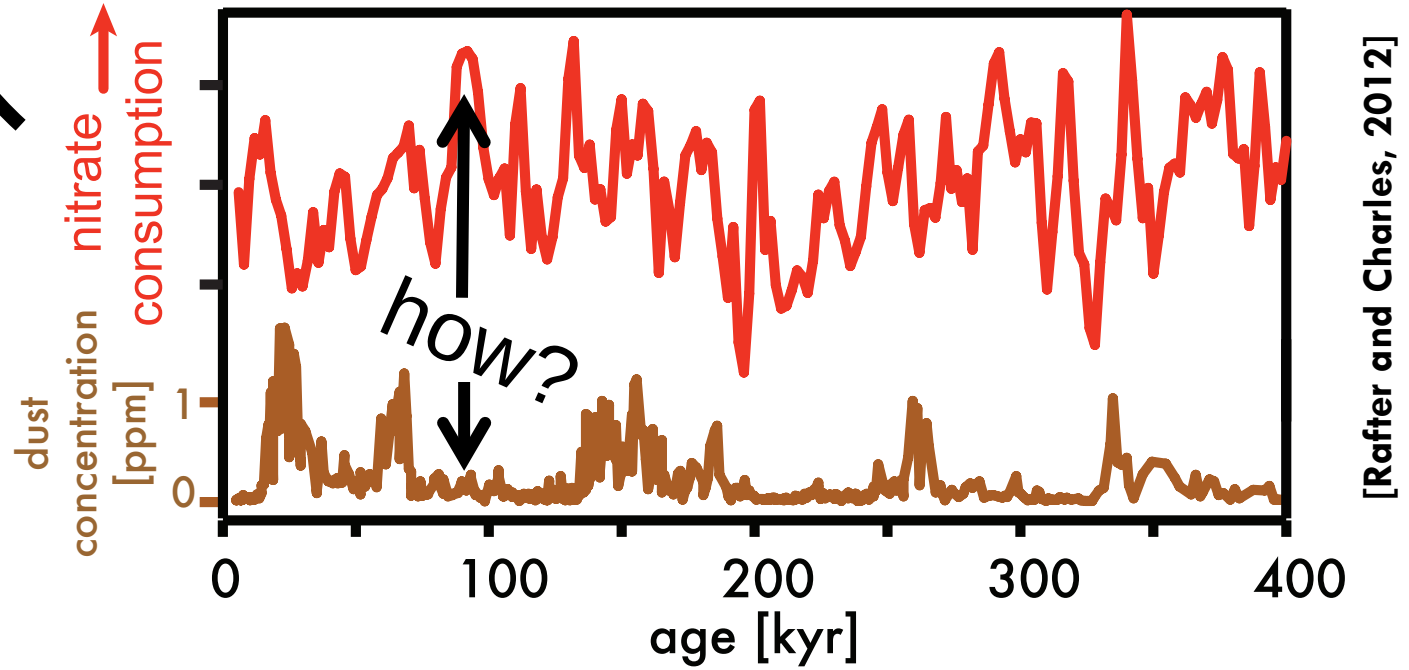

equatorial Pacific
nitrate consumption
dust concentration [ppm]
1
0
0
100
200
300
400
age [kyr]
[Rafter and Charles, 2012]

SYNOPSIS

nitrate isotopes

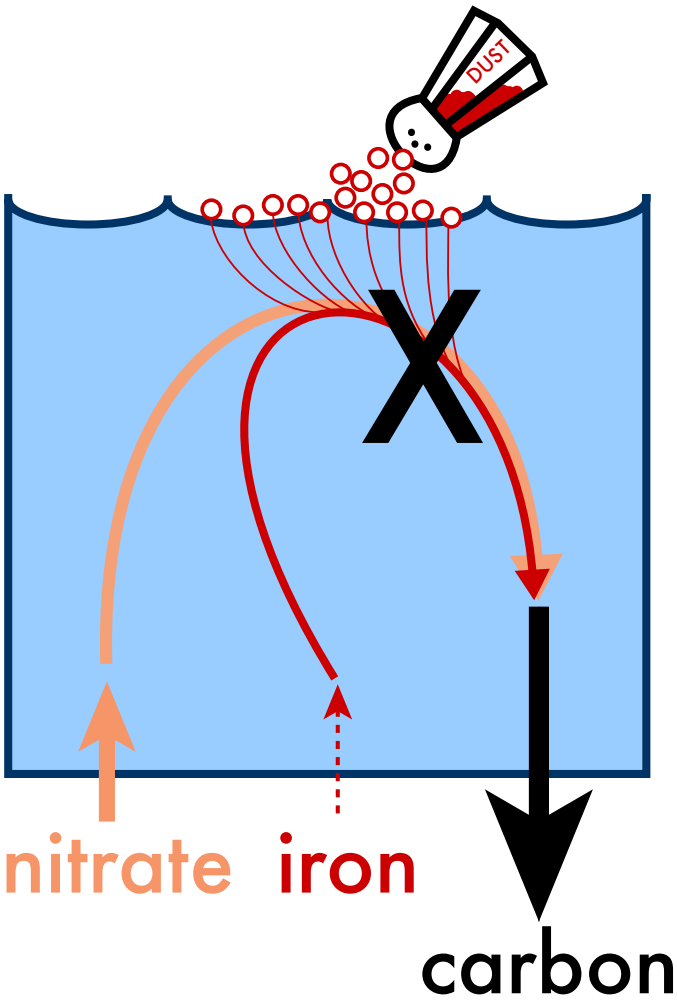
[Rafter and Charles, 2012]
[Rafter et al., 2012]
[Rafter et al., 2013]
[Rafter and Sigman 2016]
[Rafter et al. 2017]



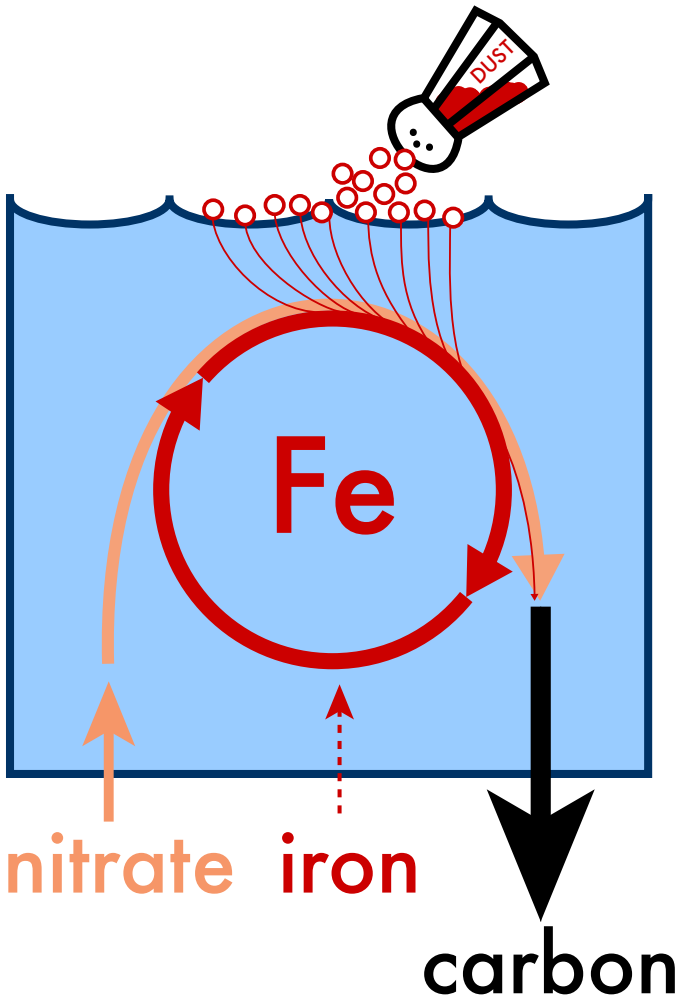


SYNOPSIS

original view



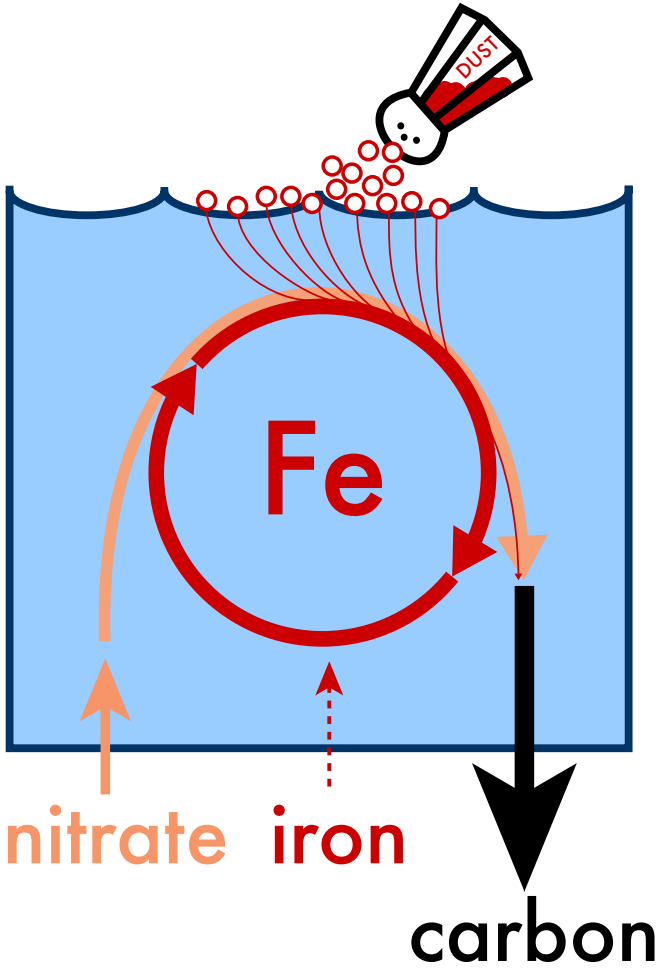
new view



Rafter, Sigman, & Mackey (2017)

