

Revisiting sedimentary iron (Fe) flux to global ocean models

Kaz Misumi, D. Tsumune, T. Tsubono

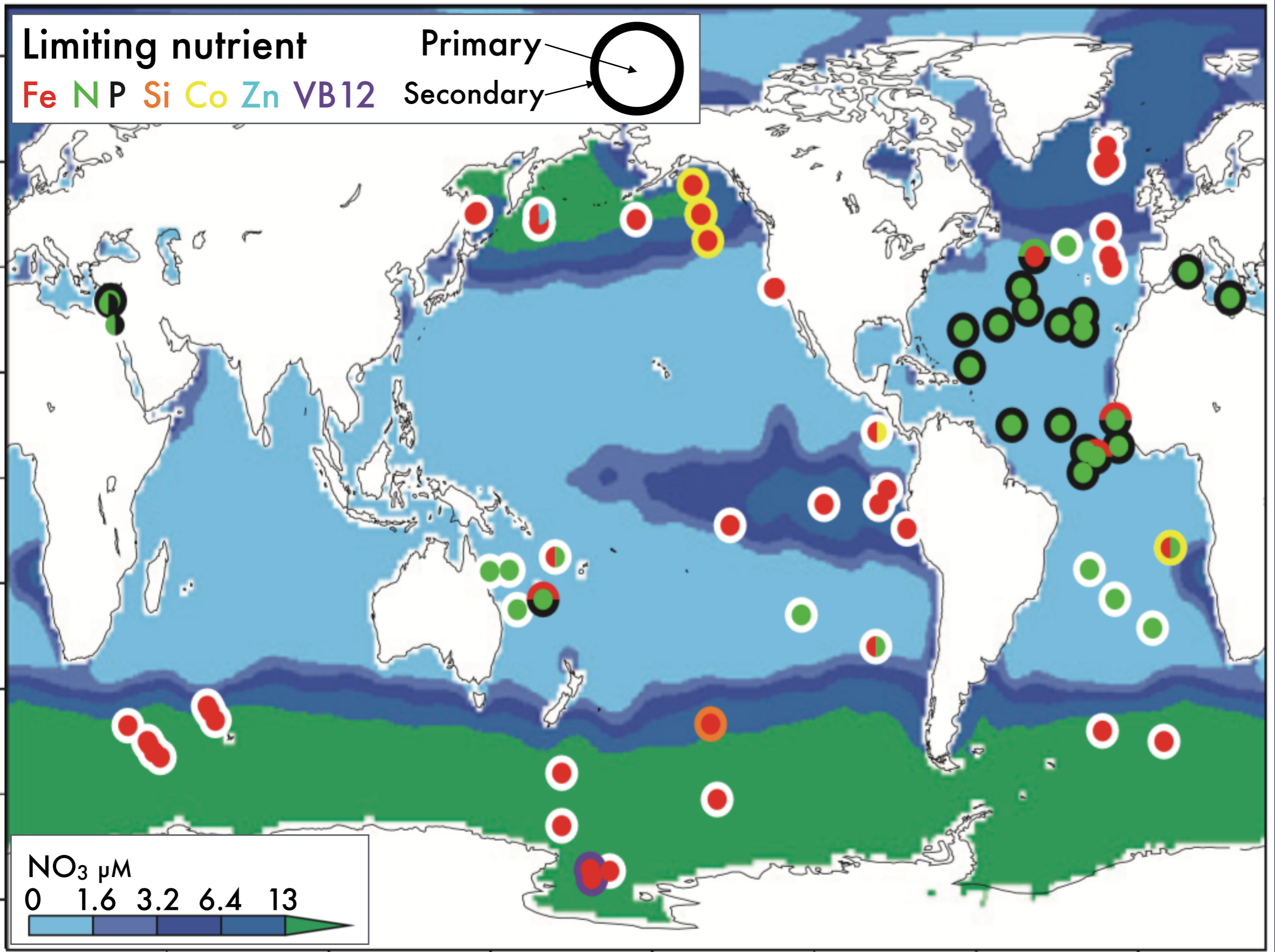
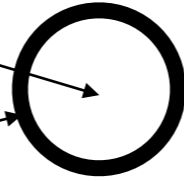
Central Research Institute of Electric Power Industry

Limiting nutrient

Fe N P Si Co Zn VB12

Primary

Secondary



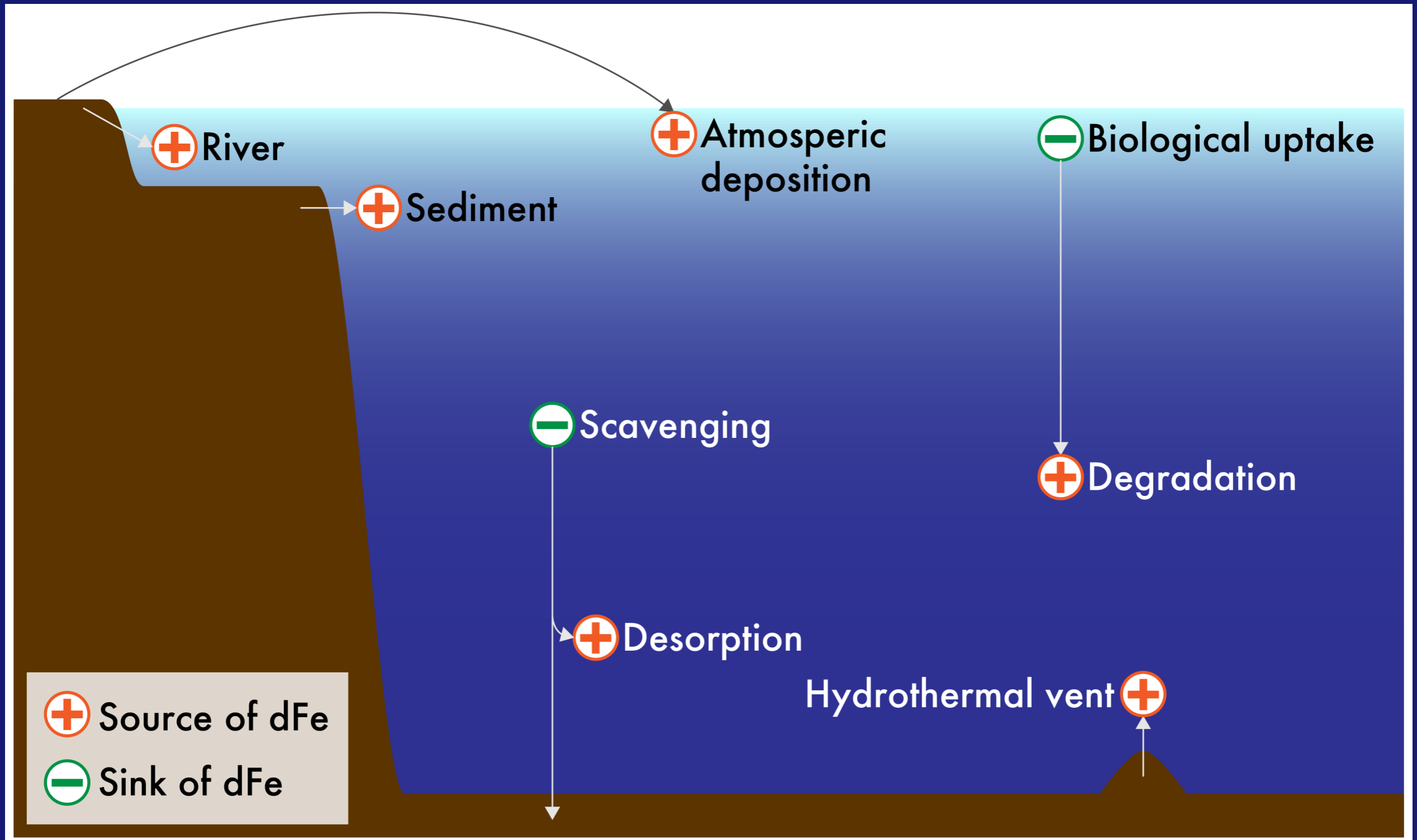
$\text{NO}_3 \mu\text{M}$

0 1.6 3.2 6.4 13



Moore et al. (2013)

Iron cycle in the ocean



Misumi & Tsumune (accepted, in Japanese)

Global Biogeochemical Cycles

RESEARCH ARTICLE

10.1002/2015GB005289

Key Points:

- First intercomparison of 13 global iron models highlights key challenges in reproducing iron data
- Wide uncertainty in iron input fluxes,

How well do global ocean biogeochemistry models simulate dissolved iron distributions?

