Oxygen-dependent zooplankton grazing in CESM-BGC

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CESM WG Meeting
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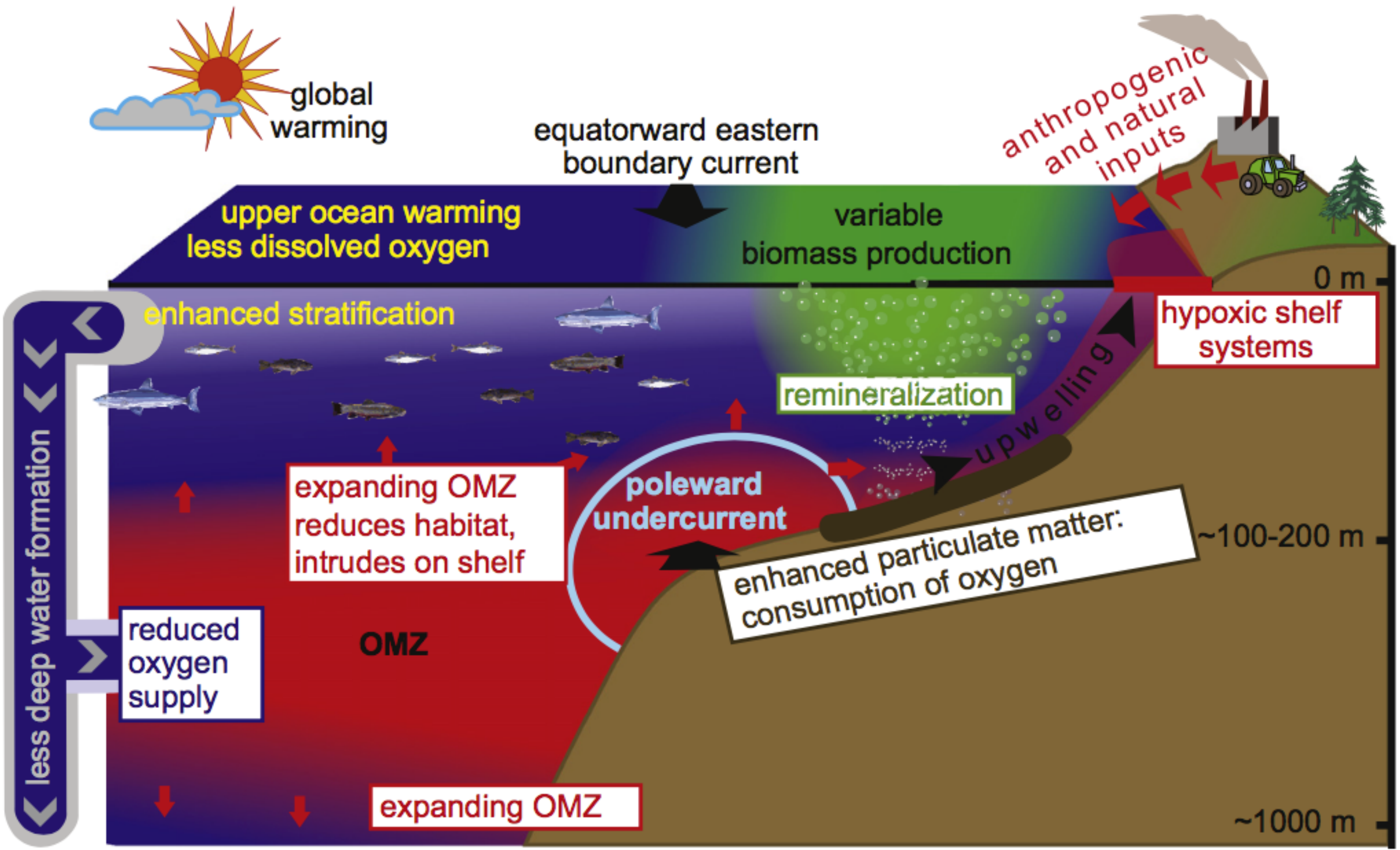
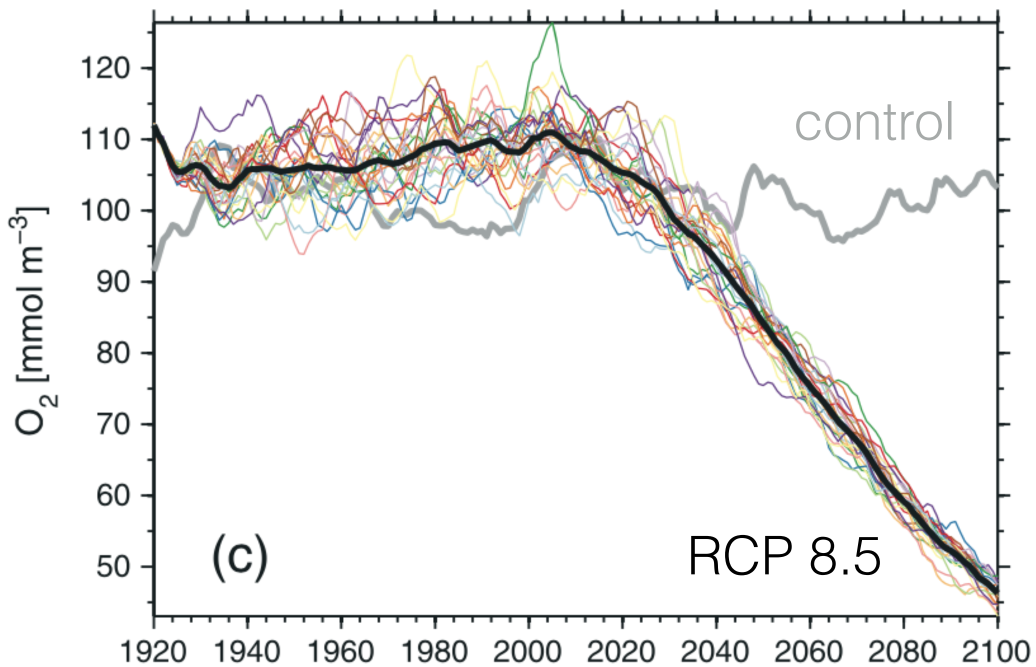
Expansions of oxygen minimum zones under climate change