SYNOPSIS

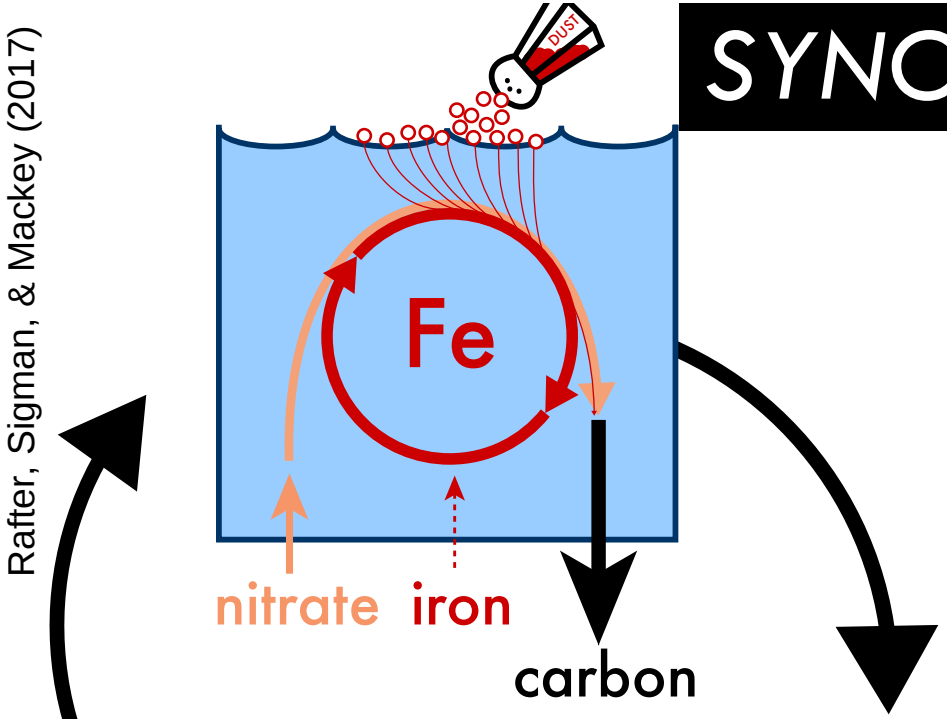
nitrate consumption and biological carbon pump cannot be explained by external supply of iron

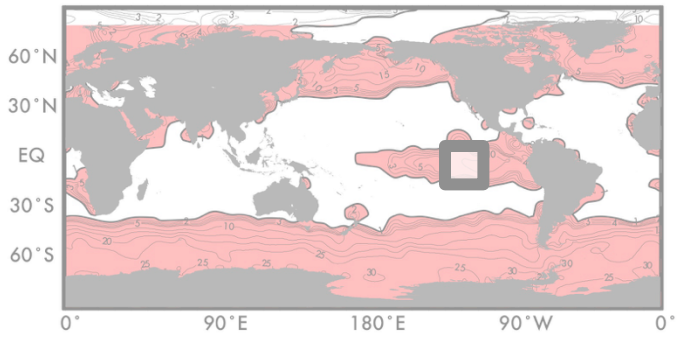


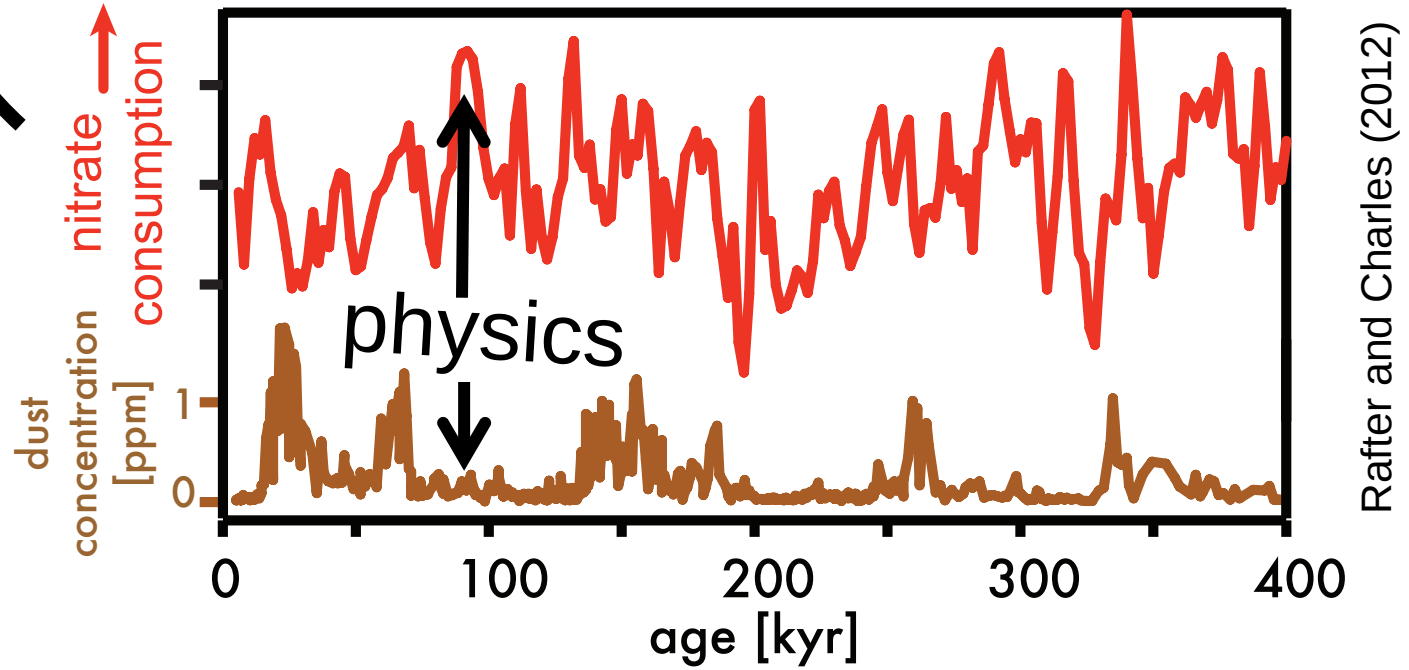
Rafter, Sigman, & Mackey (2017)

SYNOPSIS

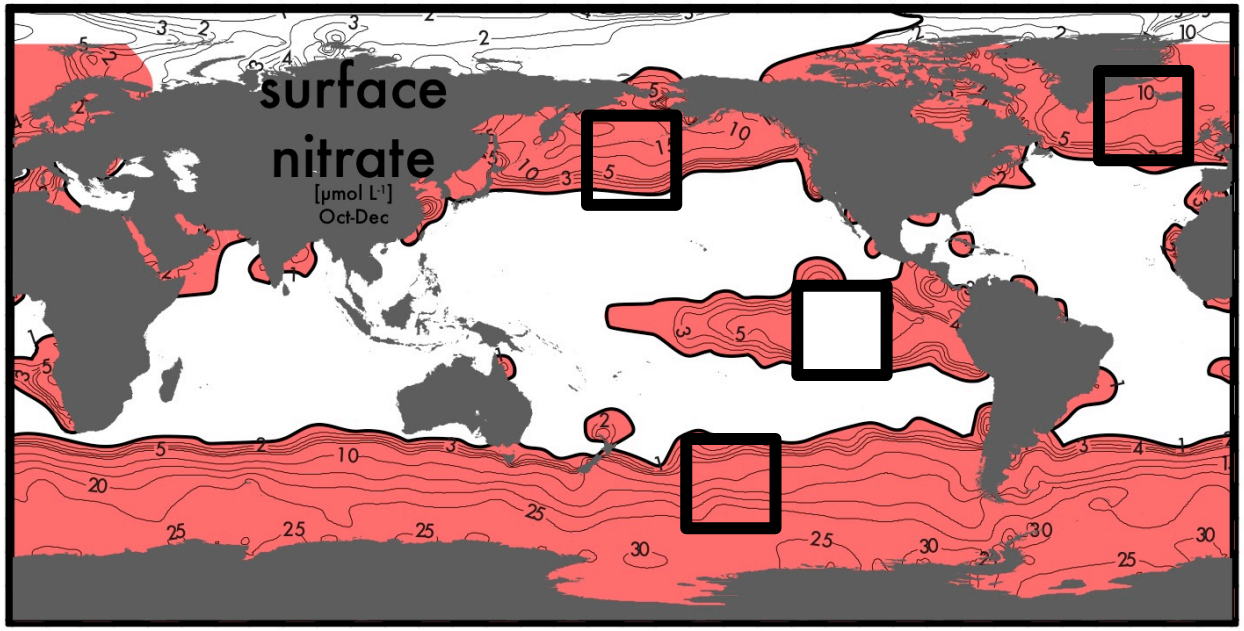
Rafter, Sigman, & Mackey (2017)