Alessandro Tagliabue¹, Olivier Aumont², Ros DeAth³, John P. Dunne⁴, Stephanie Dutkiewicz⁵, Eric Galbraith^{6,7}, Kazuhiro Misumi⁸, J. Keith Moore⁹, Andy Ridgwell^{3,10}, Elliot Sherman⁹, Charles Stock⁴, Marcello Vichi^{11,12}, Christoph Völker¹³, and Andrew Yool¹⁴

Fe Sources (Gmol yr⁻¹)

Model	Fe Sources (Gmol yr ⁻¹)					Fe Inventory (×10 ¹¹ mol)	Average Fe (nmoles L ⁻¹)	Residence Time (years)
	Dust	Sediment	Hydrothermal	Rivers	Total			
BEC	21.9	84.6	17.7	0.34	124.5	10.1	0.74	8.1
BFM	1.4	0	0	0.06	1.4	8.8	0.65	626.3
BLING	3.3	9.1	0	0	12.4	5.3	0.37	42.4
COBALT	32.5	155	0	0	182.5	6.8	0.50	3.7
GENIE	1.8	0	0	0	1.8	10.1	0.48	560.0
MEDUSA1	2.7	0	0	0	2.7	6.3	0.46	232.0
MEDUSA2	3.4	2.9	0	0	6.8	4.8	0.35	69.9
MITecco	3.5	104	0	0	107.5	8.8	0.65	8.2
MITigsm	1.4	194	0	0	195.4	9.0	0.66	4.6
PISCES1	32.7	26.6	11.3	2.5	71.0	8.1	0.59	11.5
PISCES2	32.7	26.6	11.3	2.5	71.0	11.2	0.81	15.7
REcoM	3.7	0.6	0	0	4.3	12.5	0.73	291.6
TOPAZ	13.8	74.8	0	0	88.6	6.8	0.50	7.6
				Mean	66.9	8.3	0.58	144.7
				Standard deviation	67.1	2.2	0.14	175.8

Tagliabue et al. (2016)

FeMIP multi model mean & std dev.

Fe sources Gmol yr^{-1}					Avg. Fe	Resi.
Atmos.	Sedi.	Hydro.	Rivers	Total	nmol L^{-1}	time years
$11.9_{\pm 12.6}$	$67.8_{\pm 63.8}$	$13.4_{\pm 3.0}$	$1.35_{\pm 1.2}$	$67.6_{\pm 67.8}$	$0.58_{\pm 0.14}$	$145_{\pm 211}$

- The total Fe inputs are different 2 orders of magnitudes in $\pm 1 \sigma$.
- The avg. Fe is simulated well, obs. avg. is 0.62 nmol L^{-1} , and the inter-model difference is surprisingly small.
- The burden is placed on the residence time, this is a cause of large difference in the simulated Fe distribution among the models.

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Purpose of this study

Revisit sedimentary iron flux and try to make a dataset that is acceptable to many fe modelers.

We have made some prototype datasets, and tested them using CESM1.2.2, this talk introduces the preliminary results. Any advice is welcome.

Why iron comes from sediments?

Bottom
water

Oxidizer	Organic matter (CH ₂ O) ₁₀₆ (NH ₃) ₁₆ (H ₃ PO ₄)	ΔG° kJ molC ⁻¹
O ₂	(CH ₂ O) ₁₀₆ (NH ₃) ₁₆ (H ₃ PO ₄) + 138O ₂ → 106CO ₂ + 16HNO ₃ + H ₃ PO ₄ + 122H ₂ O	-480
NO ₃	(CH ₂ O) ₁₀₆ (NH ₃) ₁₆ (H ₃ PO ₄) + 94.4HNO ₃ → 106CO ₂ + 55.2N ₂ + H ₃ PO ₄ + 177.2H ₂ O	-450
Mn(IV)	(CH ₂ O) ₁₀₆ (NH ₃) ₁₆ (H ₃ PO ₄) + 212MnO ₂ → 212Mn ²⁺ + 106CO ₃ ²⁻ + 212OH ⁻ + 16NH ₃ + H ₃ PO ₄	-241
Fe(III)	(CH ₂ O) ₁₀₆ (NH ₃) ₁₆ (H ₃ PO ₄) + 212Fe ₂ O ₃ → 424Fe ²⁺ + 106CO ₃ ²⁻ + 636OH ⁻ + 16NH ₃ + H ₃ PO ₄	-150
SO ₄	(CH ₂ O) ₁₀₆ (NH ₃) ₁₆ (H ₃ PO ₄) + 53SO ₄ ²⁻ → 53H ₂ S + 106HCO ₃ ⁻ + 16NH ₃ + H ₃ PO ₄	-77
Methane fermentation	(CH ₂ O) ₁₀₆ (NH ₃) ₁₆ (H ₃ PO ₄) → 53CO ₂ + 53CH ₄ + 16NH ₃ + H ₃ PO ₄	-62

Sediments

after Masuzawa (2005) in Japanese

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NO_3	$(\text{CH}_2\text{O})_{106}(\text{NH}_3)_{16}(\text{H}_3\text{PO}_4) + 94.4\text{HNO}_3$ $\rightarrow 106\text{CO}_2 + 55.2\text{N}_2 + \text{H}_3\text{PO}_4 + 177.2\text{H}_2\text{O}$	-450
Mn(IV)	$(\text{CH}_2\text{O})_{106}(\text{NH}_3)_{16}(\text{H}_3\text{PO}_4) + 212\text{MnO}_2$ $\rightarrow 212\text{Mn}^{2+} + 106\text{CO}_3^{2-} + 212\text{OH}^- + 16\text{NH}_3 + \text{H}_3\text{PO}_4$	-241
Fe(III)	$(\text{CH}_2\text{O})_{106}(\text{NH}_3)_{16}(\text{H}_3\text{PO}_4) + 212\text{Fe}_2\text{O}_3$ $\rightarrow 424\text{Fe}^{2+} + 106\text{CO}_3^{2-} + 636\text{OH}^- + 16\text{NH}_3 + \text{H}_3\text{PO}_4$	Fe(II) -150
SO_4	$(\text{CH}_2\text{O})_{106}(\text{NH}_3)_{16}(\text{H}_3\text{PO}_4) + 53\text{SO}_4^{2-}$ $\rightarrow 53\text{H}_2\text{S} + 106\text{HCO}_3^- + 16\text{NH}_3 + \text{H}_3\text{PO}_4$	-77
Methane fermentation	$(\text{CH}_2\text{O})_{106}(\text{NH}_3)_{16}(\text{H}_3\text{PO}_4)$ $\rightarrow 53\text{CO}_2 + 53\text{CH}_4 + 16\text{NH}_3 + \text{H}_3\text{PO}_4$	-62

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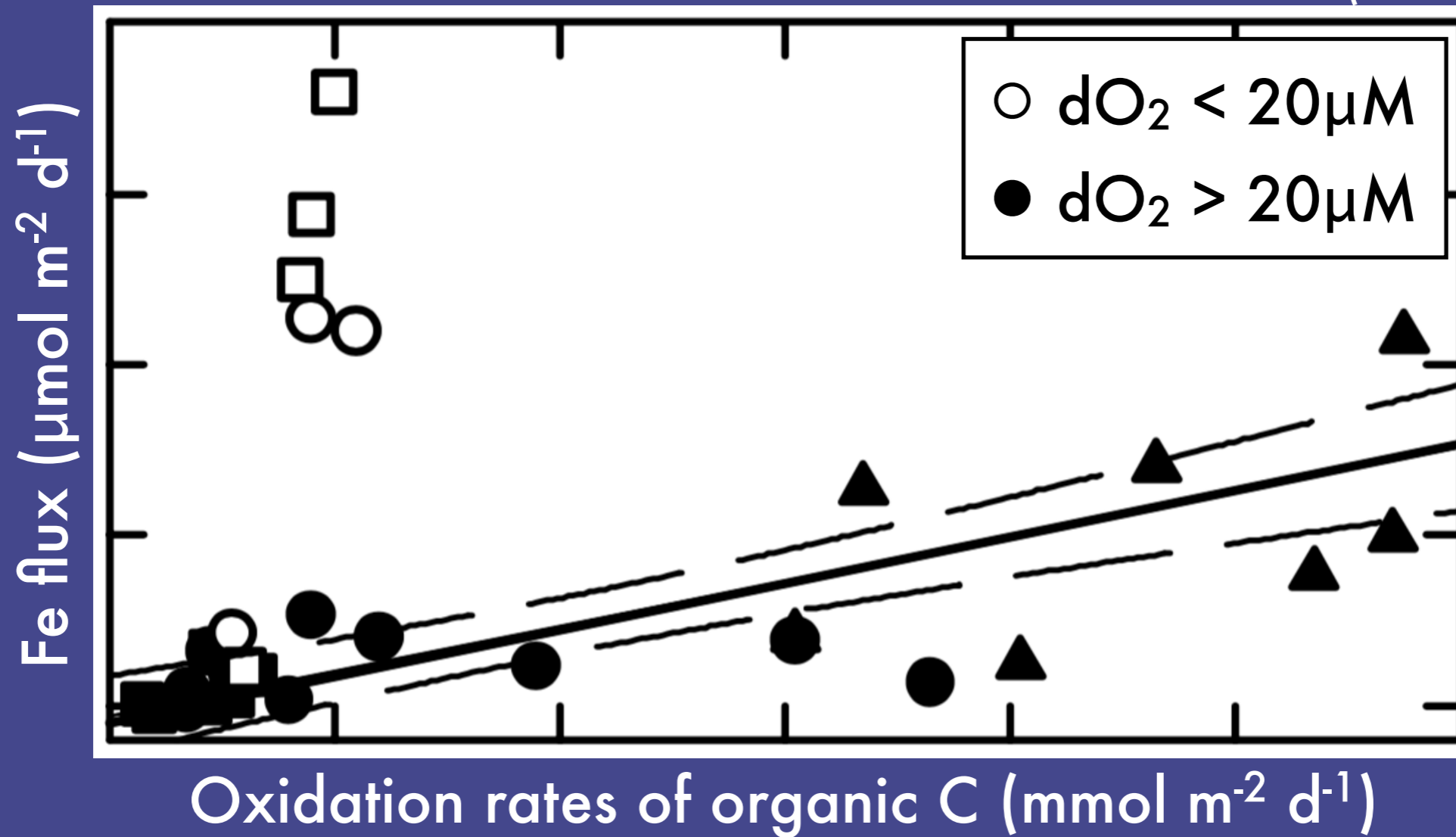
Sediments

Fe(II)

after Masuzawa (2005) in Japanese

Why iron comes from sediments?