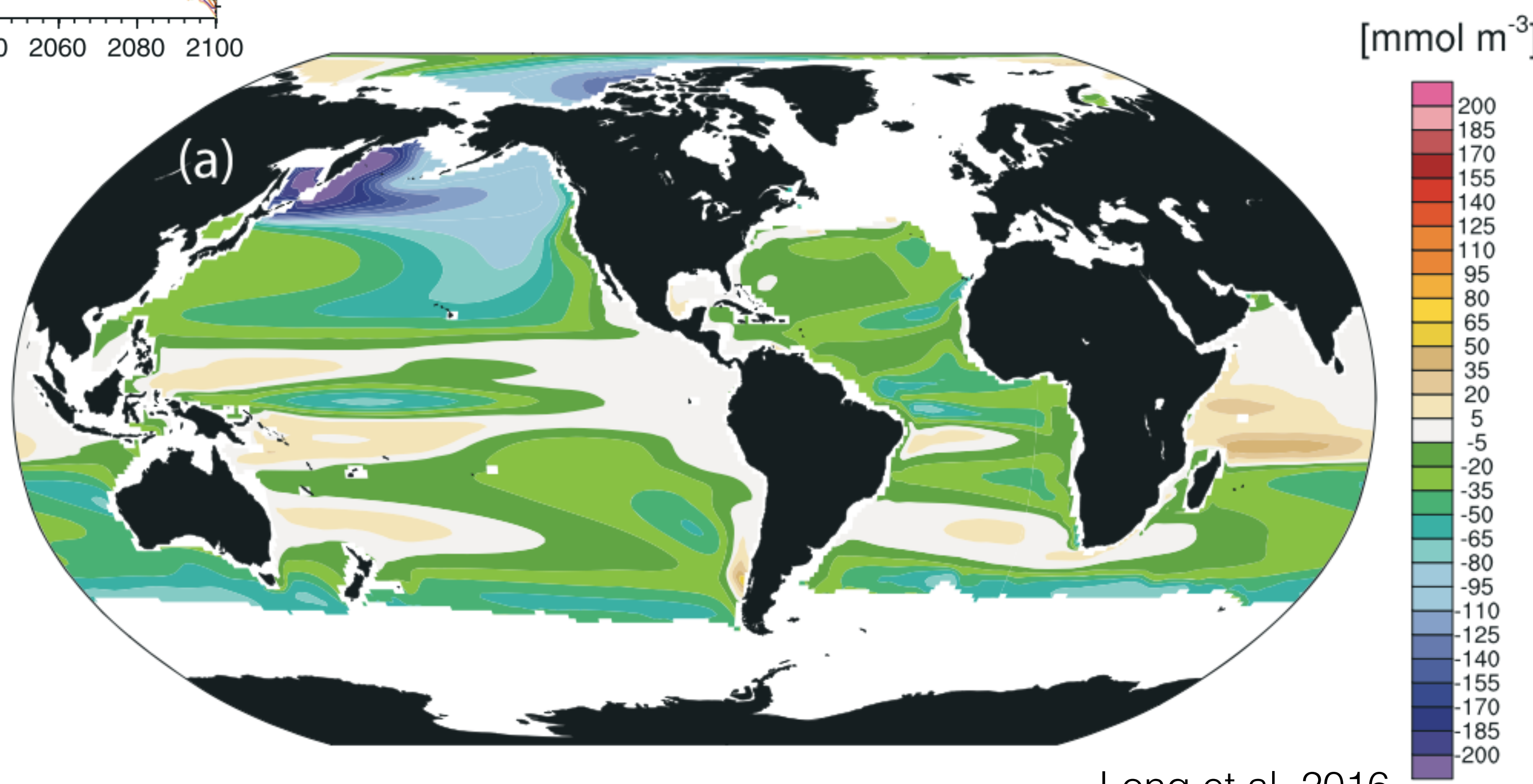
Stramma et al. 2010

Expansions of oxygen minimum zones under climate change



CESM Large Ensemble
21[th] century transient integrations

$[O_2]$ change between 1981-2000 & 2081-2100



Long et al. 2016

Effects of low oxygen on marine organisms

Franz Neidl

- For zooplankton (Ekau et al. 2010 review)
    - Decreased: respiration, feeding, egg development, hatching, abundance, and survivorship.
    - Increased avoidance, swimming, and contracted vertical range. Increased exposure to predators.
- In general: negative impacts on pelagic / upper ocean species, but mixed impacts on mesopelagic & benthic species adapted to low oxygen levels

Scientific motivation

- How are the increases in low oxygen zones under climate change going to affect plankton community composition and ocean carbon export?

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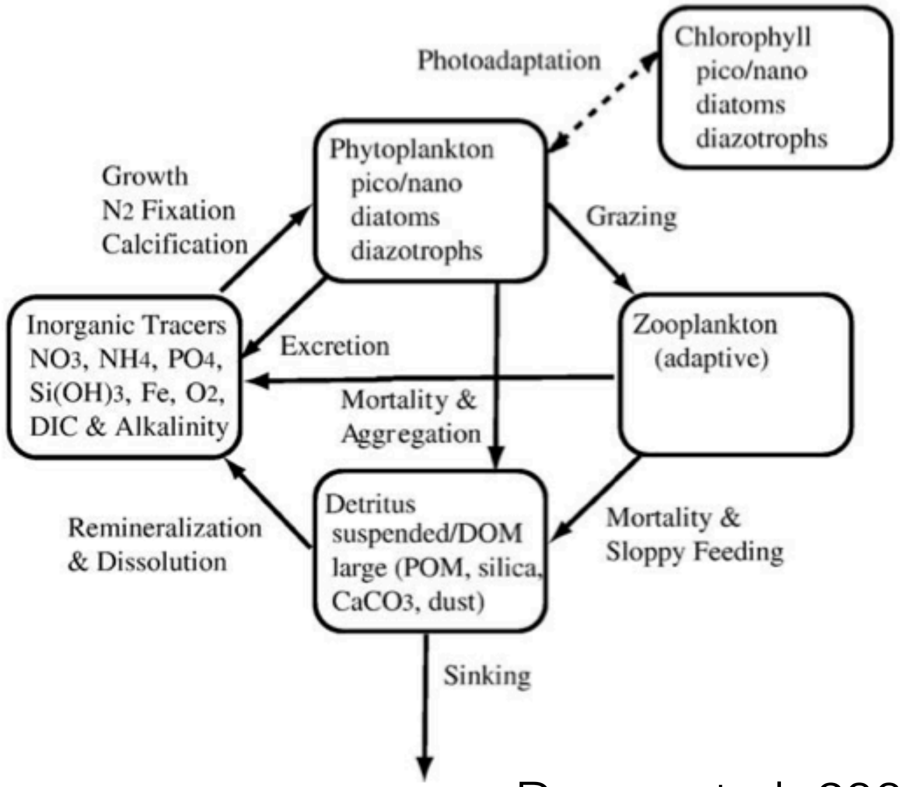
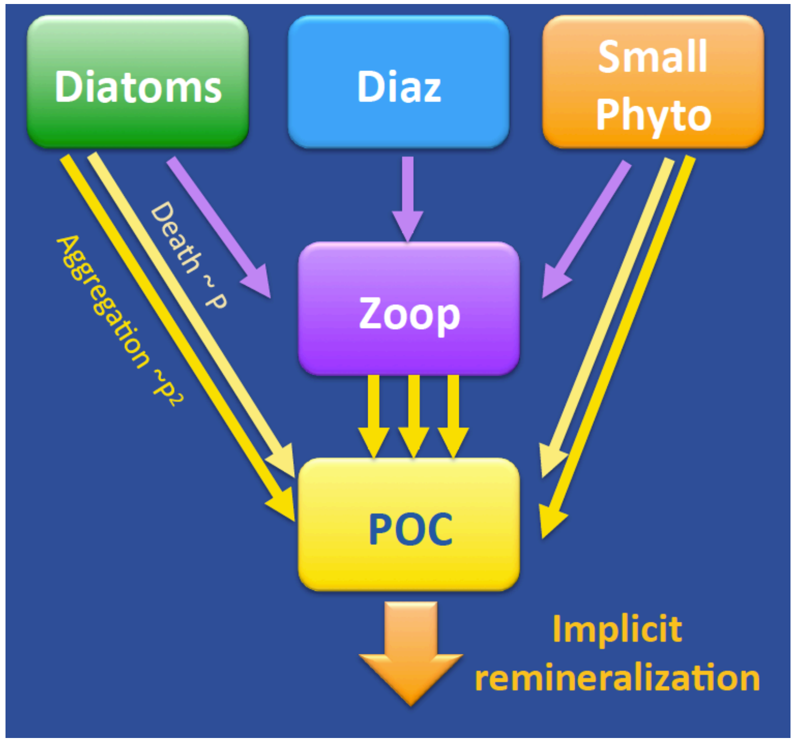
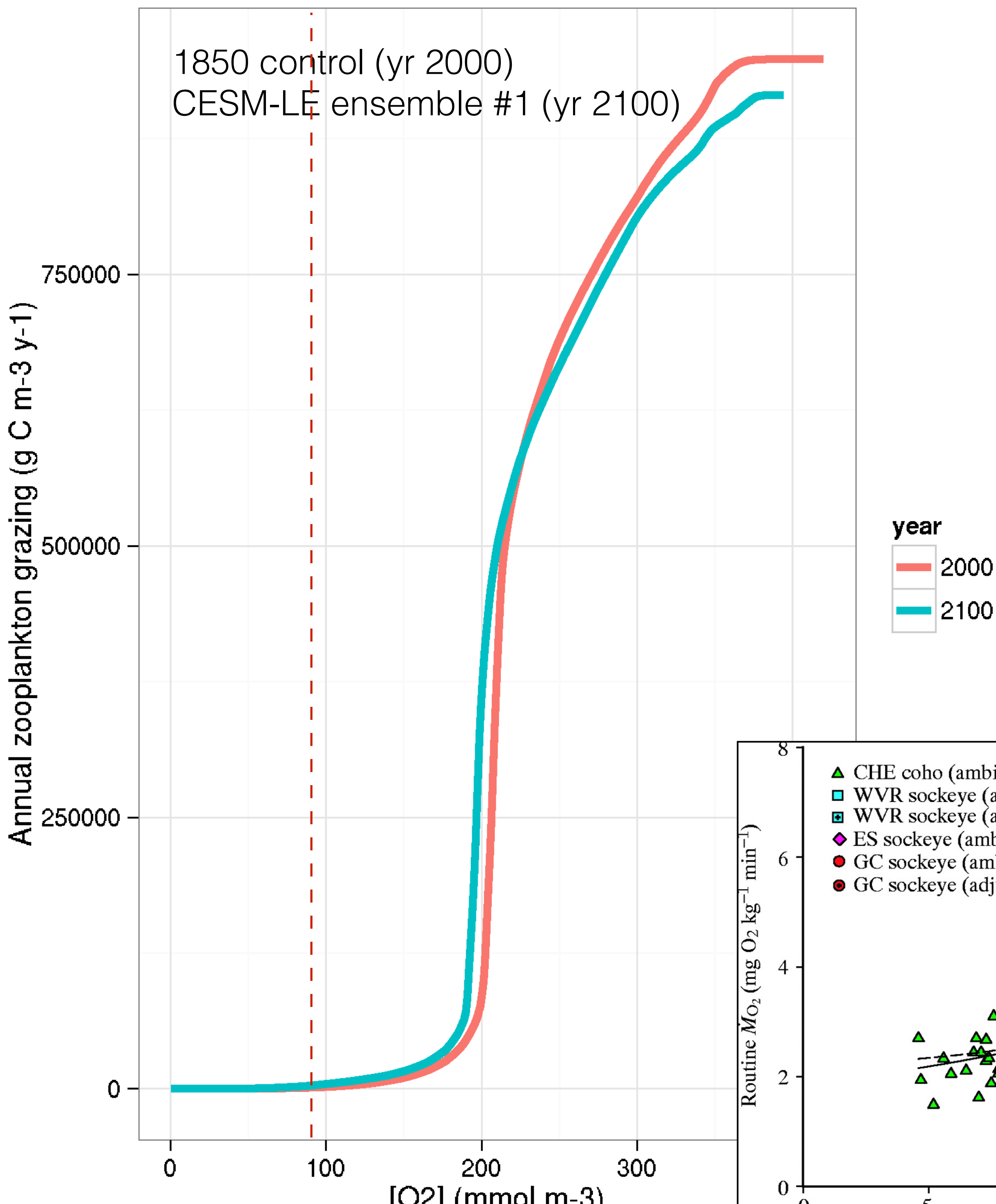