look to four iron-limited laboratories

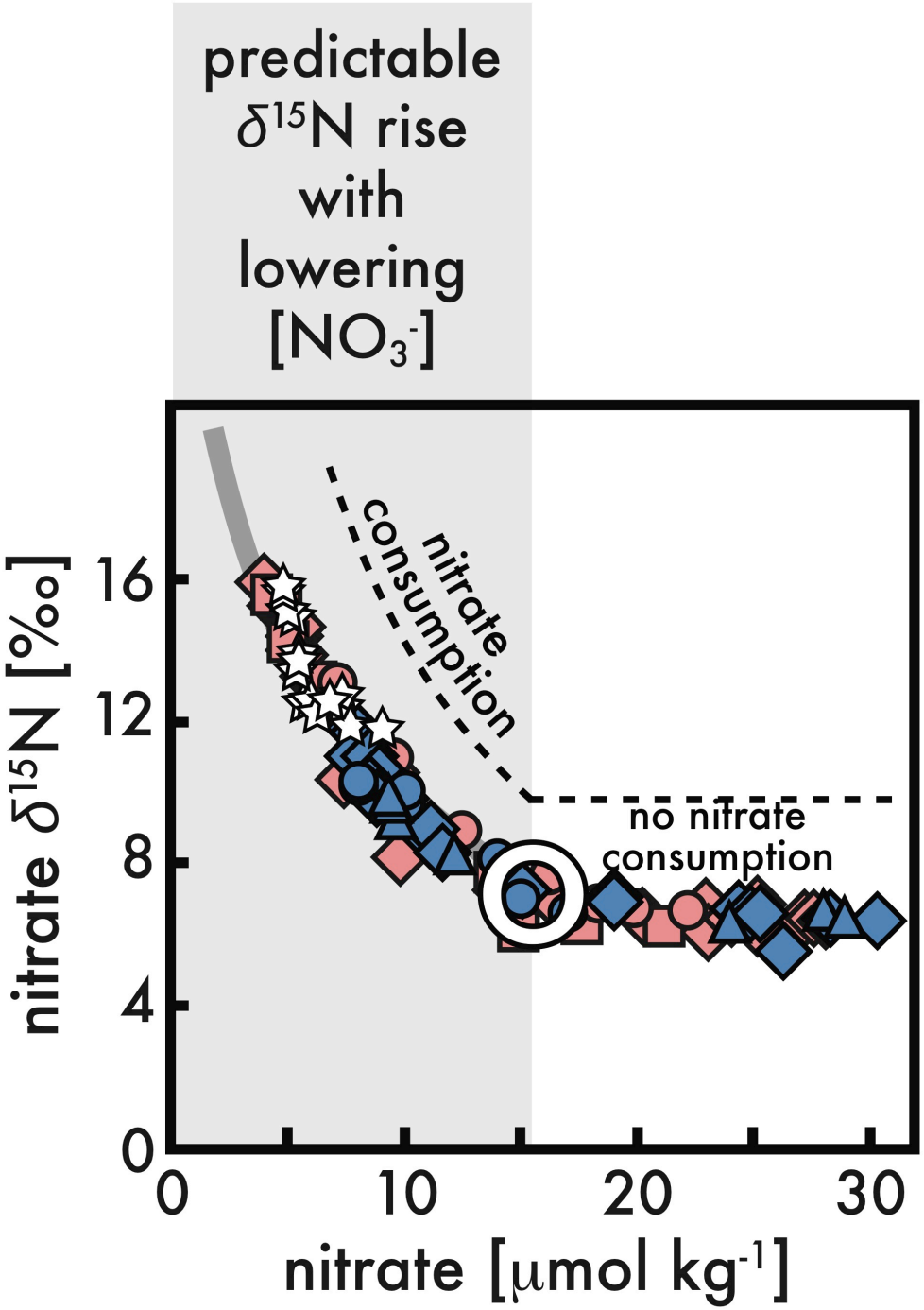


quantify nitrate consumption

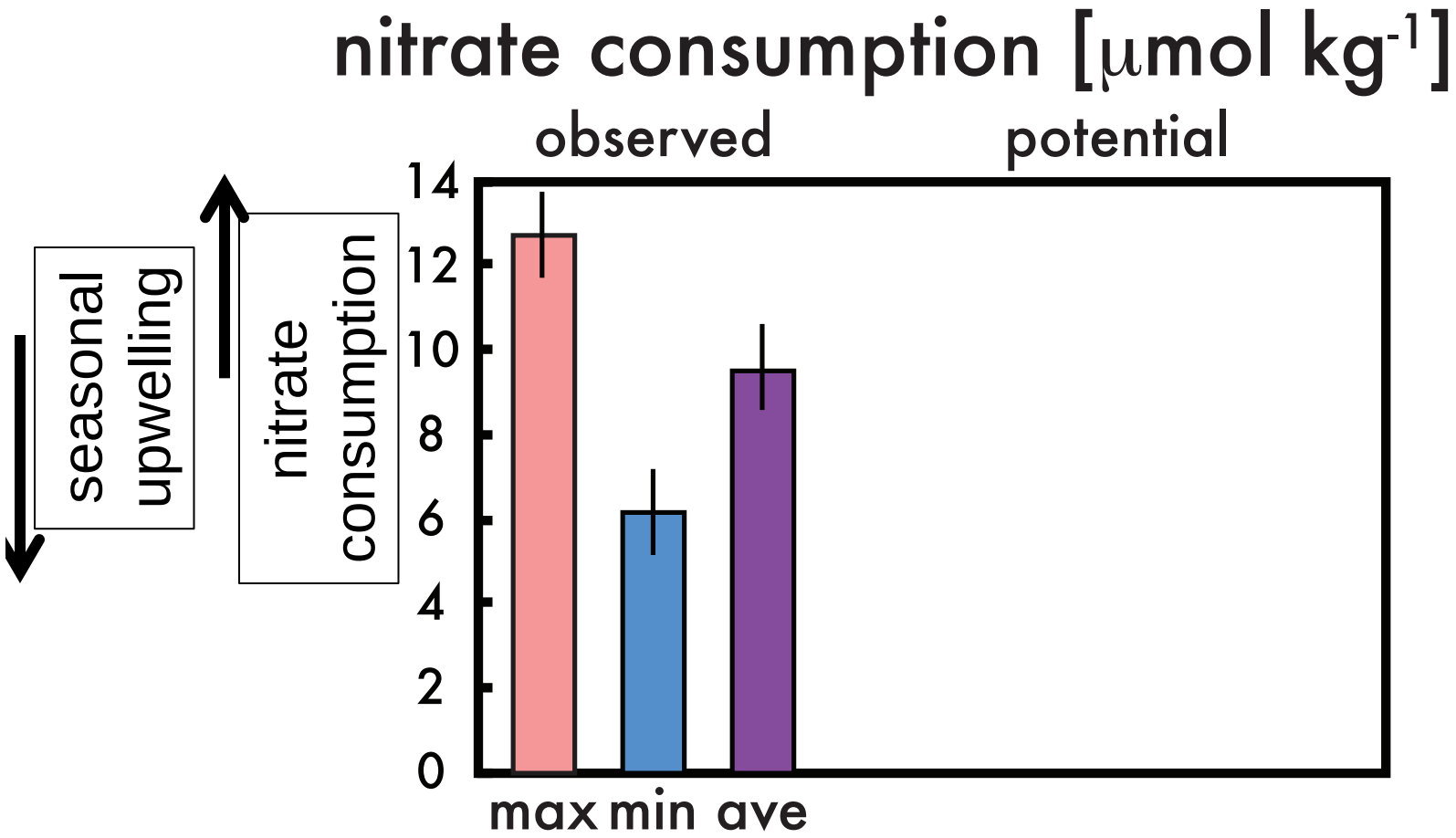
1. nitrate isotopes → source water [NO_3^-]
2. Fe/N requirements → “potential consumption”

why nitrate isotopes?

they are uniquely qualified for identifying source waters

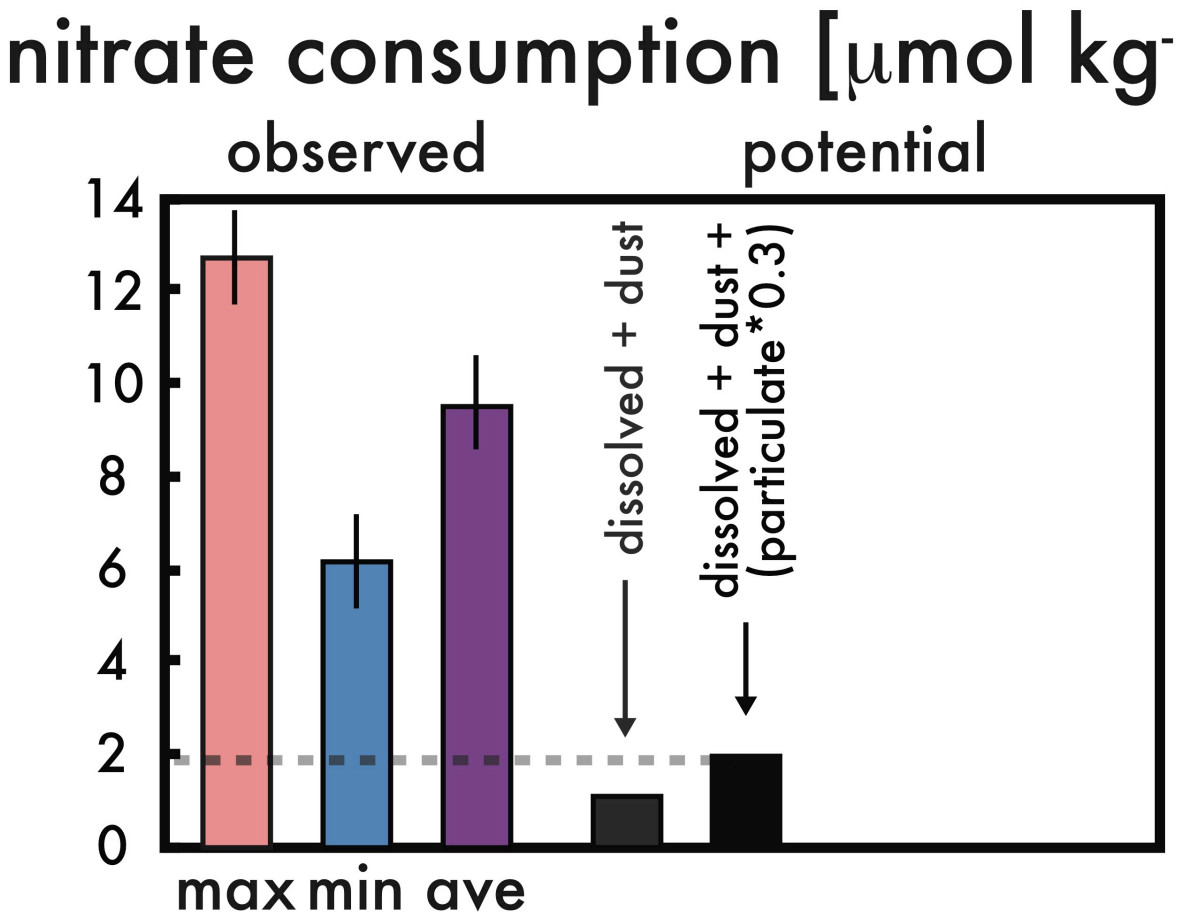


FIRST MYSTERY: why is there a relationship between consumption and upwelling?

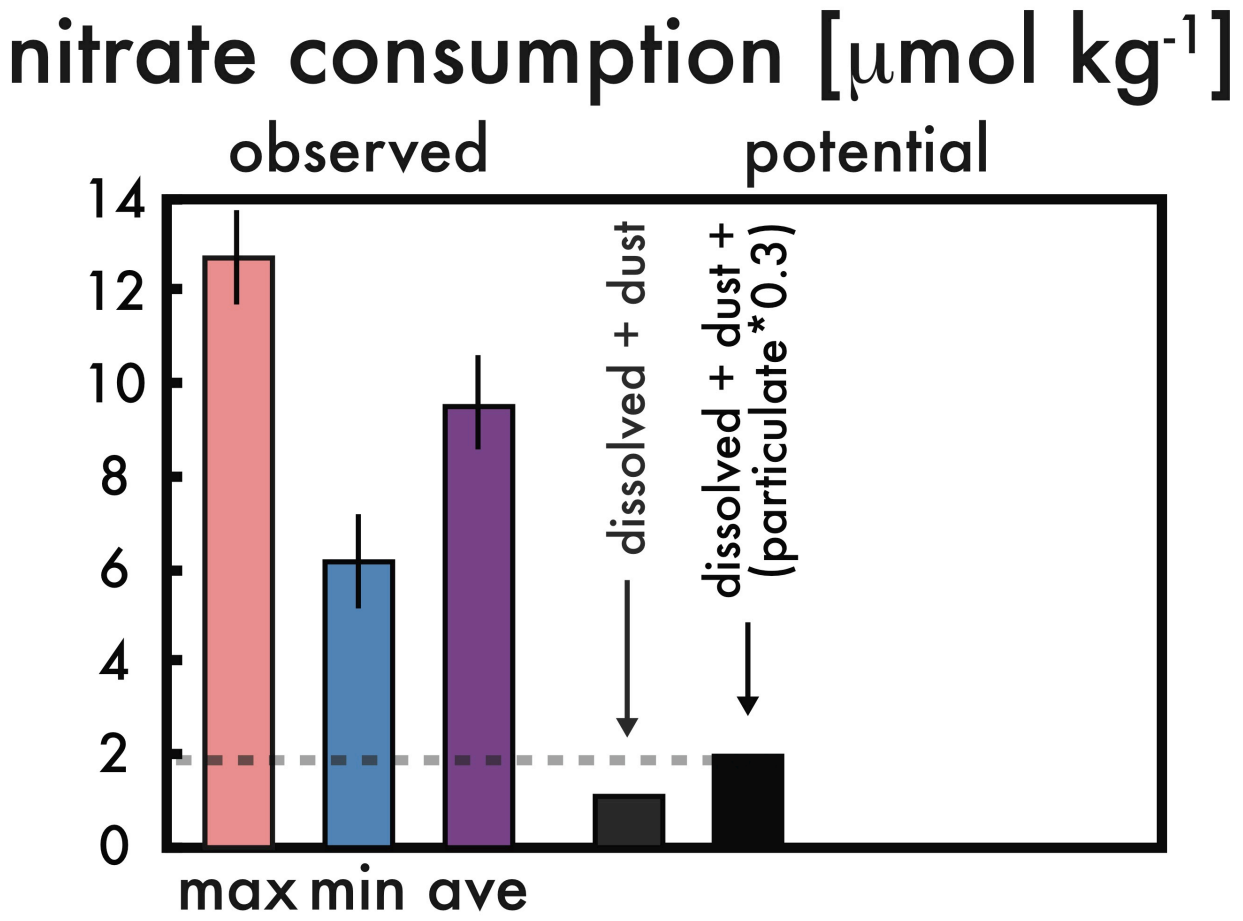


“potential” nitrate consumption (Rafter et al. 2017)