Elrod et al. (2004)



$$\text{SedFe} = 0.68 \times C_{\text{ox}} - 0.5$$

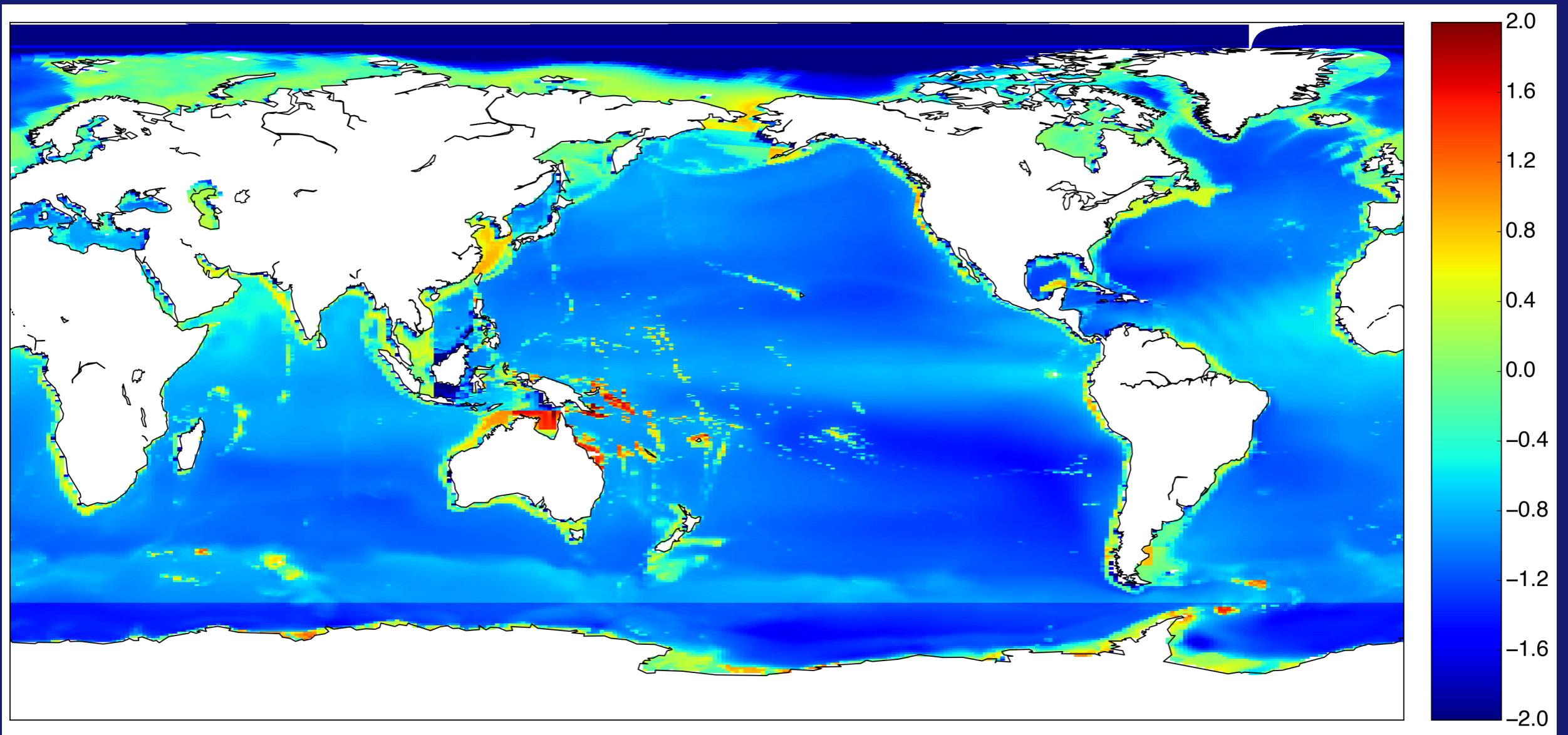
$(\mu\text{molFe m}^{-2} \text{d}^{-1} / \text{mmol m}^{-2} \text{d}^{-1})$ $(\mu\text{molFe m}^{-2} \text{d}^{-1})$

Procedure to calculate sed Fe in CESM

1. Run CESM w/ the first guess of sed Fe.
 2. Obtain Particulate Organic Carbon flux.
 3. Calculate POC flux reaching to the seafloor.
 4. Calculate sed Fe by multiplying $0.68 \mu\text{molFe m}^{-2} \text{d}^{-1} / \text{mmolC m}^{-2} \text{d}^{-1}$.
 5. Return to 1. w/ the next guess of sed Fe.
- 

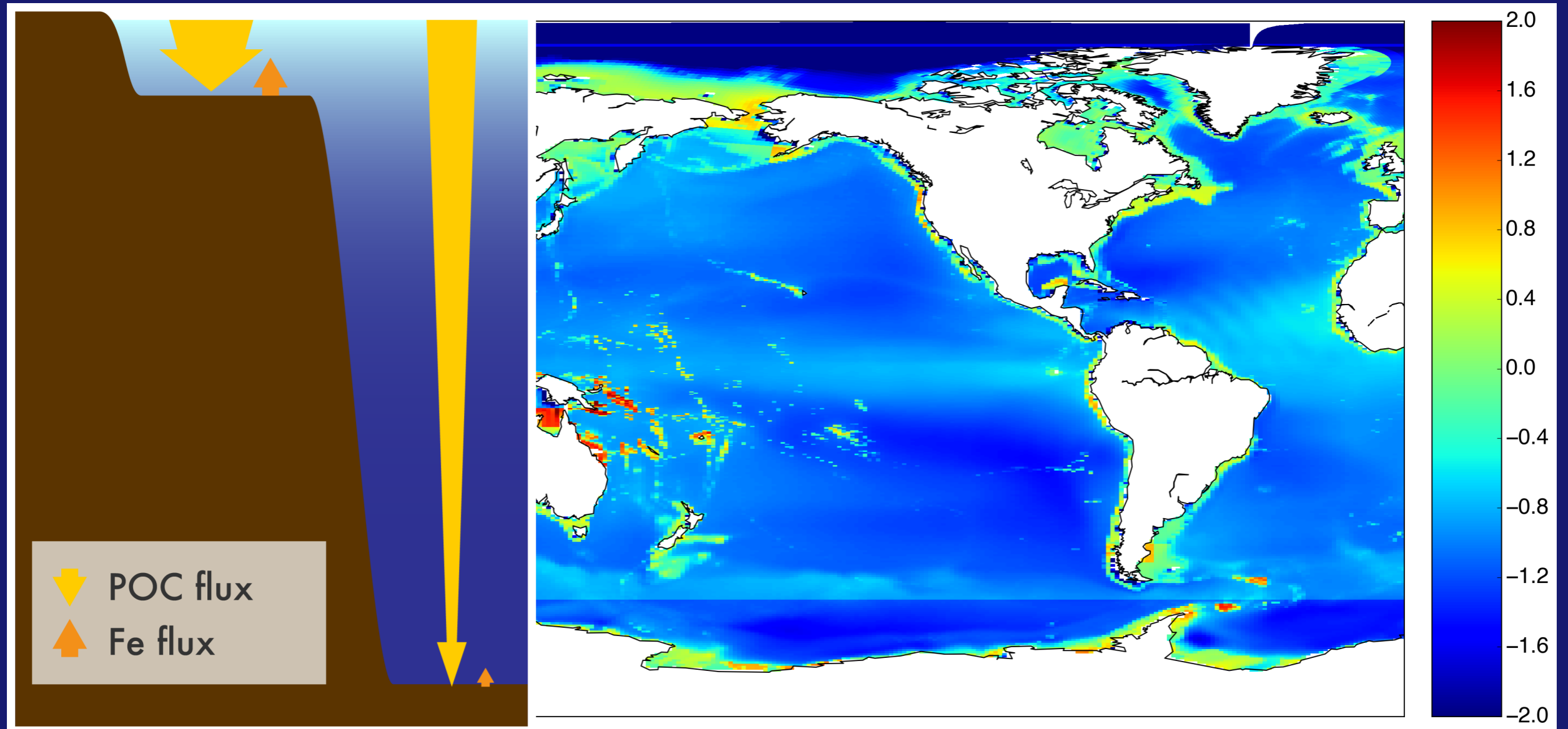
Moore & Braucher (2008)

Sed fe in CESM 1.2.2




$\log_{10} (\text{sed Fe in } \mu\text{mol m}^{-2} \text{d}^{-1})$

Sed fe in CESM 1.2.2



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Potential problems in this approach

1. Run CESM w/ the first guess of sed Fe.
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Potential problems in this approach

1. Run CESM w/ the first guess of sed Fe.

2. Obtain **Particulate Organic Carbon** flux.

3. Calculat

1. Coarse res. global models usually underestimate NPP & POC where sed Fe fluxes are large.

4. Calculat

2. Even if the procedure is the same, the estimated sed Fe varies among the models.

5. Return to 1. w/ the next guess of sed Fe.

A new approach to calculate sed Fe

1. Calculate N_{et} P_{Primary} $P_{\text{Productivity}}$ from satellite data

Behrenfeld & Falkowski, (1997).