Doney et al. 2009

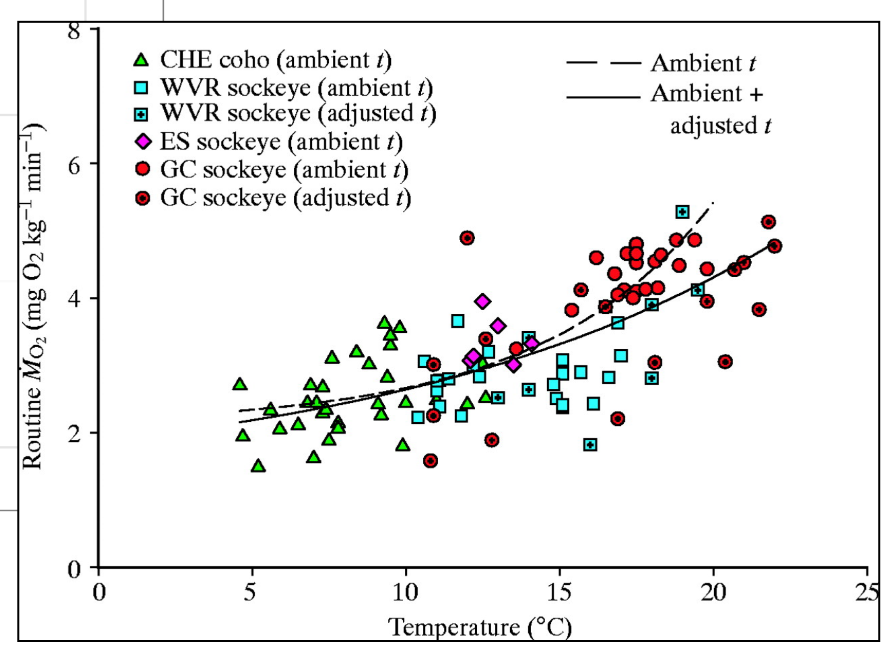


Harrison et al. *in prep*

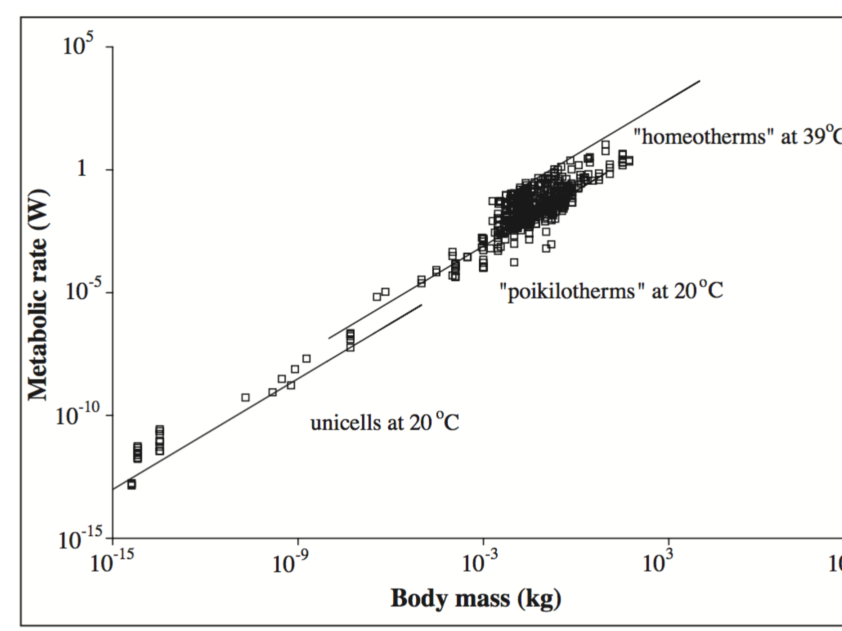
Zooplankton metabolism and low oxygen



- Very little grazing at anoxic or hypoxic (< 90 mmol m^{-3}) levels
- Increased activity also increases oxygen demand (up to 8x!)
- Also consider effects of temperature and body size



Lee et al. 2003



Gillooly et al. 2001

"Metabolic Index (MI)"