(uses constraints from Twining 2011; Kaupp 2011; Gordon 1997)

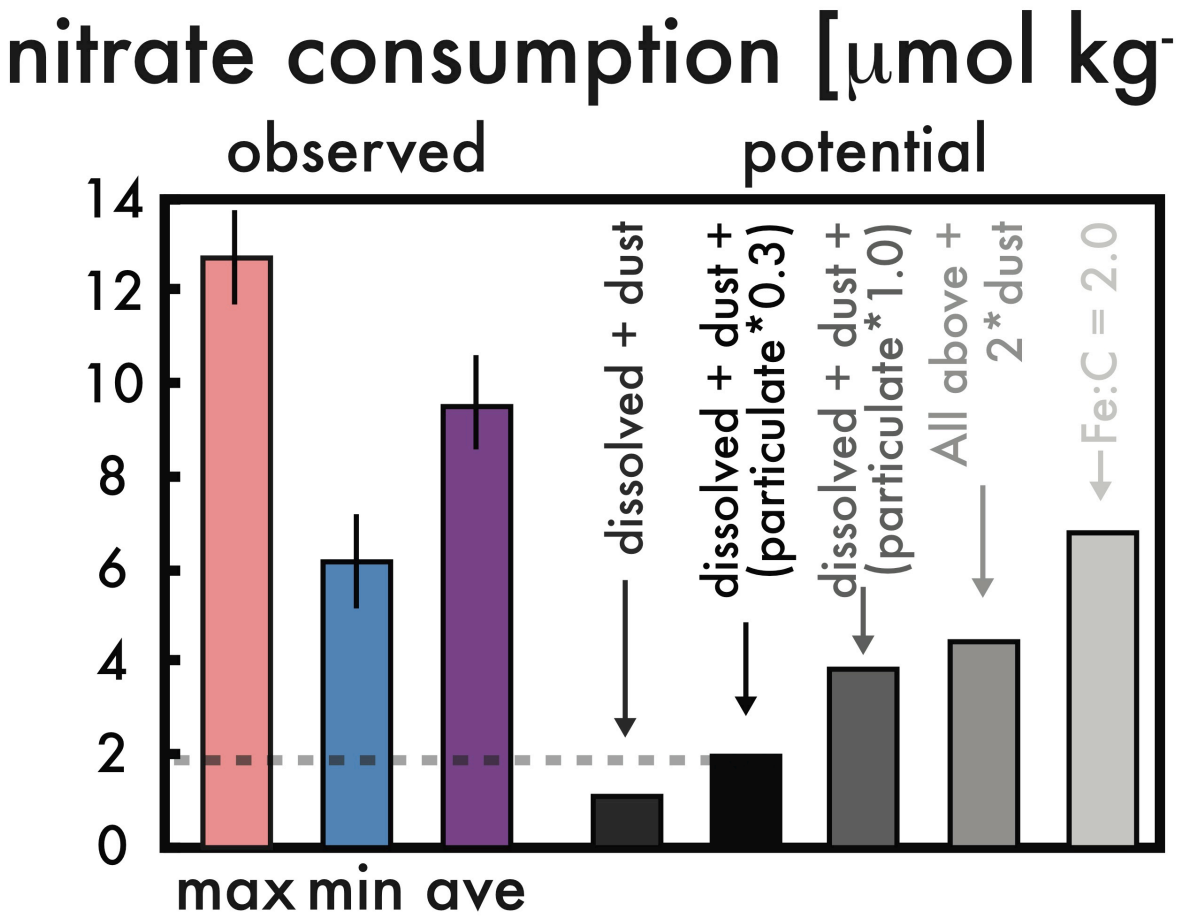


SECOND MYSTERY: why observed nitrate consumption so much higher than predicted nitrate consumption ?



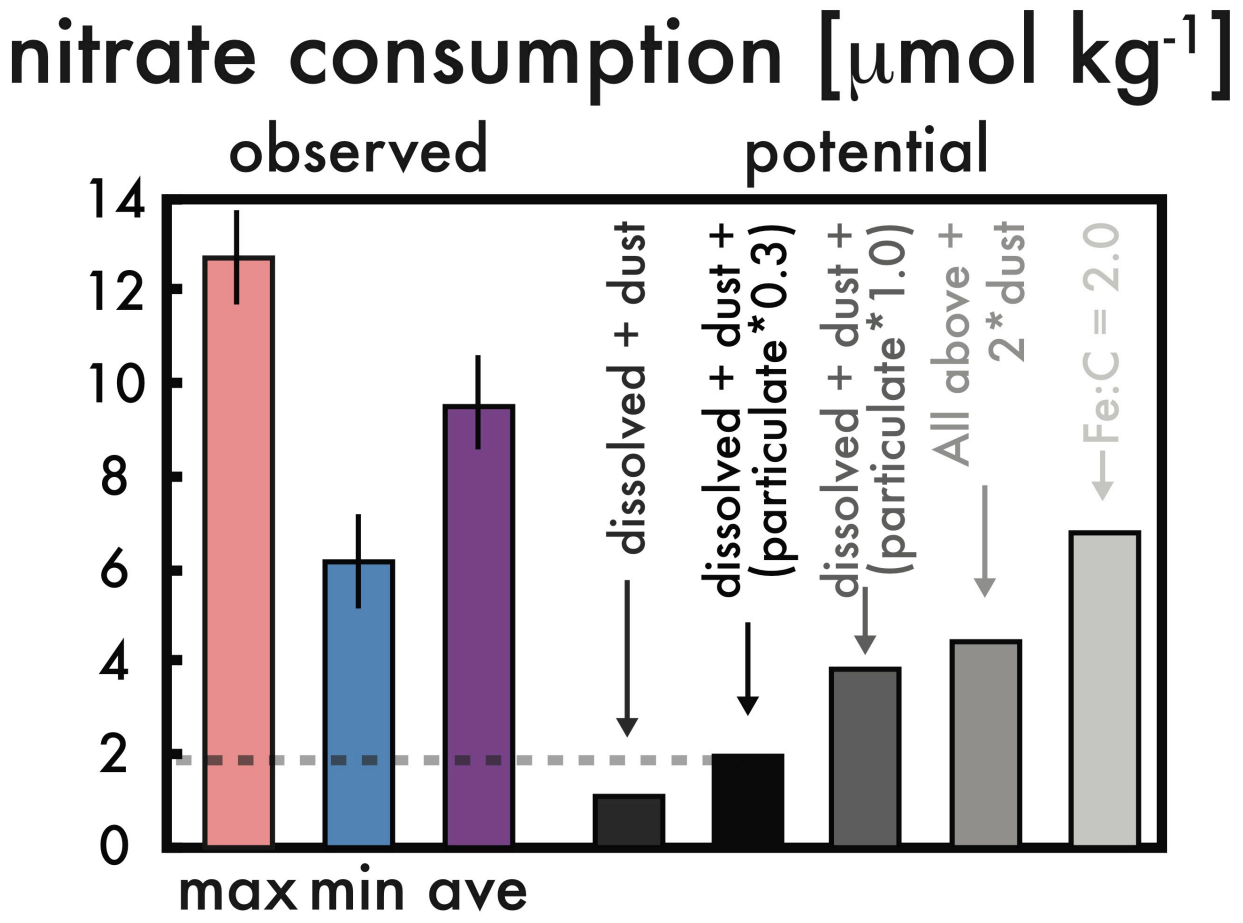
Sensitivity tests cannot replicate observed range of nitrate consumption

(Rafter et al. 2017)



these only consider diatom Fe requirements (<10% of biomass)

(*Taylor et al*. 2011)