2. Convert NPP to E_{Export} $P_{\text{Production}}$ using an empirical relationship Dunne et al. (2005).

3. Calculate POC flux reaching to the seafloor

Martin et al. (1987).

4. Calculate sed Fe by multiplying $0.68 \mu\text{molFe m}^{-2} \text{d}^{-1} / \text{mmolC m}^{-2} \text{d}^{-1}$.

Correcting sed Fe considering bottom water properties

Bottom water

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Sediments

Fe(II)

after Masuzawa (2005) in Japanese

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Sediments

after Masuzawa (2005) in Japanese

Correcting sed Fe considering bottom water properties

The oxidation rates depend on dO_2 , Temp, Salt and pH.

Bottom water

Sediments

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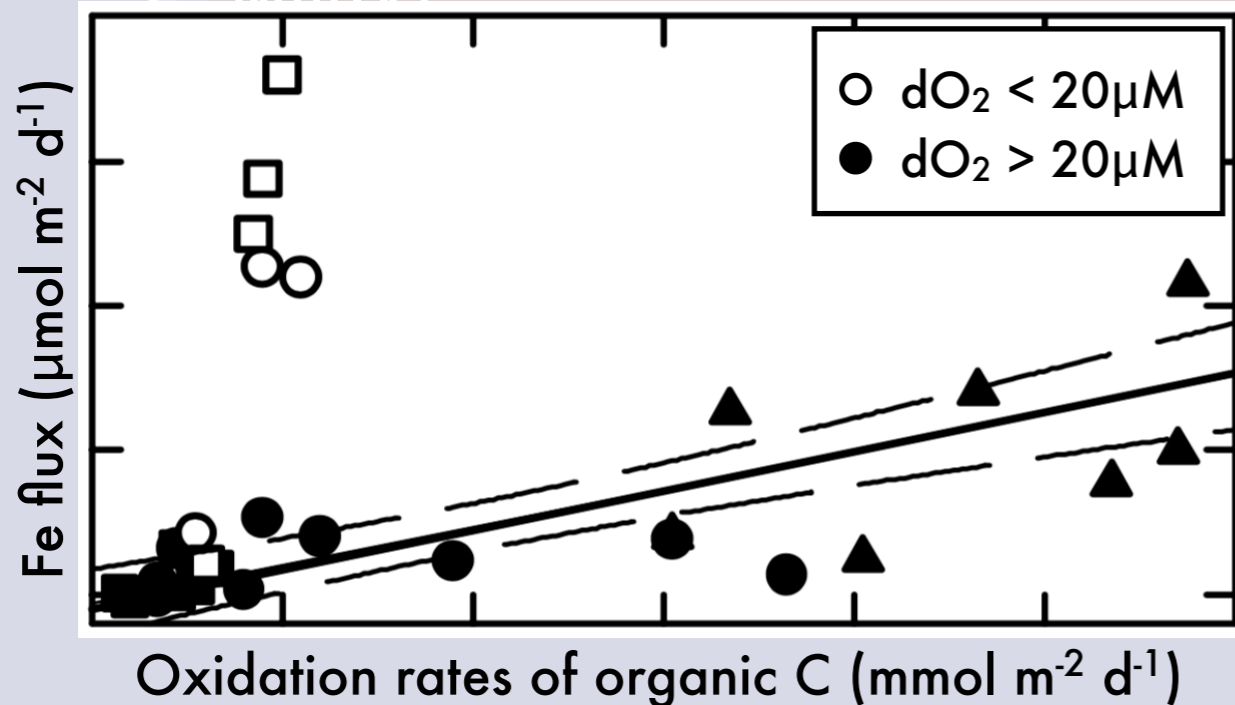
after Masuzawa (2005) in Japanese

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	$(CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + H_3PO_4$ $\rightarrow 106CO_2 + 16NH_3 + H_3PO_4$		-62



after Masuzawa (2005) in Japanese

Correcting **sed Fe** considering bottom water properties

$$\log_{10} k'_{ox} = 35.407 - 6.7109\text{pH} + 0.5342\text{pH}^2 - \frac{5362.6}{T_k} - 0.04406S^{0.5} - 0.002847S$$

$$k_{ox} = k'_{ox} \frac{O_2}{O_{2\text{sat}}} \quad [\text{sec}^{-1}]$$

Tagliabue et al. (2011)

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Tagliabue et al. (2011)