Deutsch et al. 2015
Gillooly et al. 2016

$$\mathrm{MI} = \frac{\text{Oxygen supply}}{\text{Oxygen demand}}$$

$$\mathrm{MI} = \frac{s(\text{env. oxygen, organismal uptake})}{d(\text{temperature, body mass, activity})}$$

$$s = \frac{K \Delta p O_2}{\mathrm{RBT}} \mathrm{RSA}$$

RBA = respiratory surface area
RBT = respiratory barrier thickness

$$d = c_i M^b * \text{temperature scaling}$$

$$\exp\left(\frac{-E_a}{kT}\right) \qquad Q10^{\frac{T}{10}}$$

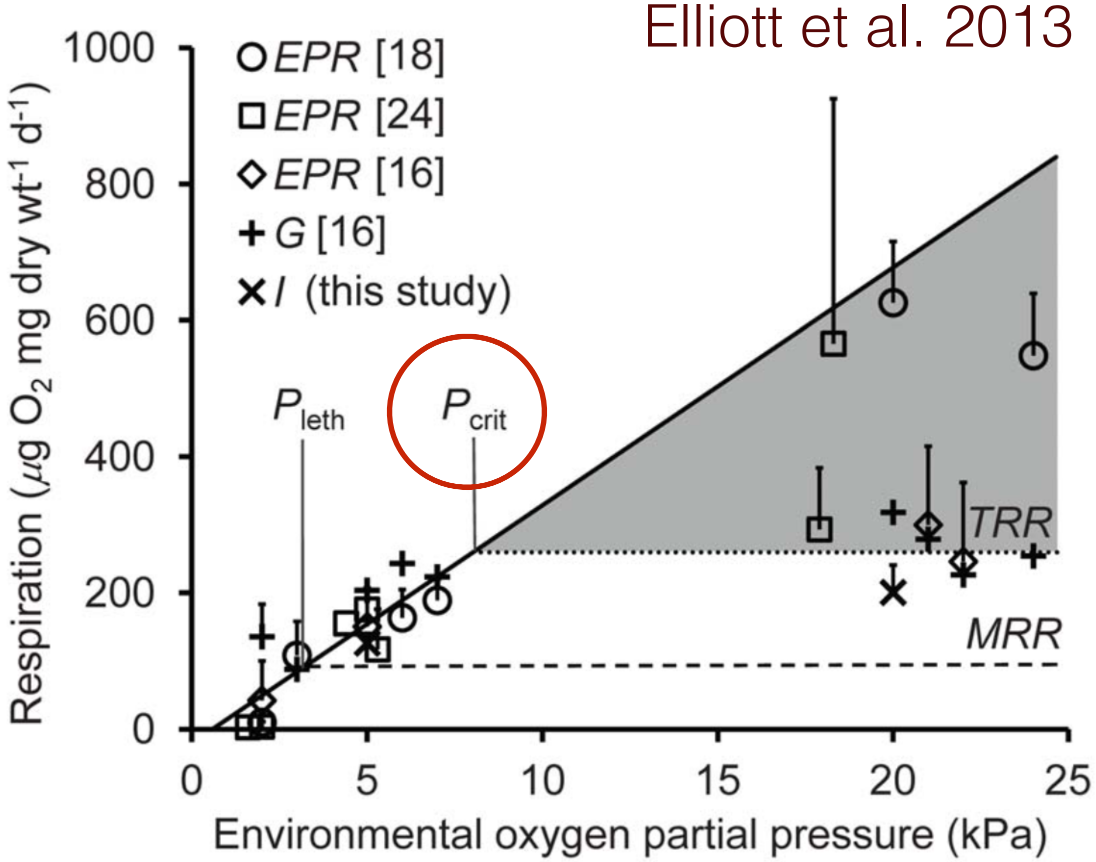
$$\mathrm{MI} = \frac{\frac{K \Delta p O_2}{\mathrm{RBT}} \mathrm{RSA}}{c_i M^b Q10^{\frac{T}{10}}} = \frac{K c_a c_t M^{a-t} p O_2}{c_i M^b Q10^{\frac{T}{10}}}$$

$$\mathrm{MI} = c M^x \frac{[O_2]}{Q10^{\frac{T}{10}}}$$

Determining the functional form

Compilation data on *Acartia tonsa*

Elliott et al. 2013



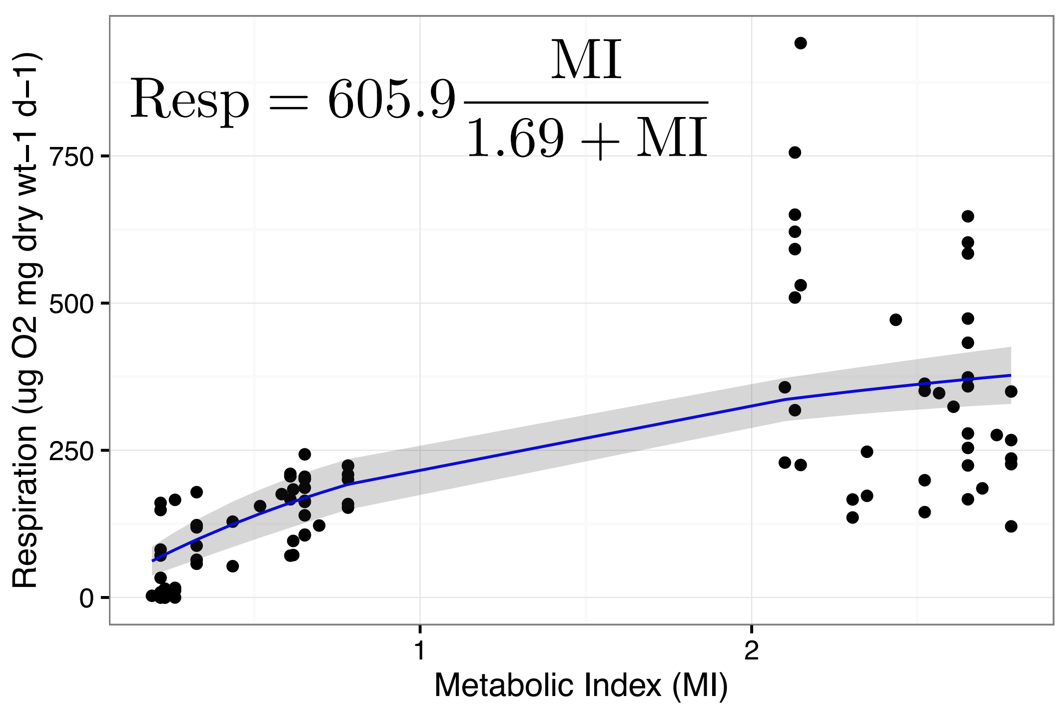
- P_{crit} equivalent to MI = 1

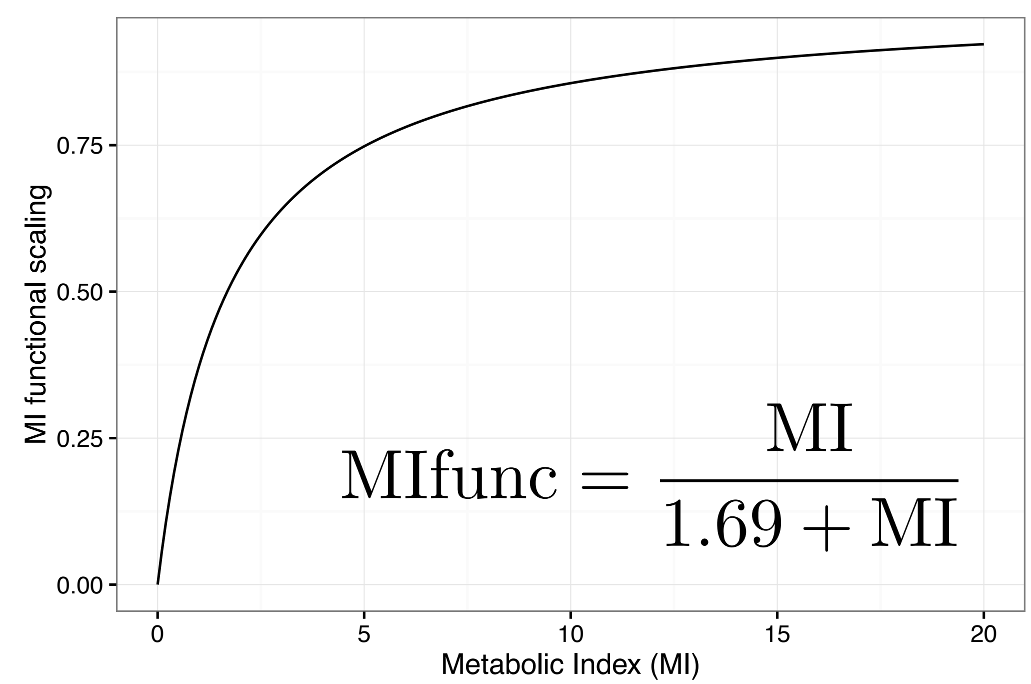
$$\mathrm{MI} = cM^x \frac{[O_2]}{Q10^{\frac{T}{10}}}$$