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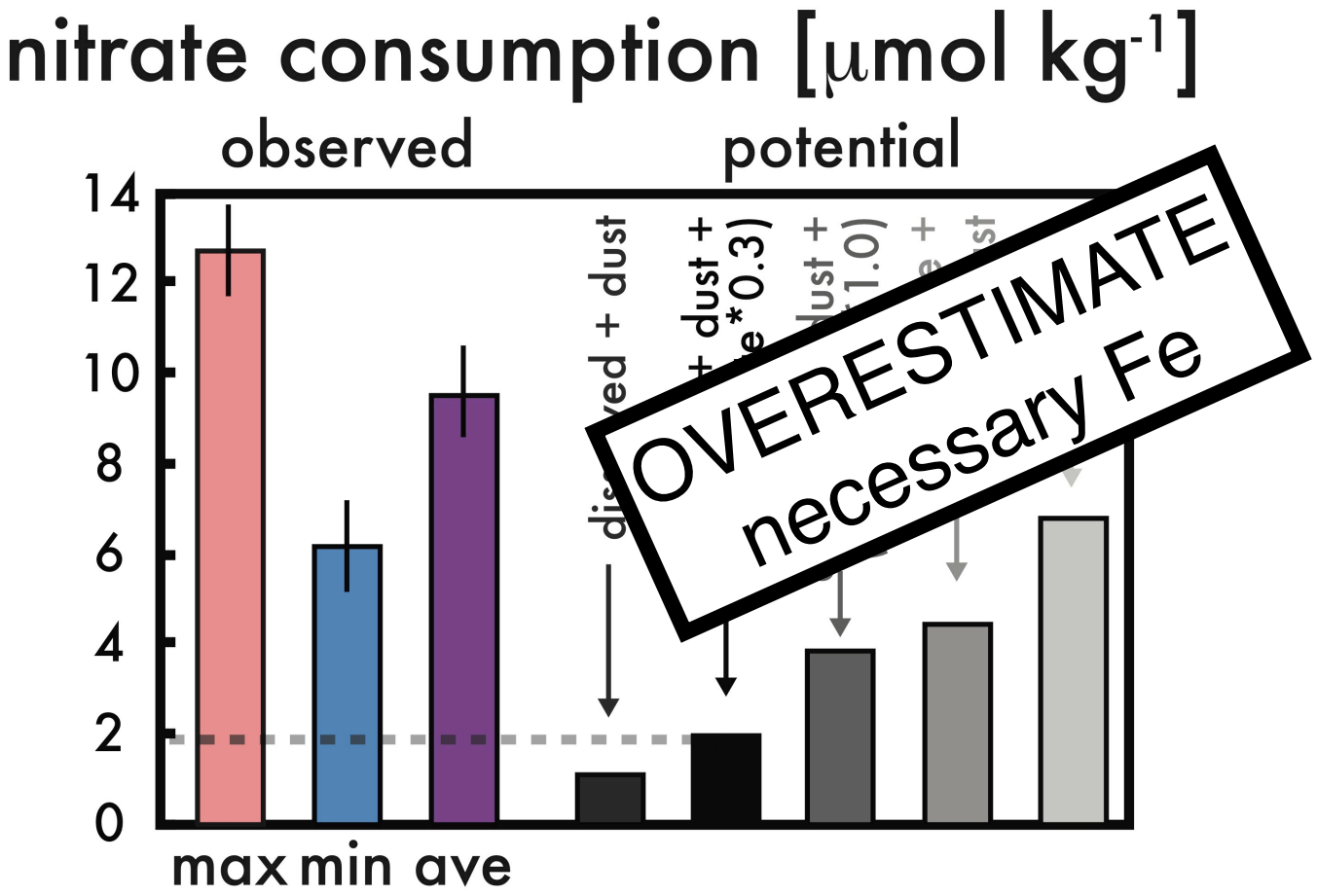
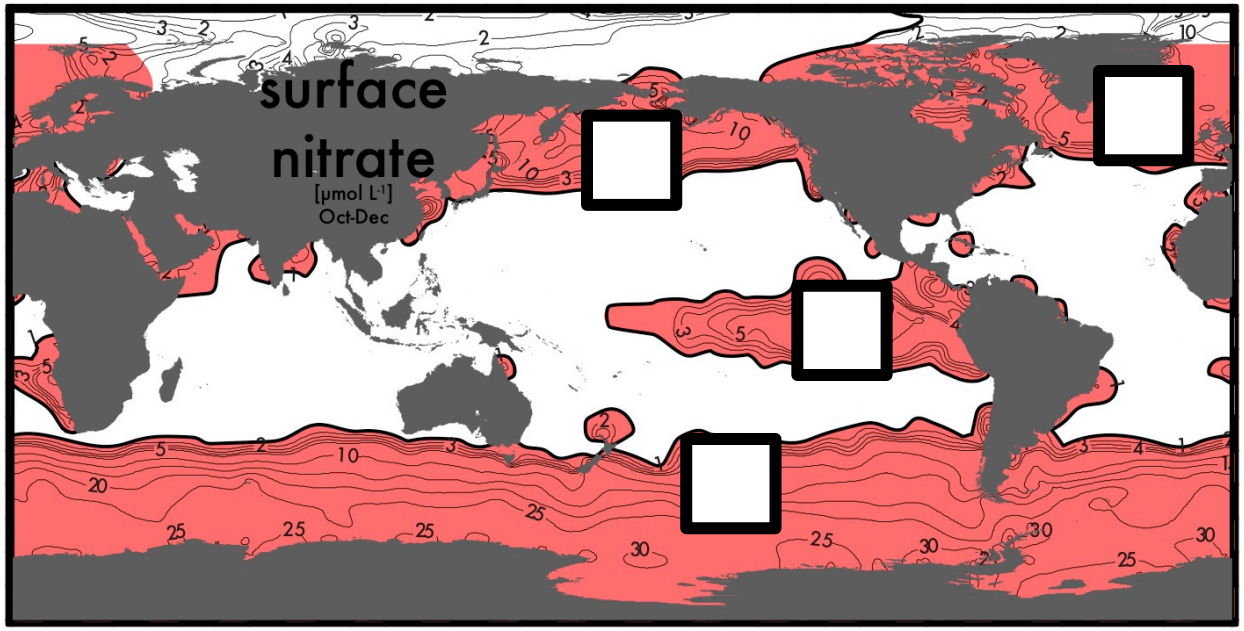


four iron-limited laboratories

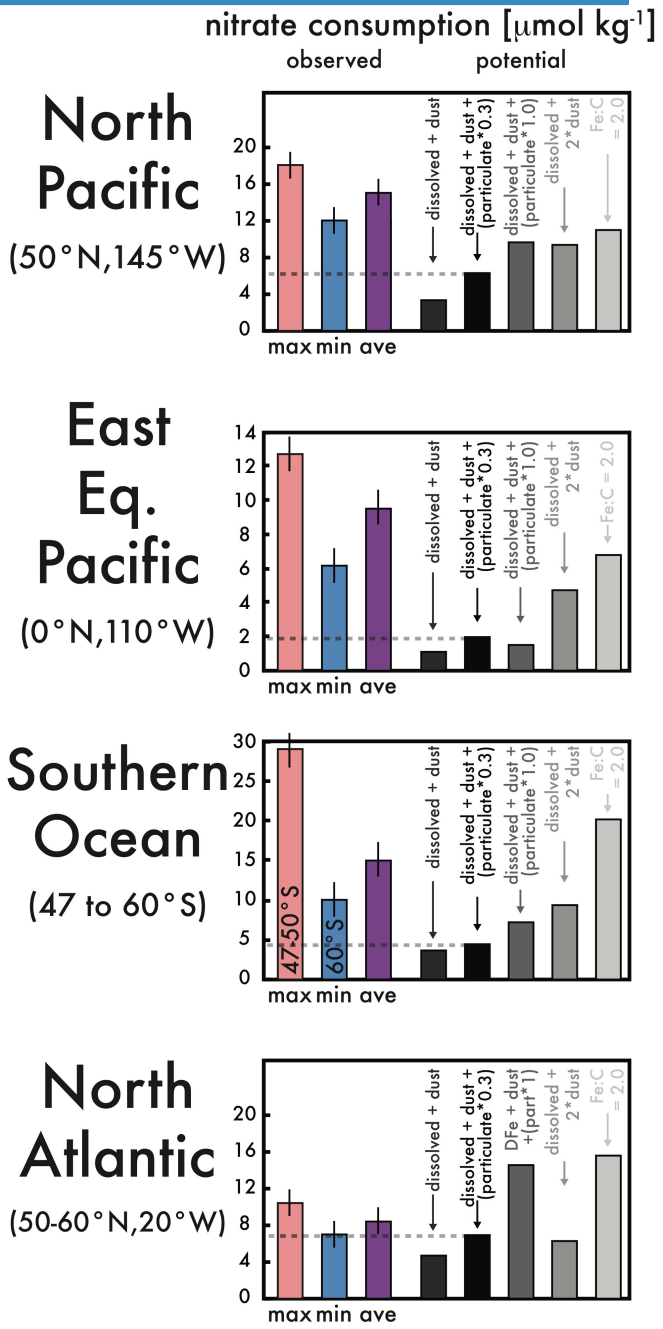


Quantify both observed and "potential" nitrate consumption (based on iron supply)

four iron-limited laboratories

Sensitivity tests cannot replicate observed range of nitrate consumption

(Rafter et al. 2017)



four iron-limited laboratories

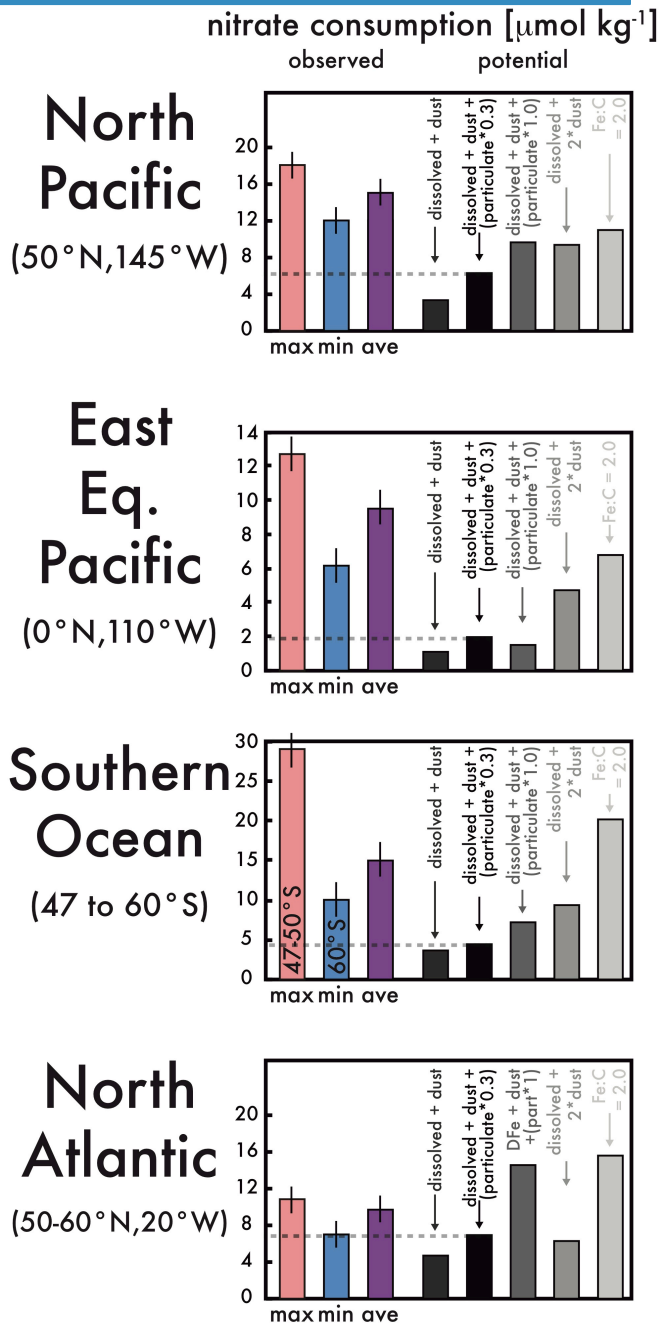
Sensitivity

OVERESTIMATE necessary Fe

observed

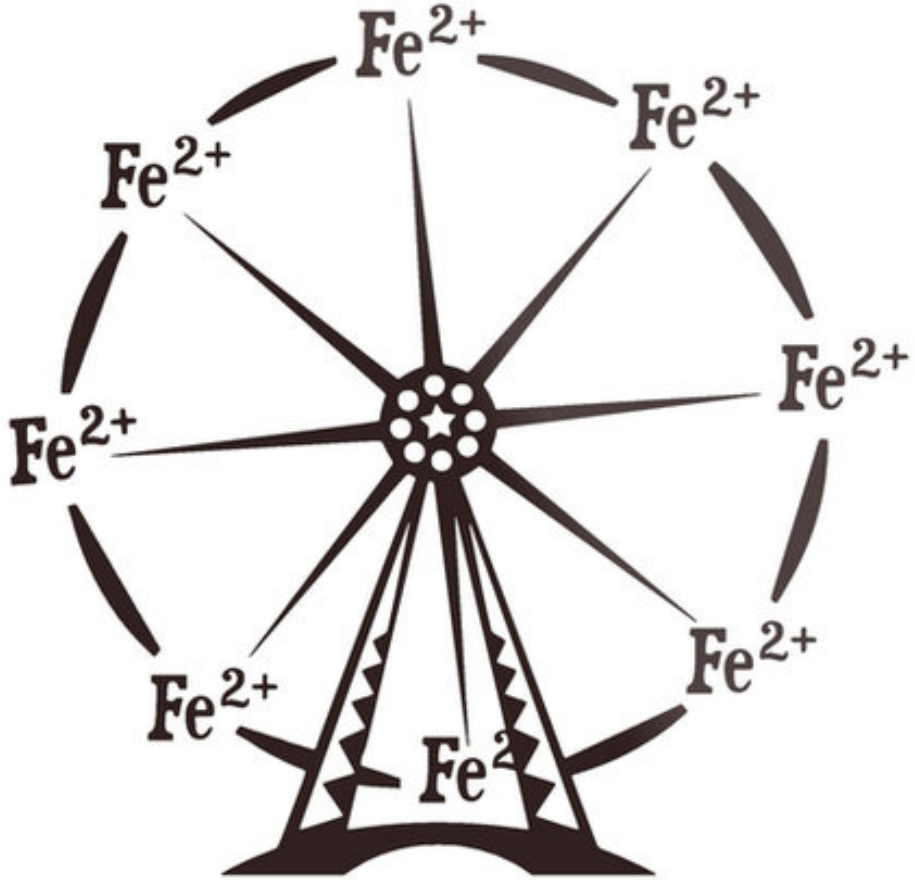
range of nitrate consumption

(Rafter et al. 2017)