$$f_{bt} = \left(\frac{k_{ox}}{k_{ox@CA}} \right)^{-1}$$

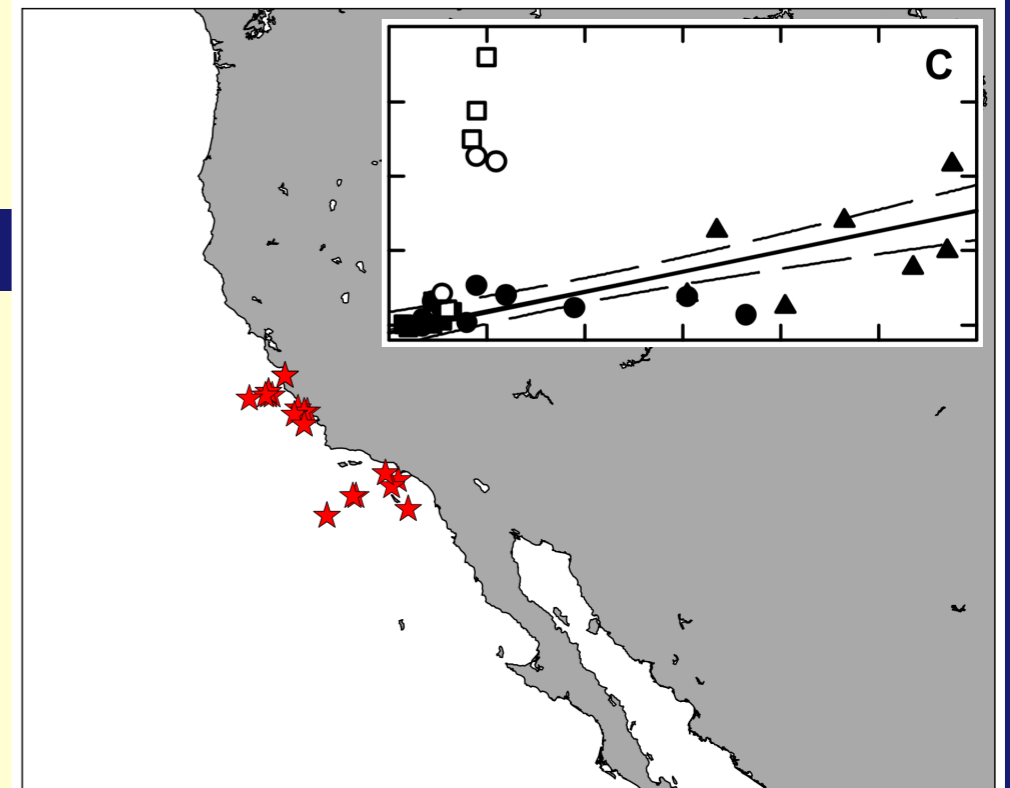
This study

Correcting sed Fe considering bottom water properties

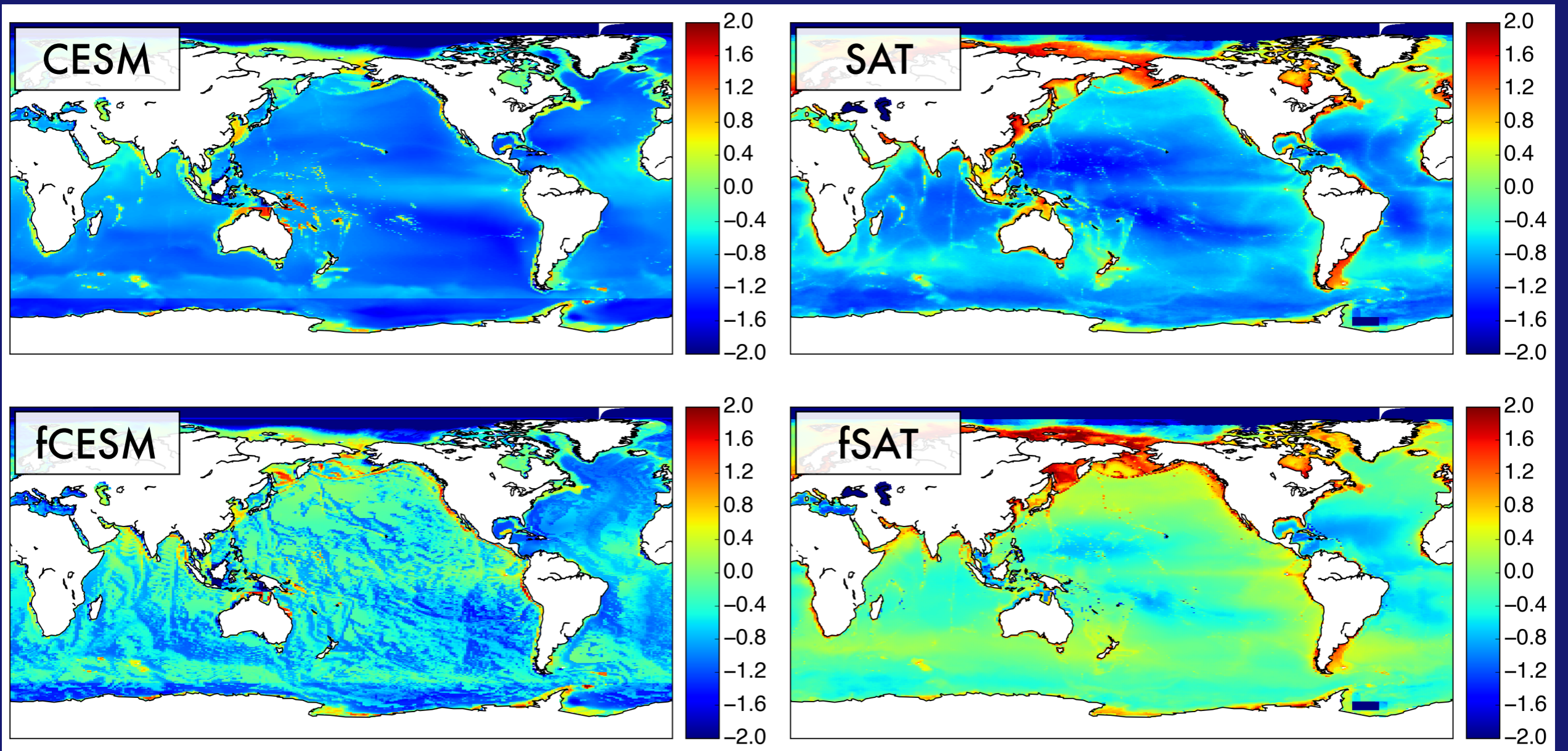
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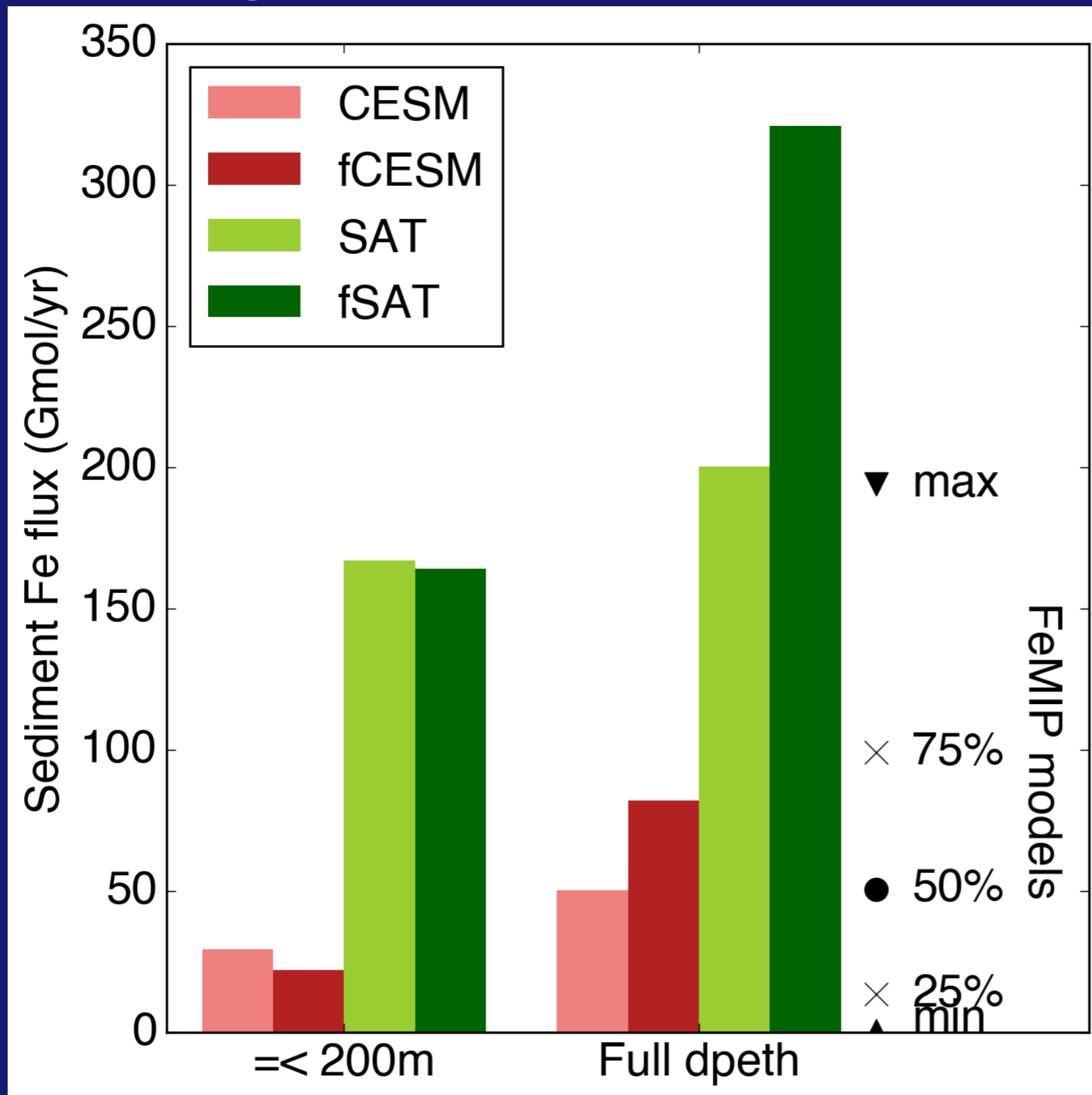
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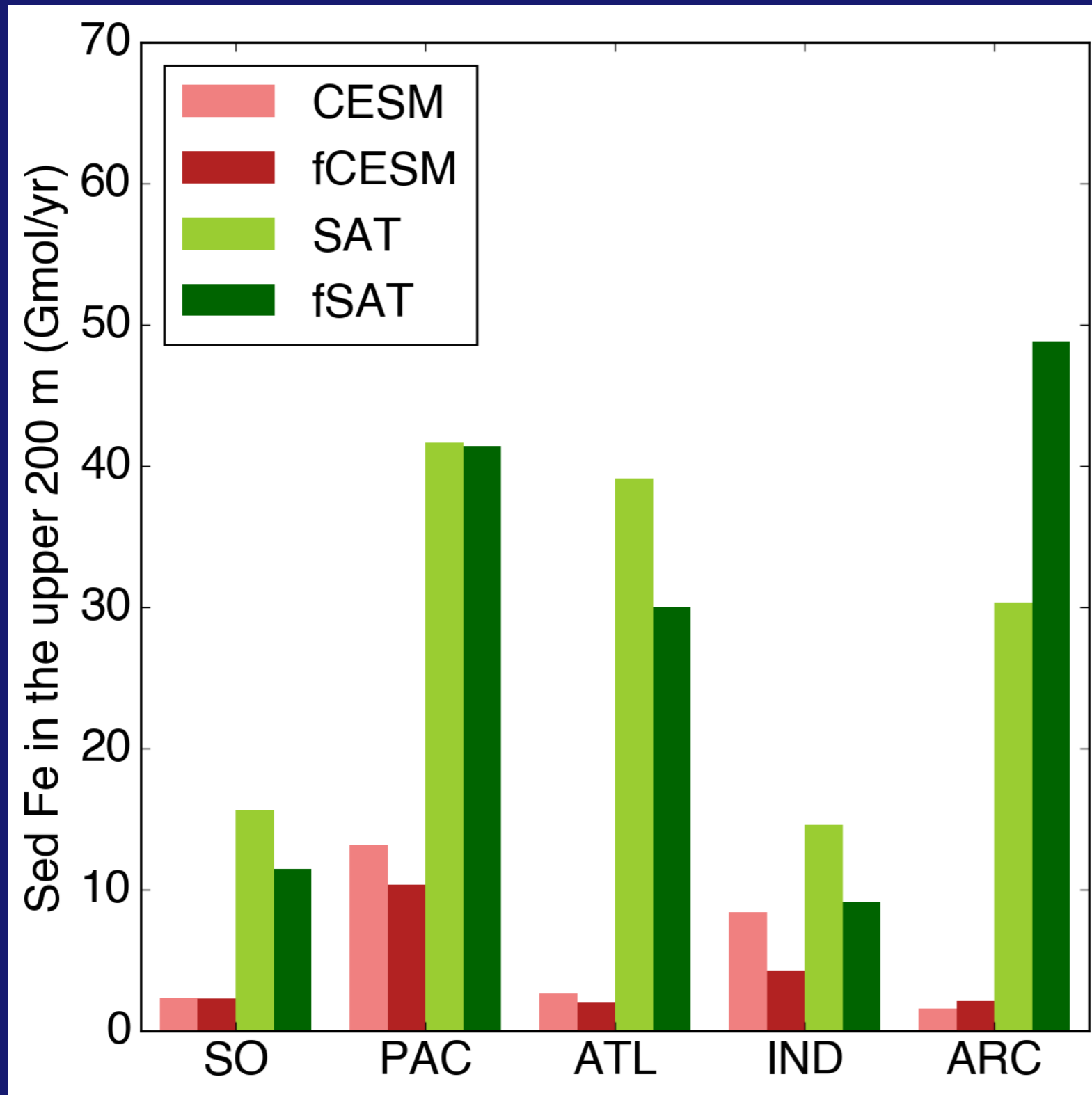
Vertically integrated Sed Fe