- Respiration rates fit to Michaelis-Menten curve

- Functional scaling applied to zooplankton grazing

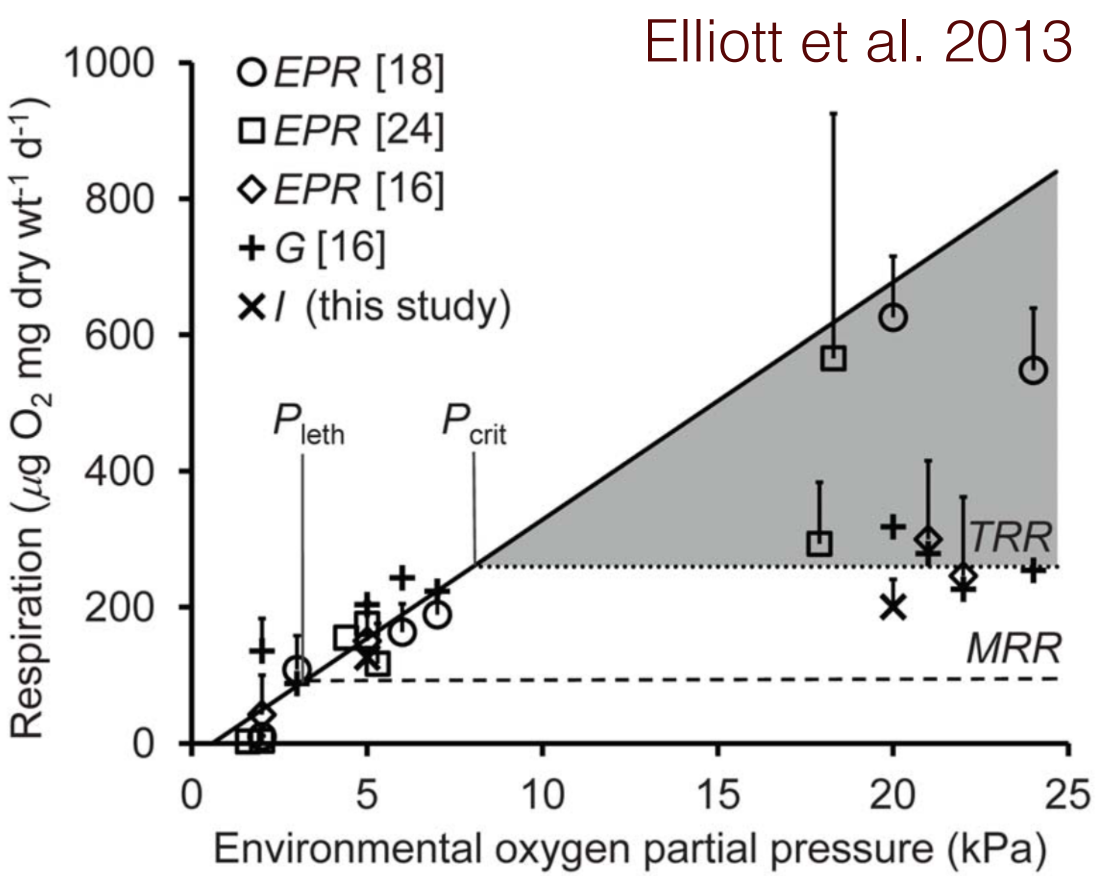
$$\dot{g} = \mu_{max} Z \frac{P}{K_m + P} * \mathrm{Tfunc} * \mathrm{MIfunc}$$