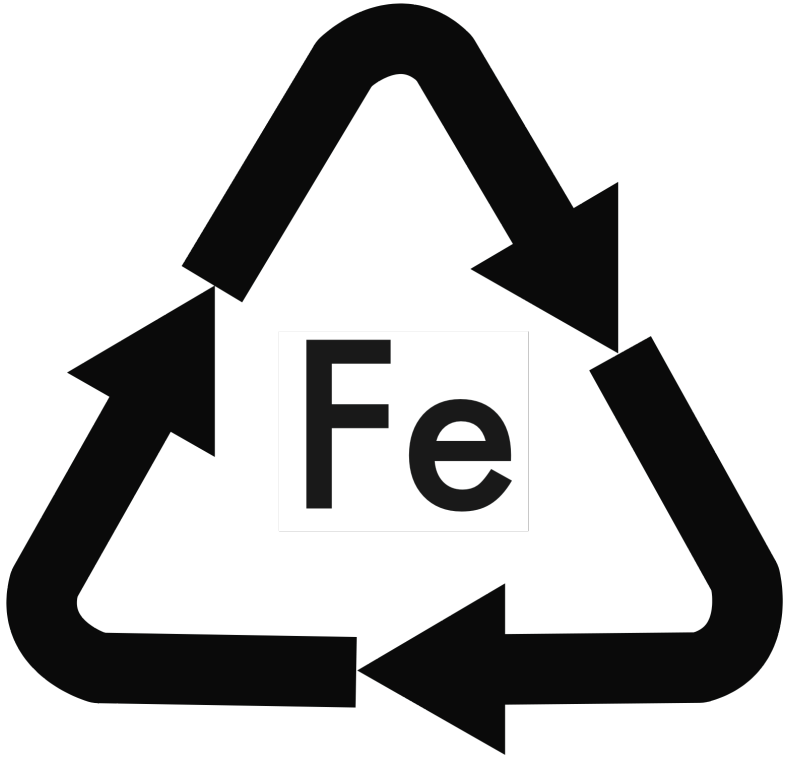


where is the “missing” iron**?**

riding the “Ferrous Wheel”

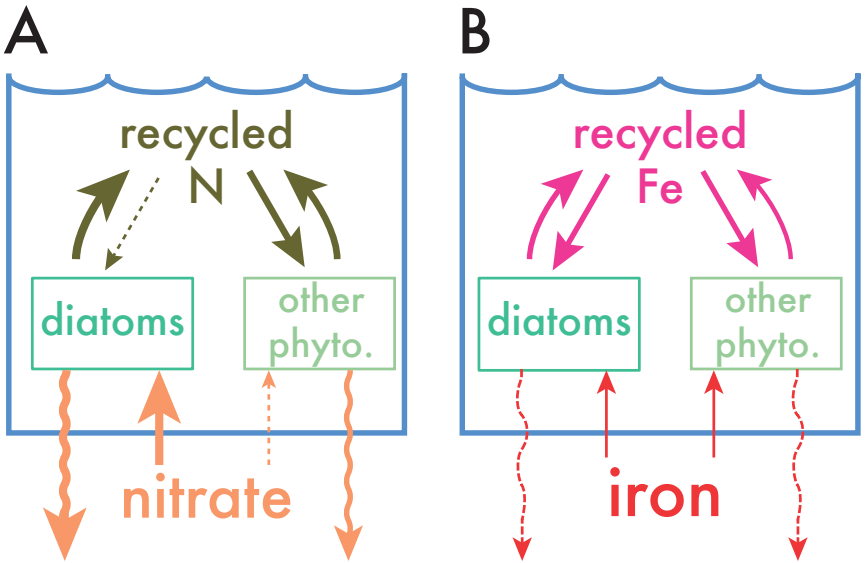


iron recycling—known knowns



- observed in equatorial and subantarctic Pacific (*Hutchins et al.* 1997; *Strzepek* 2005)
- large part of surface ocean iron budgets (*Strzepek* 2005; *Boyd* 2005)
- suspected to fuel diatom blooms (Southern Ocean: *Bowie* 2001)
- *never directly linked to nitrate consumption, new primary production, & biological pump*

put these ideas into a box model

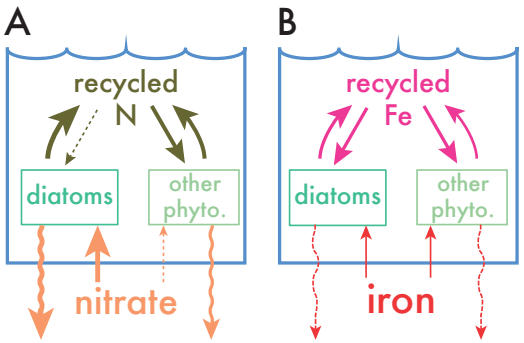


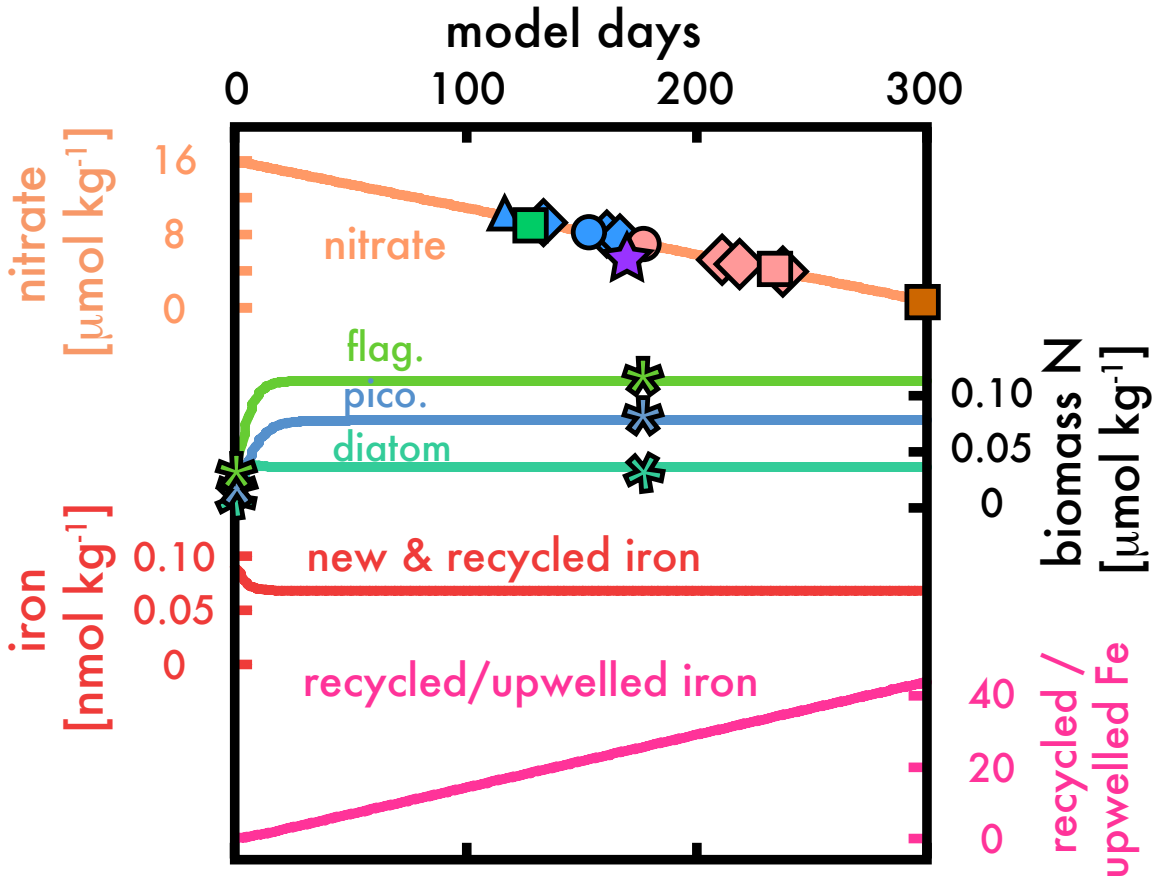
- Simulate upwelling to and along surface

- closed system
- 3 phytoplankton groups
- N and Fe recycling pathways

- Dynamic growth rates (Monod nutrient limitation)
- Mortality & grazing
- Fit to observed biomass

put these ideas into a box model

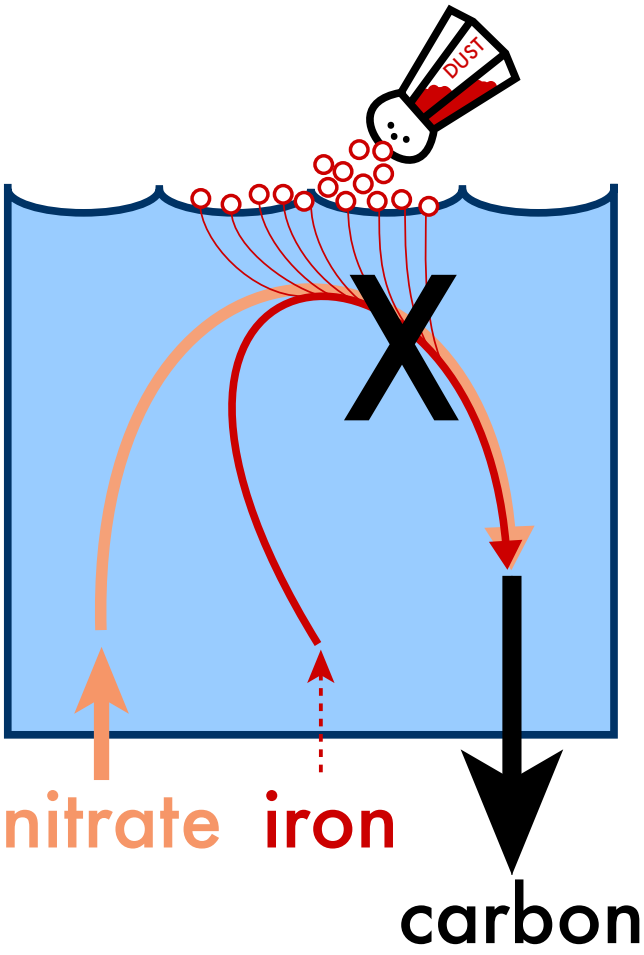




it can work

based on numerical models (Rafter et al. 2017)