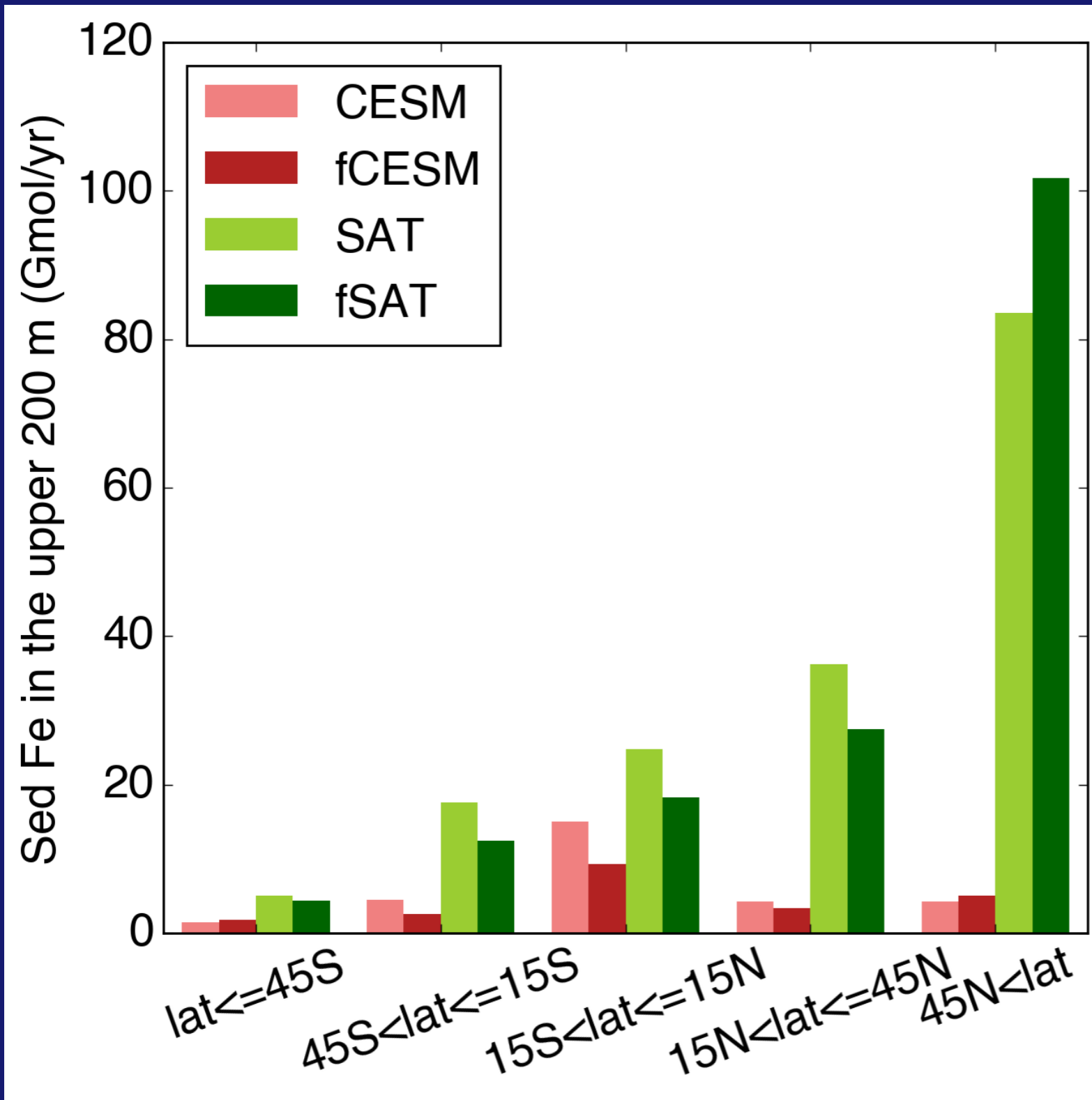
The global sum of sed Fe



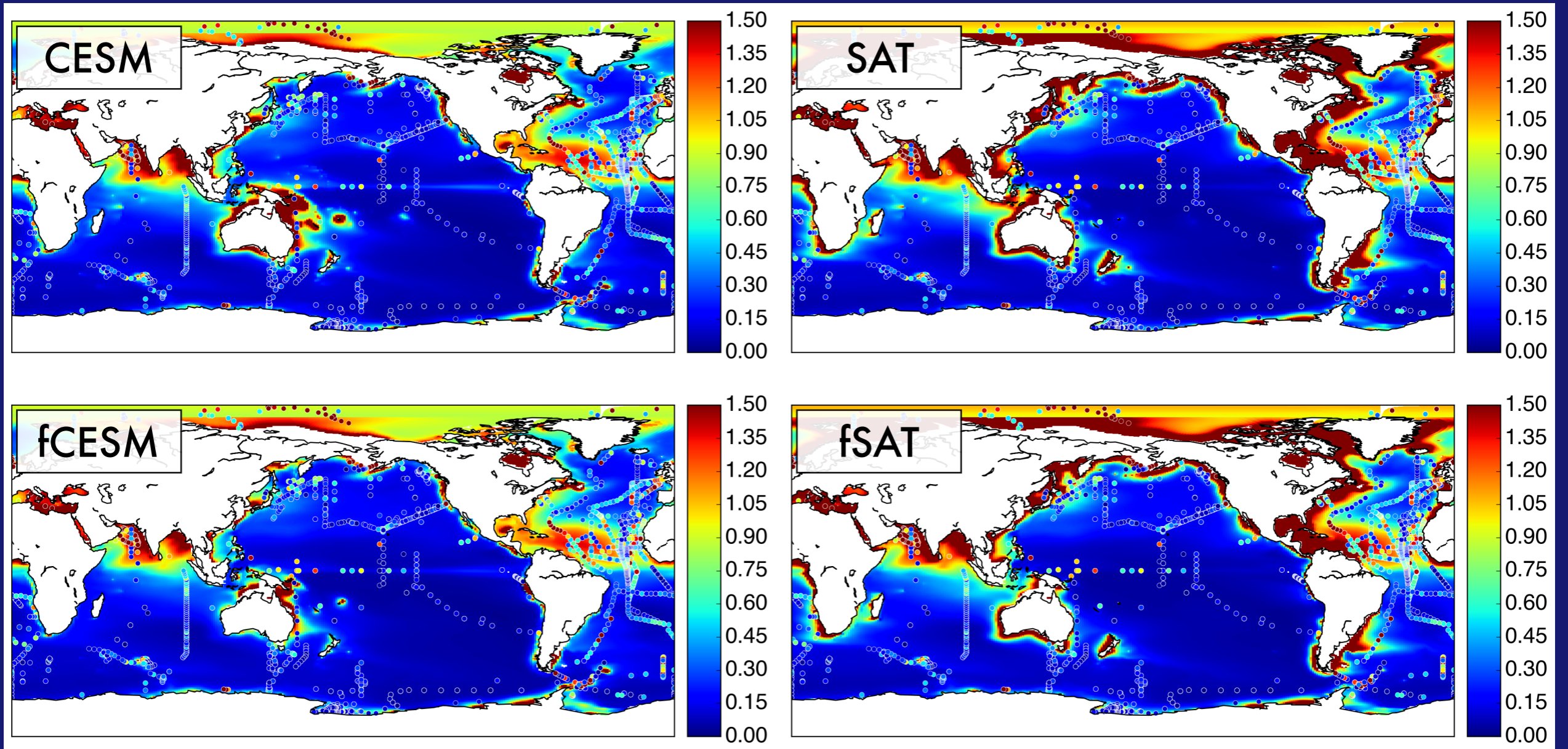
The basin sum of sed Fe



The lat-band sum of sed Fe

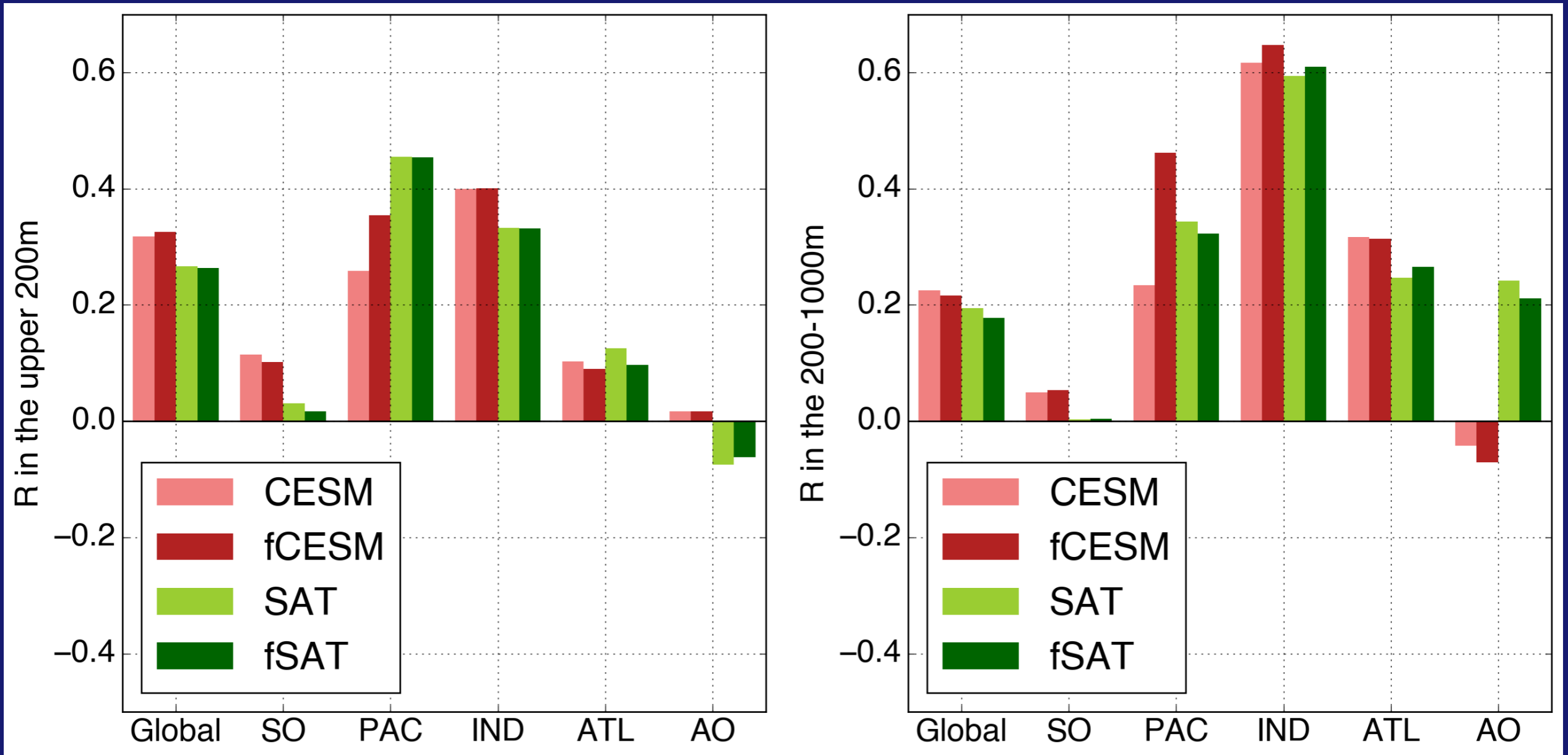


Model simulation

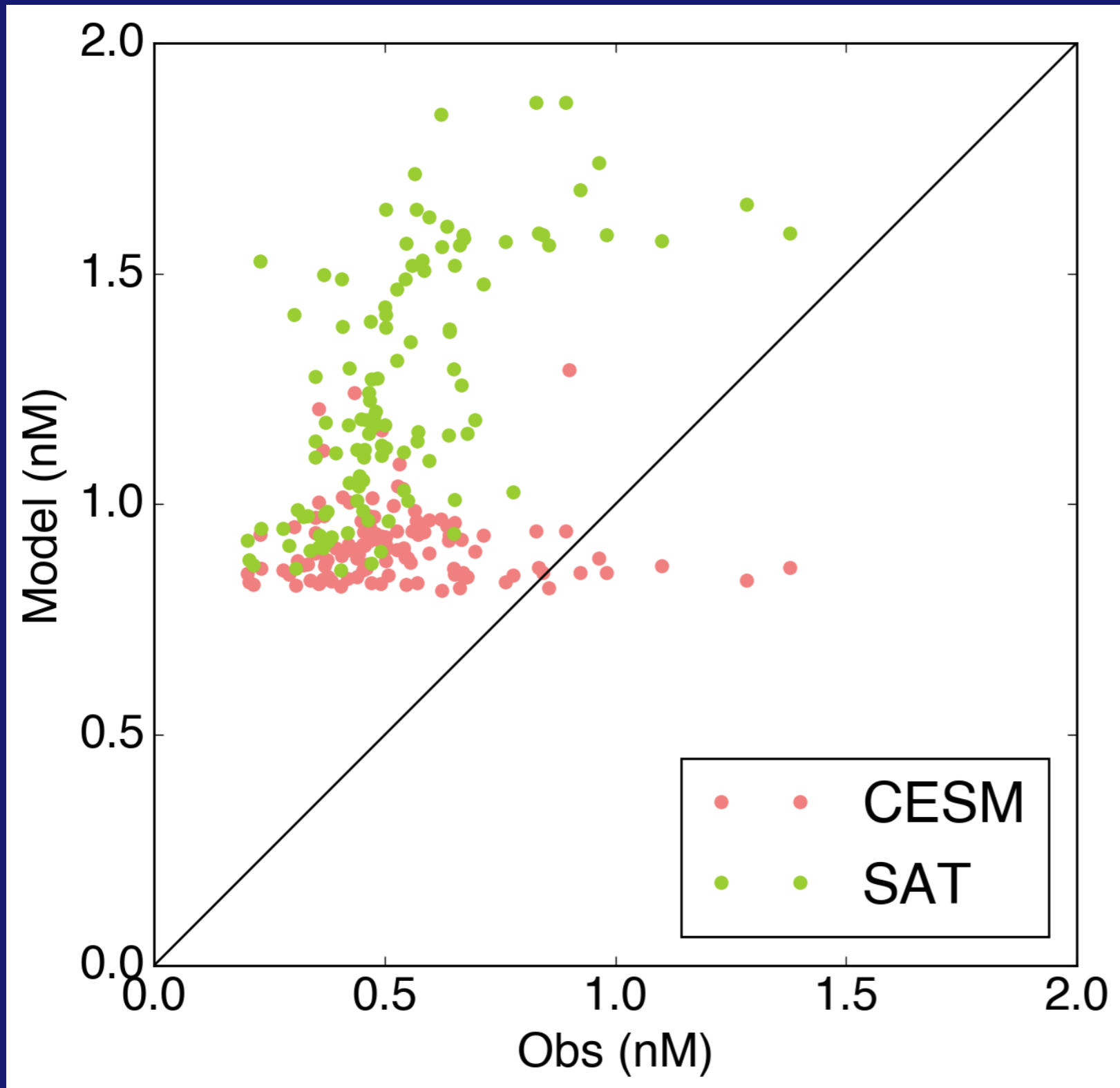