Determining the functional form

Compilation data on *Acartia tonsa*



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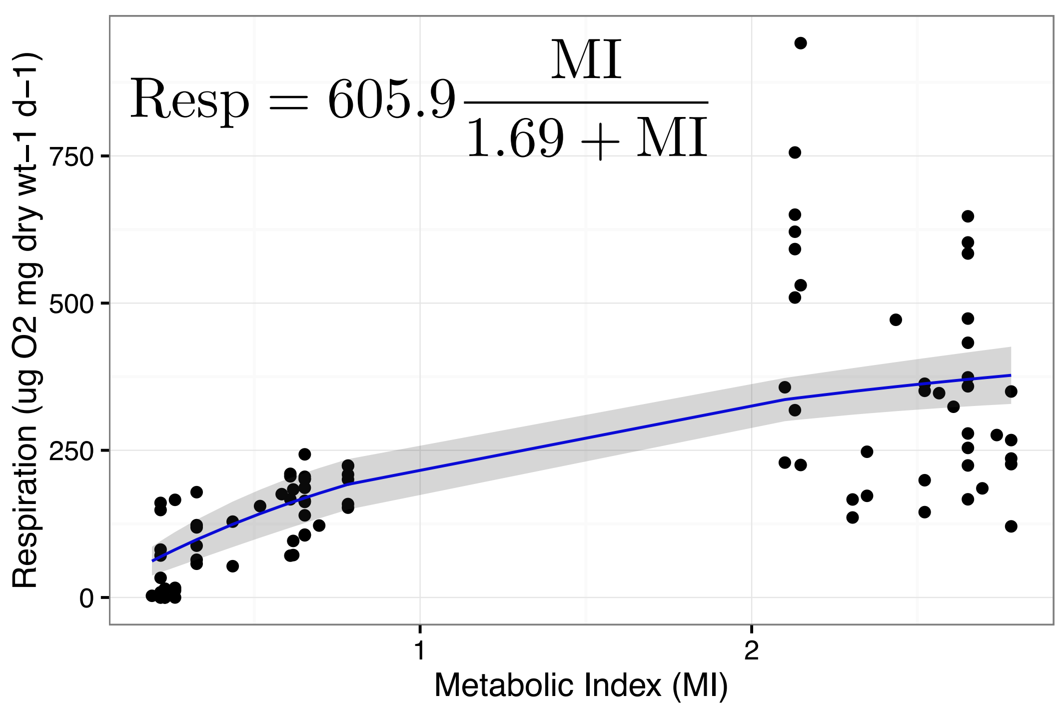
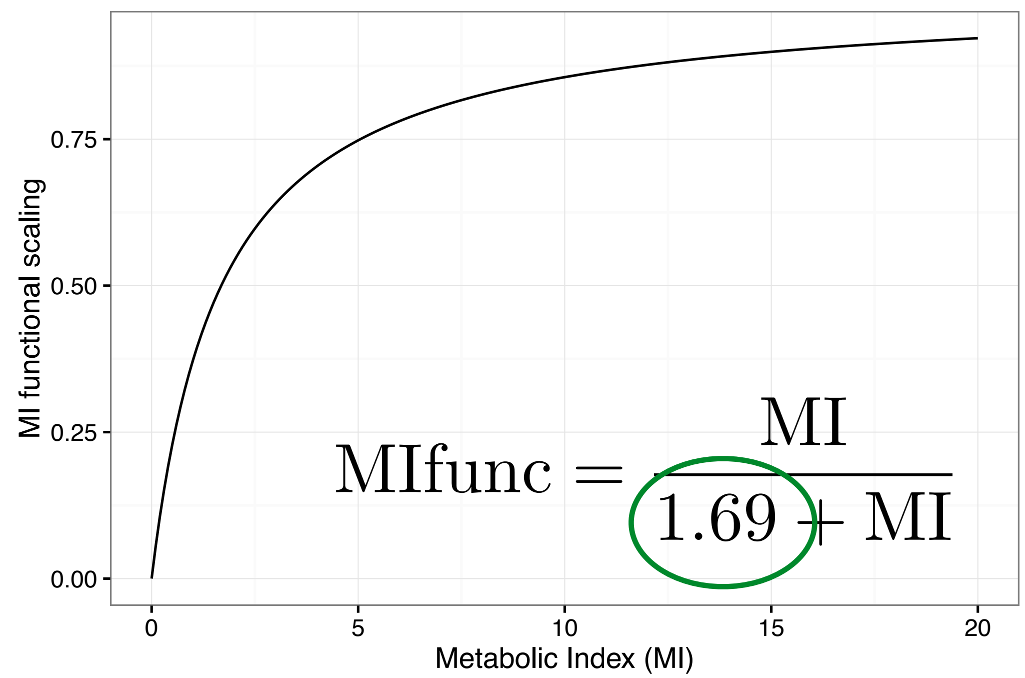
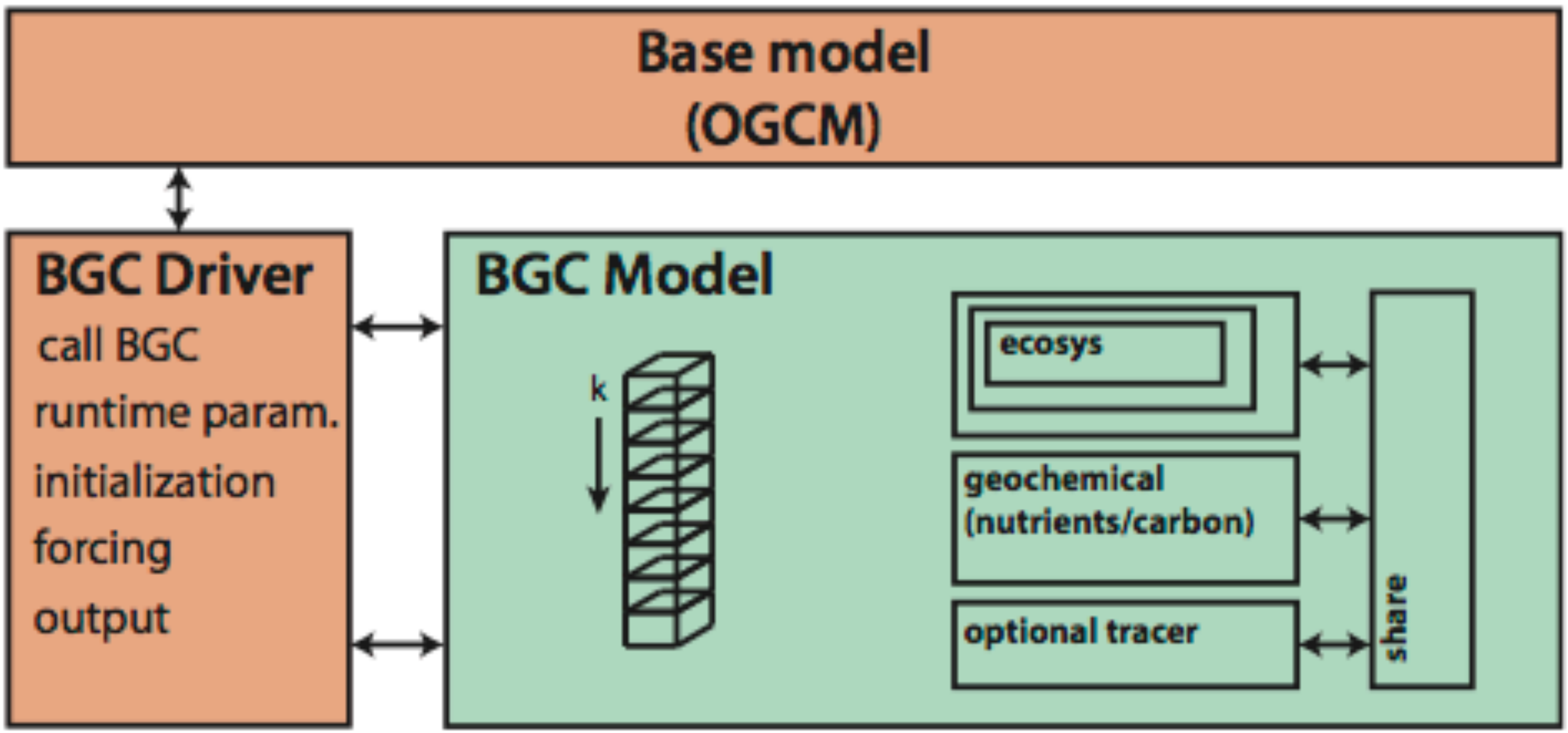
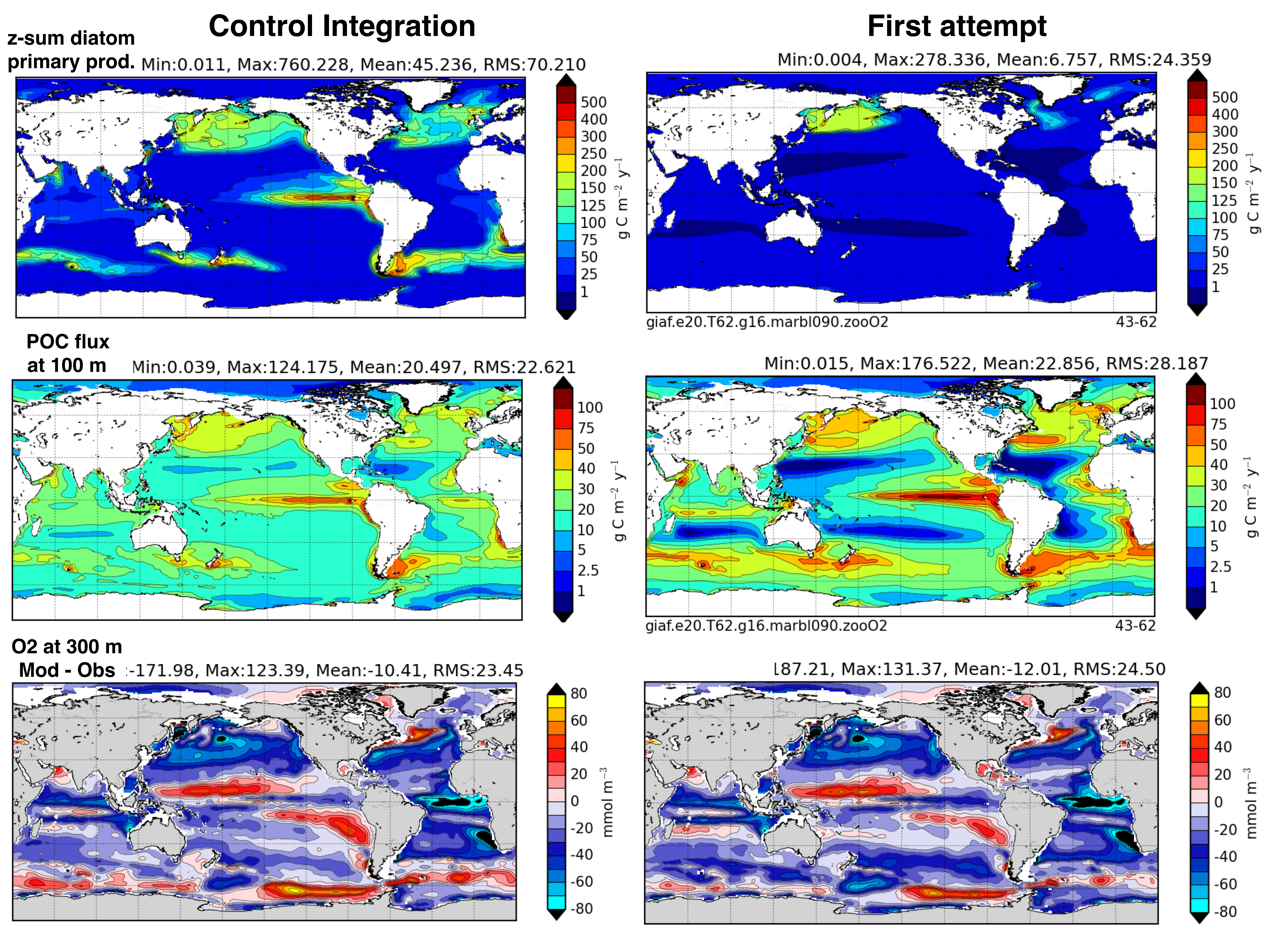