original view

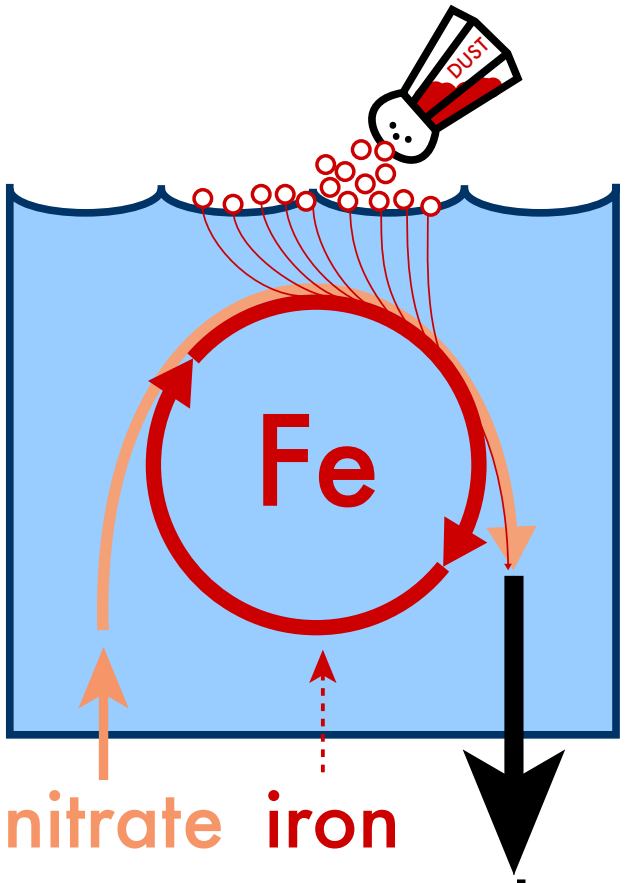


ADDED nutrients drive
biological pump efficiency

cannot
explain
nitrate
consumption
in major
HNLC
regions

new view

ADDED nutrients drive
biological pump efficiency



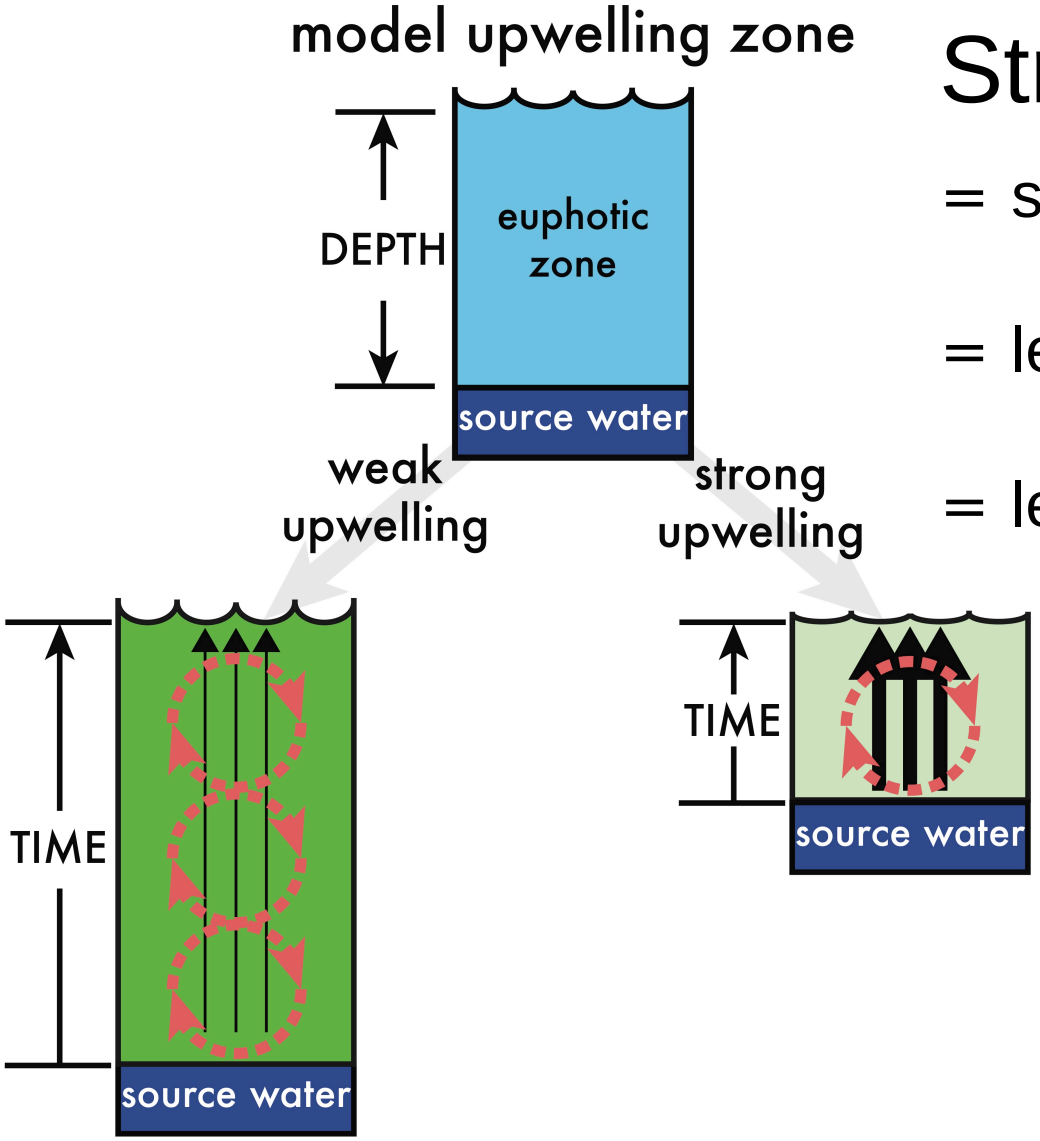
new and recycled nutrients
determine efficiency

SECOND MYSTERY: why observed
higher than predicted nitrate consumption ?

iron must be recycled / preferentially
retained in upper ocean

FIRST MYSTERY: relationship between
consumption and upwelling?