Calculate the ocean only CSM for 110 yrs, and made the monthly mean of the last 10 yr simulation. Then compare the results with the observed dFe data by Tagliabue et al. (2015).

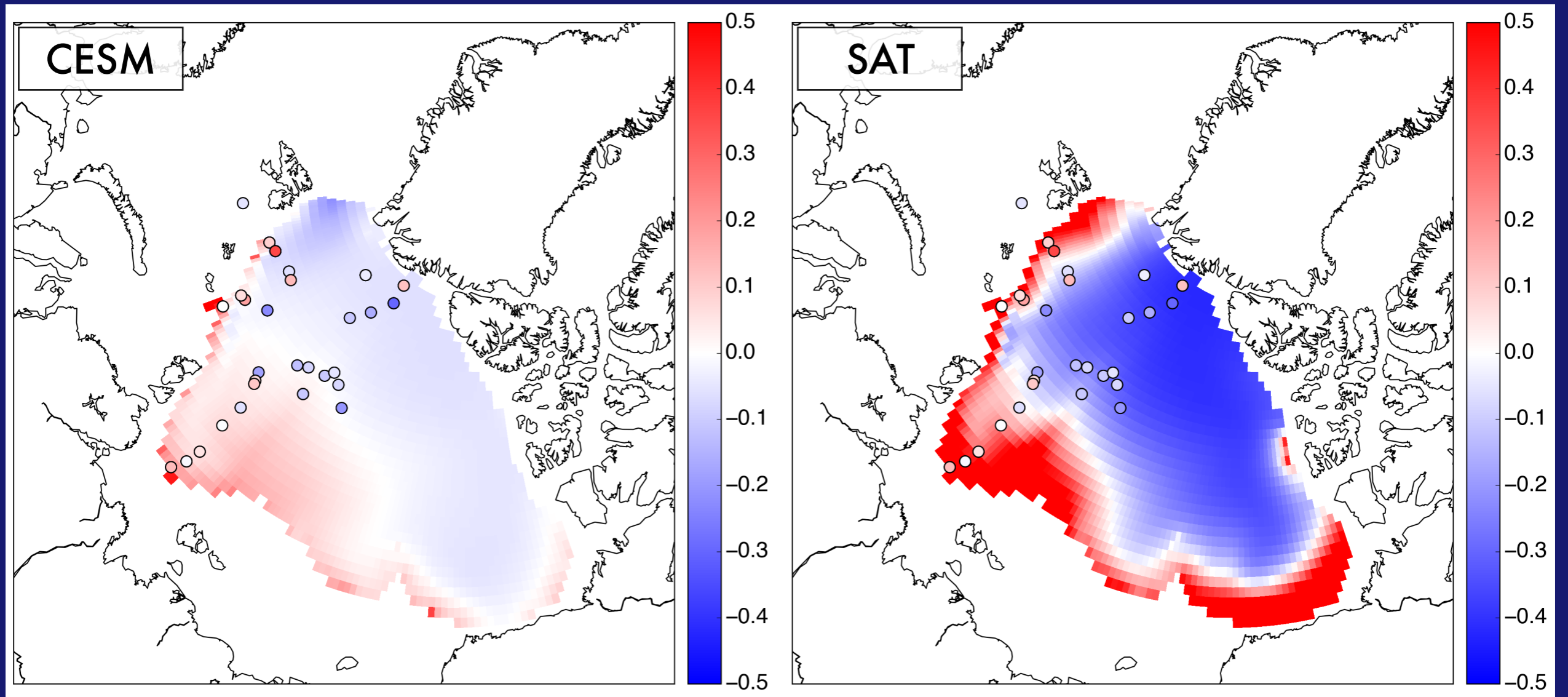
Correlation w/ obs. in the open ocean > 100 km