Marine Biogeochemistry Library (MARBL)




Control Integration
First attempt
z-sum diatom primary prod.
Min:0.011, Max:760.228, Mean:45.236, RMS:70.210
Min:0.004, Max:278.336, Mean:6.757, RMS:24.359
500 400 300 250 200 150 125 100 75 50 25 1
g C m^-2 y^-1
giaf.e20.T62.g16.marbl090.zooO2
43-62
POC flux at 100 m
Min:0.039, Max:124.175, Mean:20.497, RMS:22.621
Min:0.015, Max:176.522, Mean:22.856, RMS:28.187
100 75 50 40 30 20 10 5 2.5 1
g C m^-2 y^-1
giaf.e20.T62.g16.marbl090.zooO2
43-62
O2 at 300 m
Mod - Obs
:-171.98, Max:123.39, Mean:-10.41, RMS:23.45
187.21, Max:131.37, Mean:-12.01, RMS:24.50
80 60 40 20 0 -20 -40 -60 -80
mmol m^-3

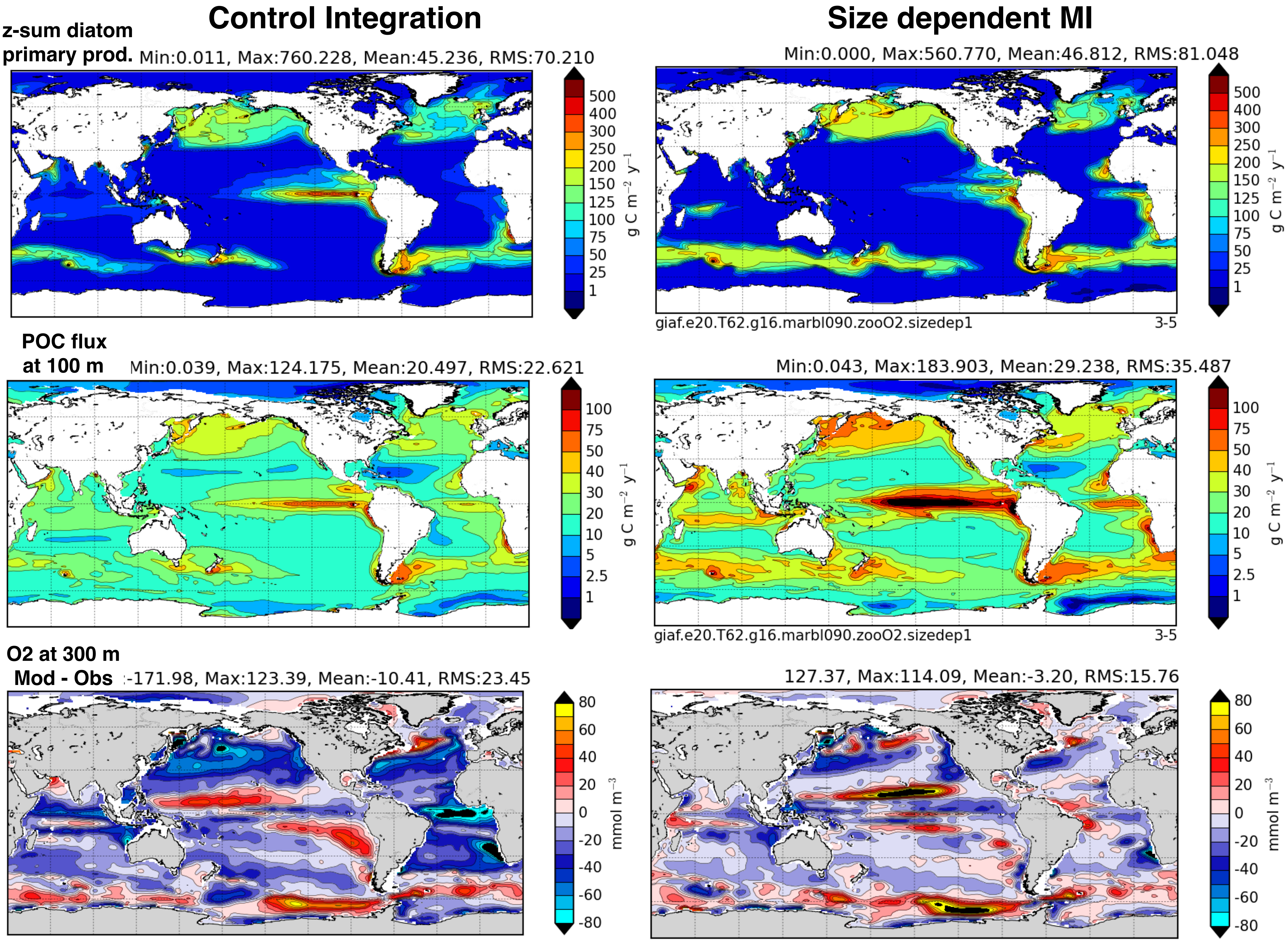
$$\mathrm{MI} = cM^{x}\frac{[O_2]}{Q10^{\frac{T}{10}}}$$