upwelling varies residence time



Stronger Upwelling

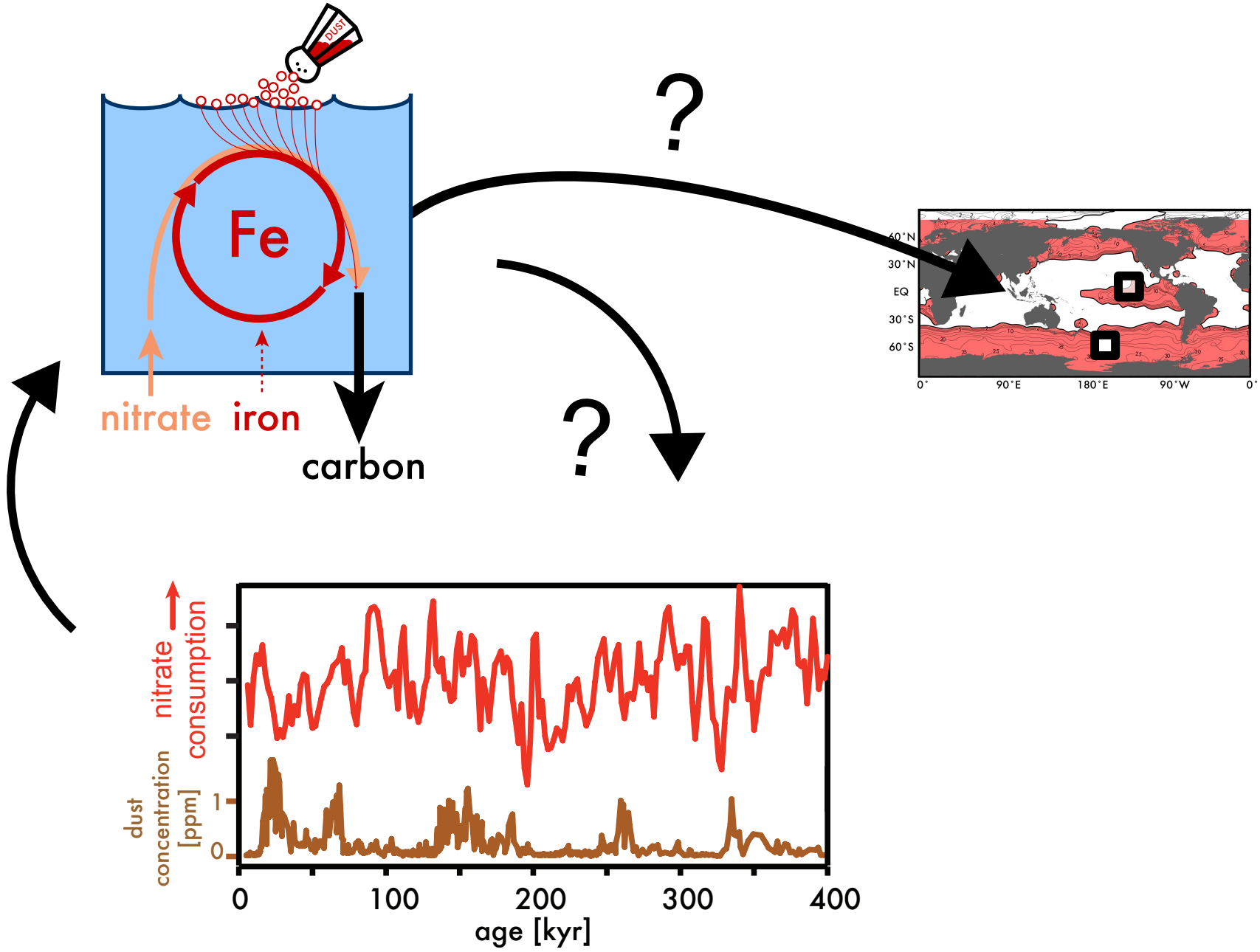
= shorter residence time

= less iron recycling

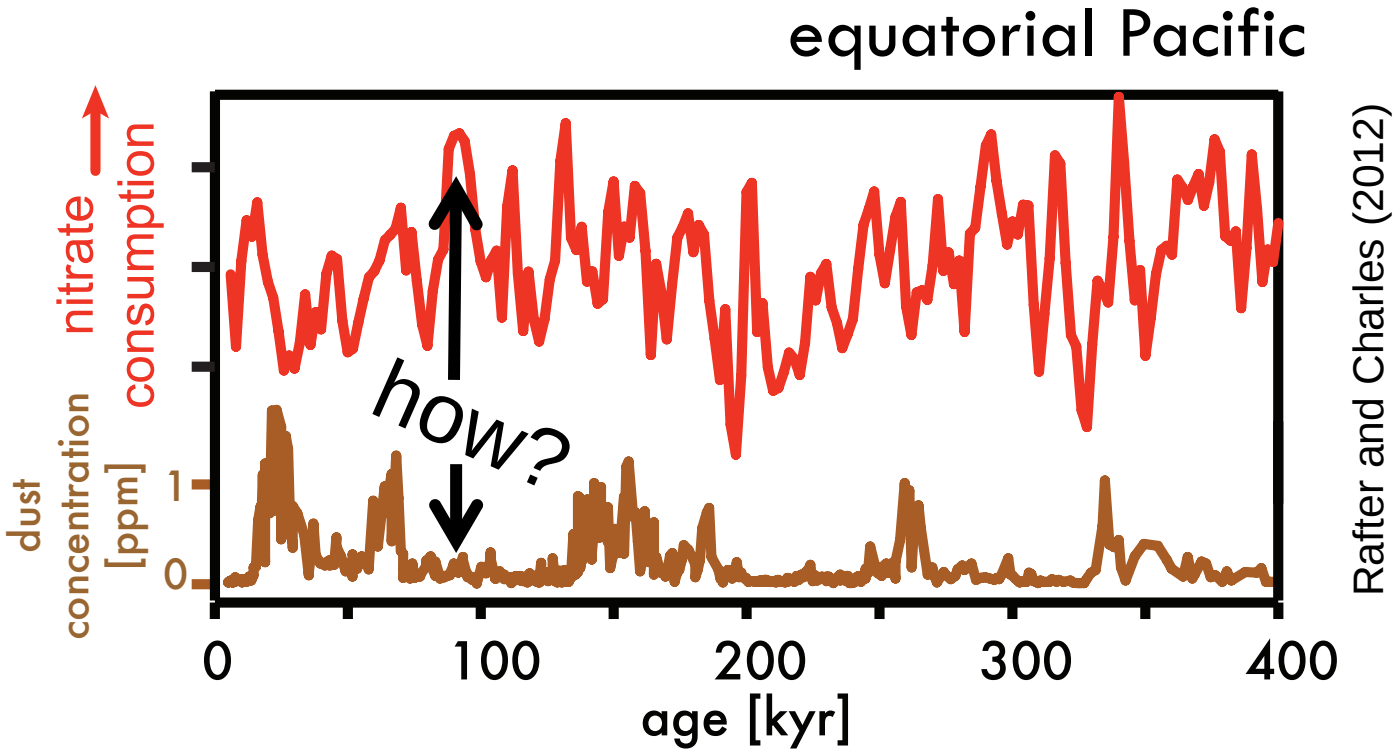
= less nitrate consumption

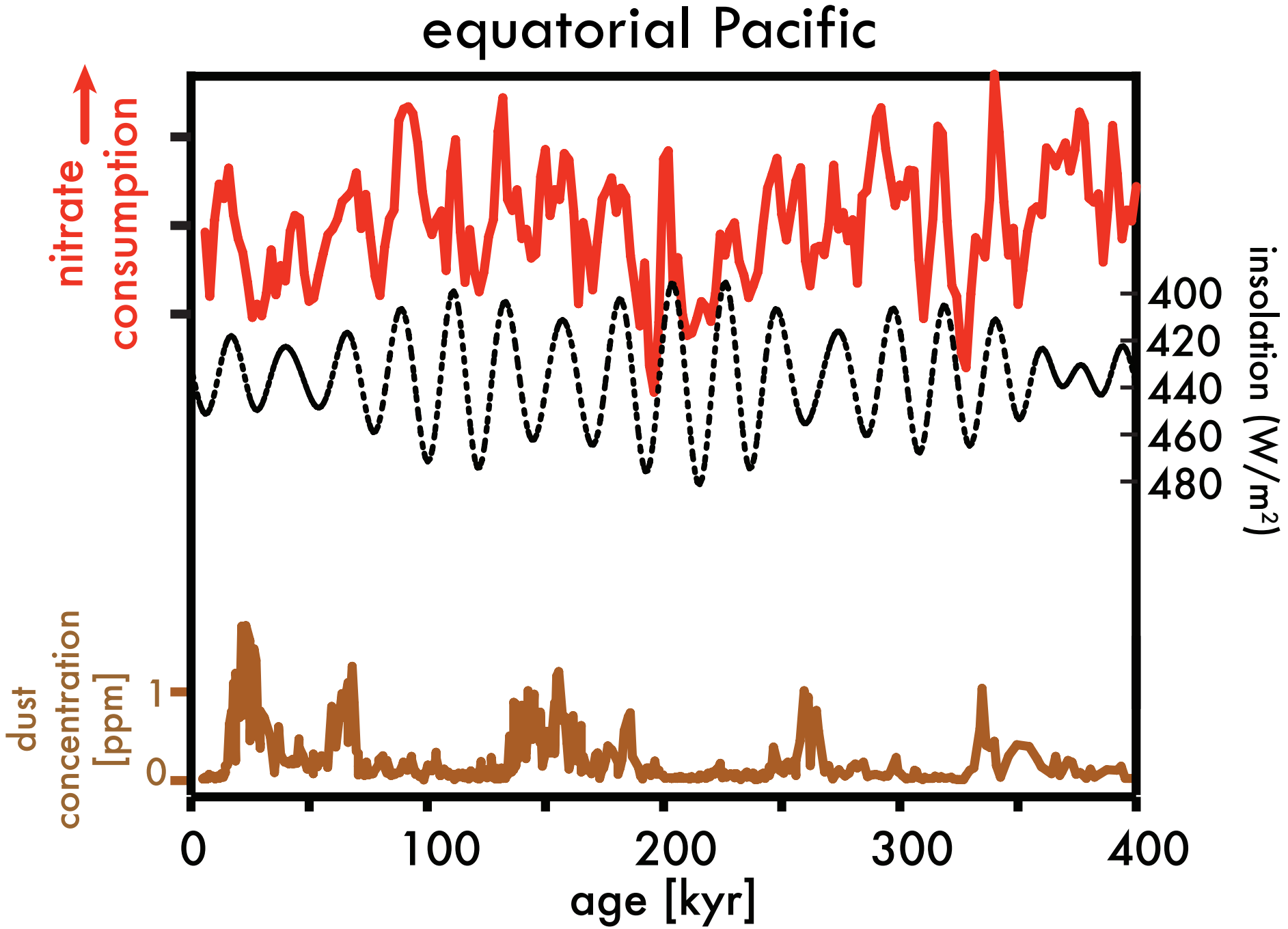
links ocean physics with biology and chemistry

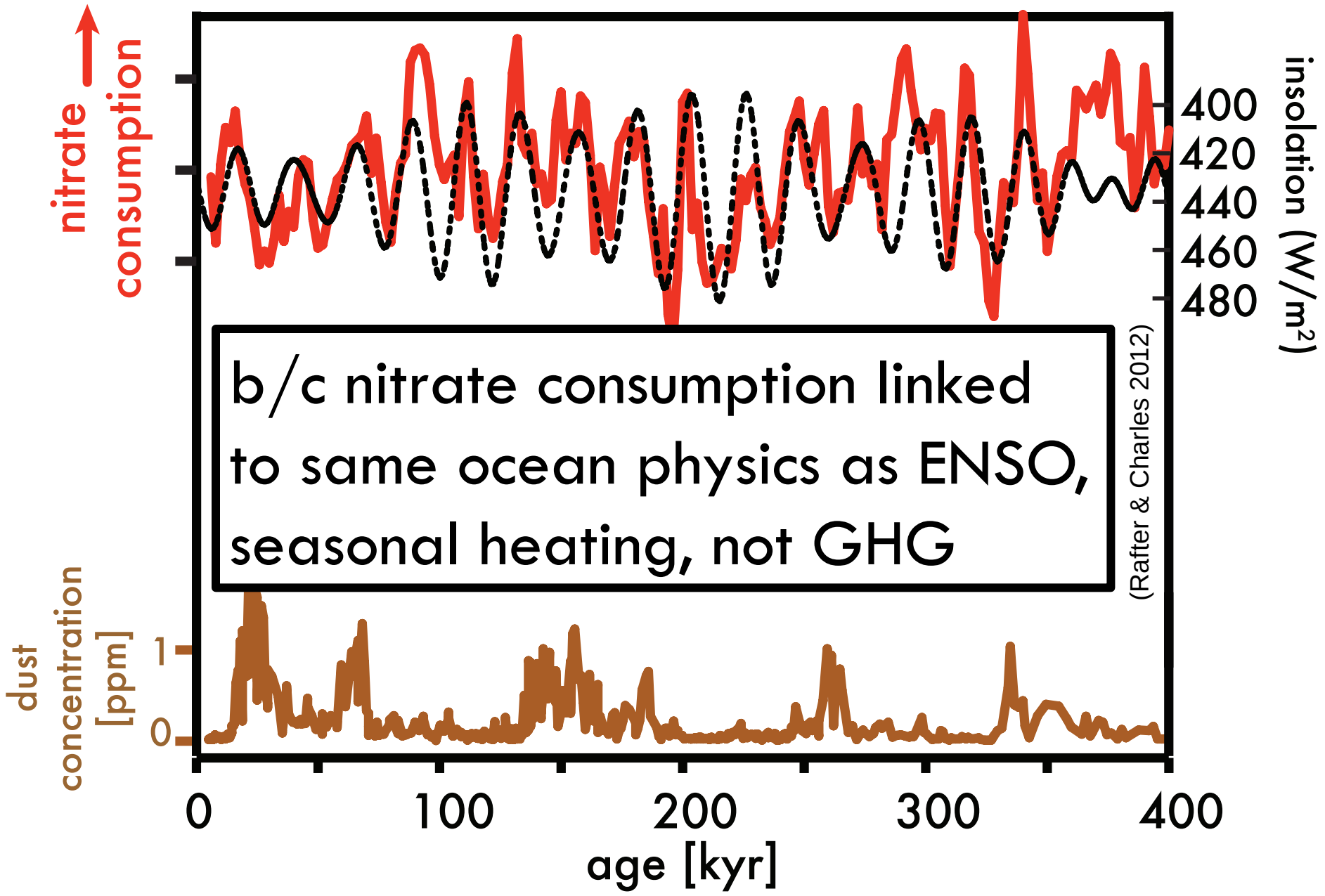
implications for paleoceanography



First insight: equatorial Pacific upwelling/nitrate consumption linked to seasonal heating (as I suspected)




equatorial Pacific
nitrate consumption
insolation (W/m²)
400
420
440
460
480
dust concentration [ppm]
1
0
0
100
200
300
400
age [kyr]


nitrate consumption
400
420
440
460
480
insolation (W/m²)
b/c nitrate consumption linked to same ocean physics as ENSO, seasonal heating, not GHG
(Rafter & Charles 2012)
dust concentration [ppm]
1
0
0
100
200
300
400
age [kyr]

SUMMARY

iron-recycling drives most primary production in iron-limited waters

upwelling rate (residence time) modulates extent of iron recycling and therefore nitrate consumption

helps explain several mysteries in modern biogeochemistry & paleoceanography

thanks

D. Sigman and K.R.M. Mackey

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prafter.com
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