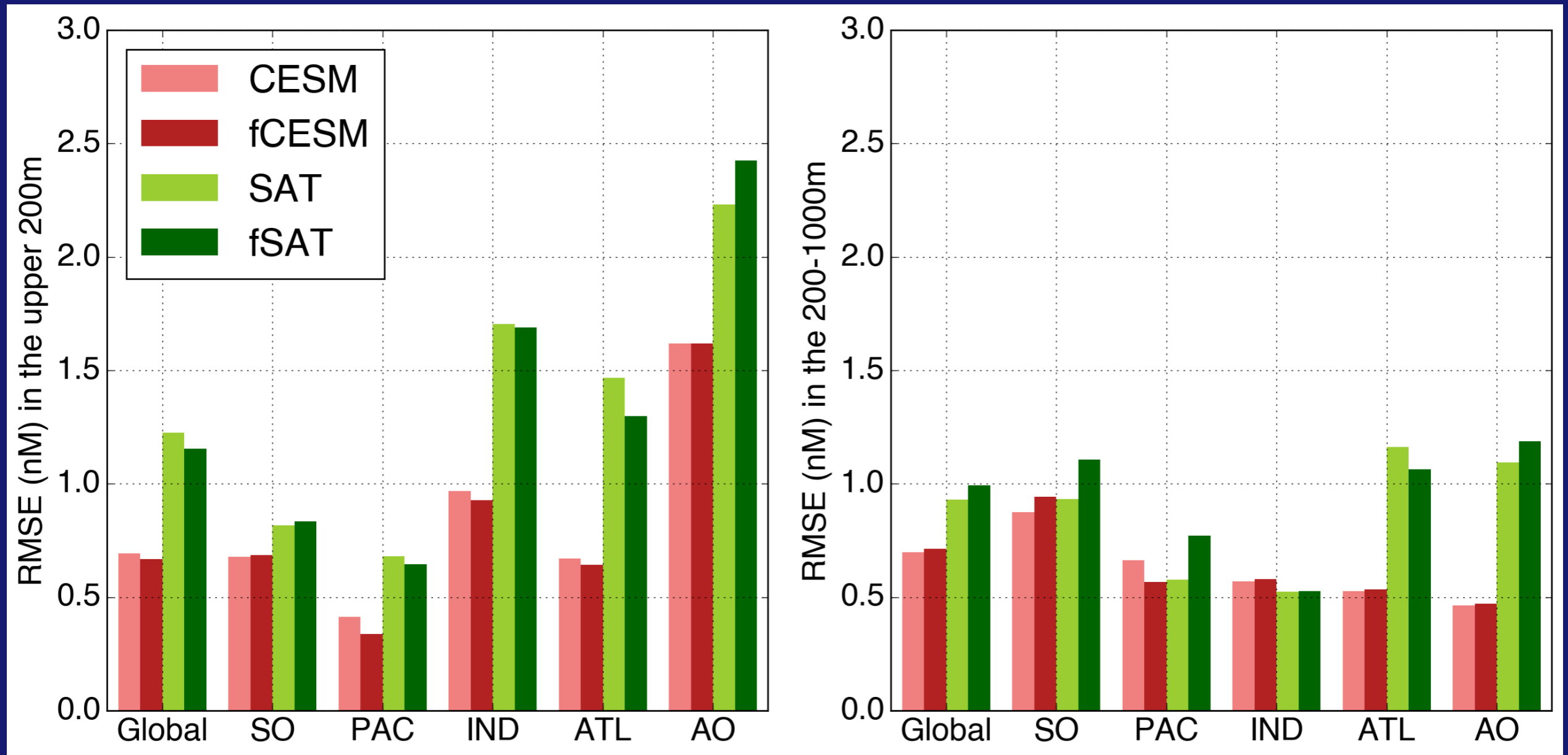
Arctic 200-1000 m depth dFe anomaly



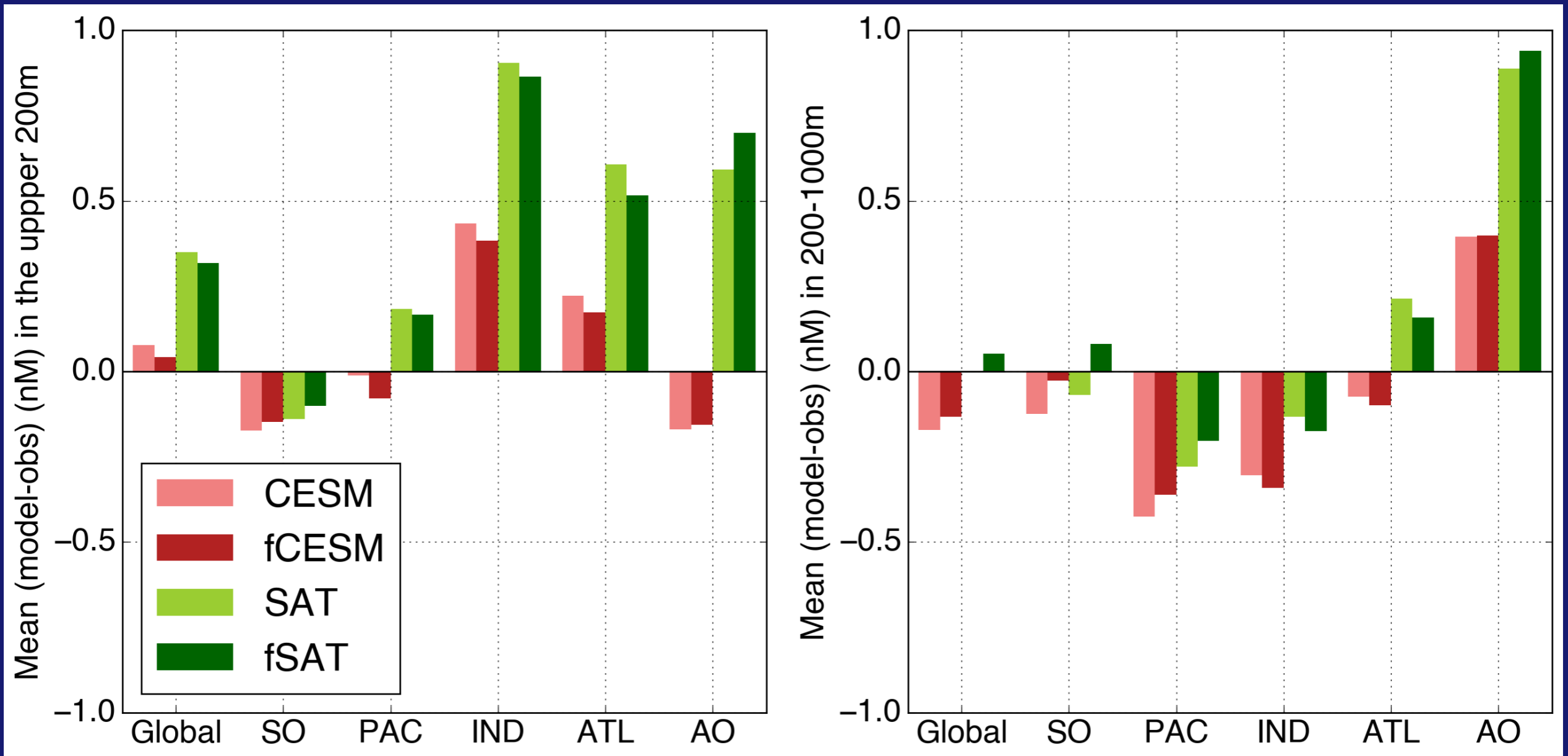
Arctic 200-1000 m depth dFe anomaly



RMSE w/ obs. in the open ocean > 100 km



BIAS w/ obs. in the open ocean > 100 km



Summary

1. We made sedimentary iron-flux datasets based on satellite data.
2. The satellite-based data are model independent, and are suitable to use model intercomparison.
3. The satellite-based fluxes are larger than those used in the current Fe models.
4. The flux distribution is significantly different compared with the original CESM data.

Summary

5. Despite the large difference, the correlation between simulated dFe and obs. were the similar level.
6. RMSEs were, however, increase modestly (0.5-0.2 nM)
7. The positive BIASes are systematically observed in the surface waters, while they are both positive and negative in the intermediate depth.
8. Considering the bottomwater properties hardly change the simulated dFe.

What's next

1. Investigate how the other model groups estimate sed Fe flux, and take in good points.
2. Reconsider formulation of fox.
3. Make a standard data set for FeMIP that is ongoing in SCOR WG151.