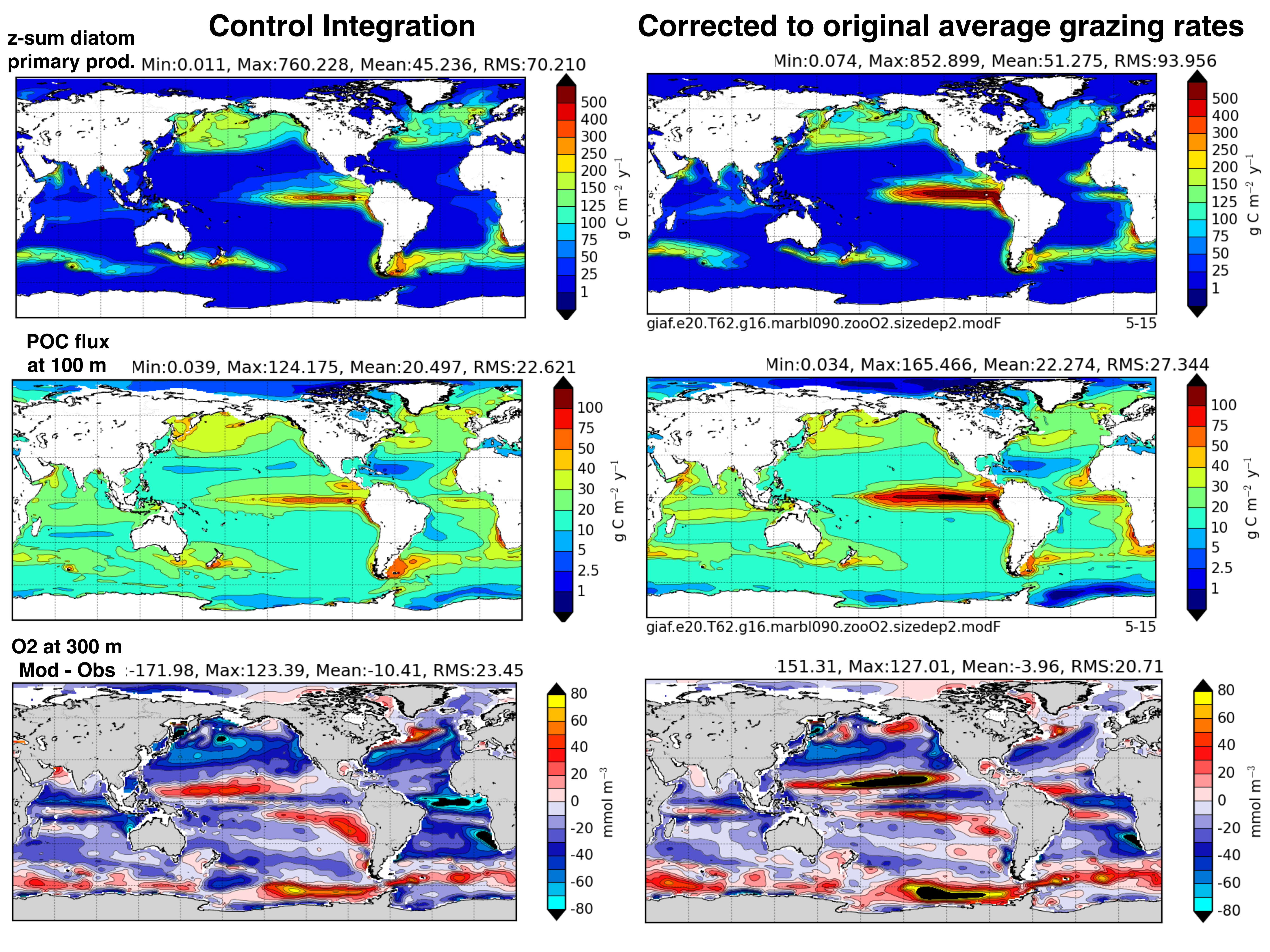
MI_{sm}

MI_{lg}

$$\mathrm{MIfunc} = \frac{\mathrm{MI}}{1.69 + \mathrm{MI}}$$

$$\dot{g} = \mu_{max} Z \frac{P}{K_m + P} * \mathrm{Tfunc} * \mathrm{MIfunc}$$


Control Integration
Size dependent MI
z-sum diatom
primary prod.
Min:0.011, Max:760.228, Mean:45.236, RMS:70.210
Min:0.000, Max:560.770, Mean:46.812, RMS:81.048
500
400
300
250
200
150
125
100
75
50
25
1
g C m^-2 y^-1
giaf.e20.T62.g16.marbl090.zooO2.sizedep1
3-5
POC flux
at 100 m
Min:0.039, Max:124.175, Mean:20.497, RMS:22.621
Min:0.043, Max:183.903, Mean:29.238, RMS:35.487
100
75
50
40
30
20
10
5
2.5
1
g C m^-2 y^-1
giaf.e20.T62.g16.marbl090.zooO2.sizedep1
3-5
O2 at 300 m
Mod - Obs
:-171.98, Max:123.39, Mean:-10.41, RMS:23.45
127.37, Max:114.09, Mean:-3.20, RMS:15.76
80
60
40
20
0
-20
-40
-60
-80
mmol m^-3



Control Integration
Corrected to original average grazing rates
z-sum diatom primary prod.
Min:0.011, Max:760.228, Mean:45.236, RMS:70.210
Min:0.074, Max:852.899, Mean:51.275, RMS:93.956
500
400
300
250
200
150
125
100
75
50
25
1
g C m^{-2} y^{-1}
giaf.e20.T62.g16.marbl090.zooO2.sizedep2.modF
5-15
POC flux at 100 m
Min:0.039, Max:124.175, Mean:20.497, RMS:22.621
Min:0.034, Max:165.466, Mean:22.274, RMS:27.344
100
75
50
40
30
20
10
5
2.5
1
g C m^{-2} y^{-1}
giaf.e20.T62.g16.marbl090.zooO2.sizedep2.modF
5-15
O2 at 300 m Mod - Obs
:-171.98, Max:123.39, Mean:-10.41, RMS:23.45
151.31, Max:127.01, Mean:-3.96, RMS:20.71
80
60
40
20
0
-20
-40
-60
-80
mmol m^{-3}

$$\mathrm{MI} = cM^x \frac{[O_2]}{Q10^{\frac{T}{10}}}$$

→ MI_{sm}

→ MI_{lg}

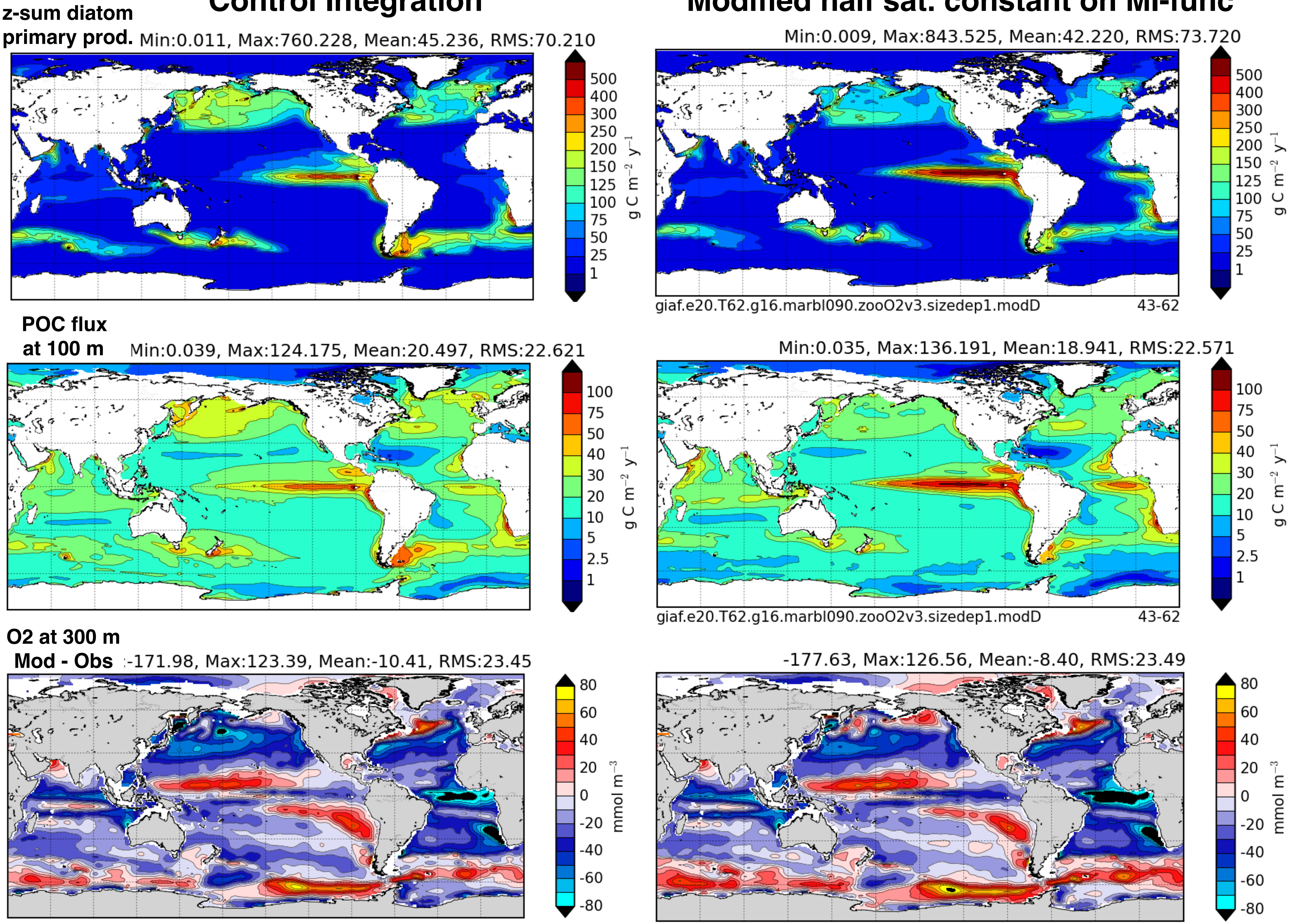
$$\mathrm{MIfunc} = \frac{\mathrm{MI}}{1.69 + \mathrm{MI}}$$

1.69 → 1.5

$$\dot{g} = \mu_{max} Z \frac{P}{K_m + P} * \mathrm{Tfunc} * \mathrm{MIfunc}$$

Control Integration

Modified half sat. constant on MI-func

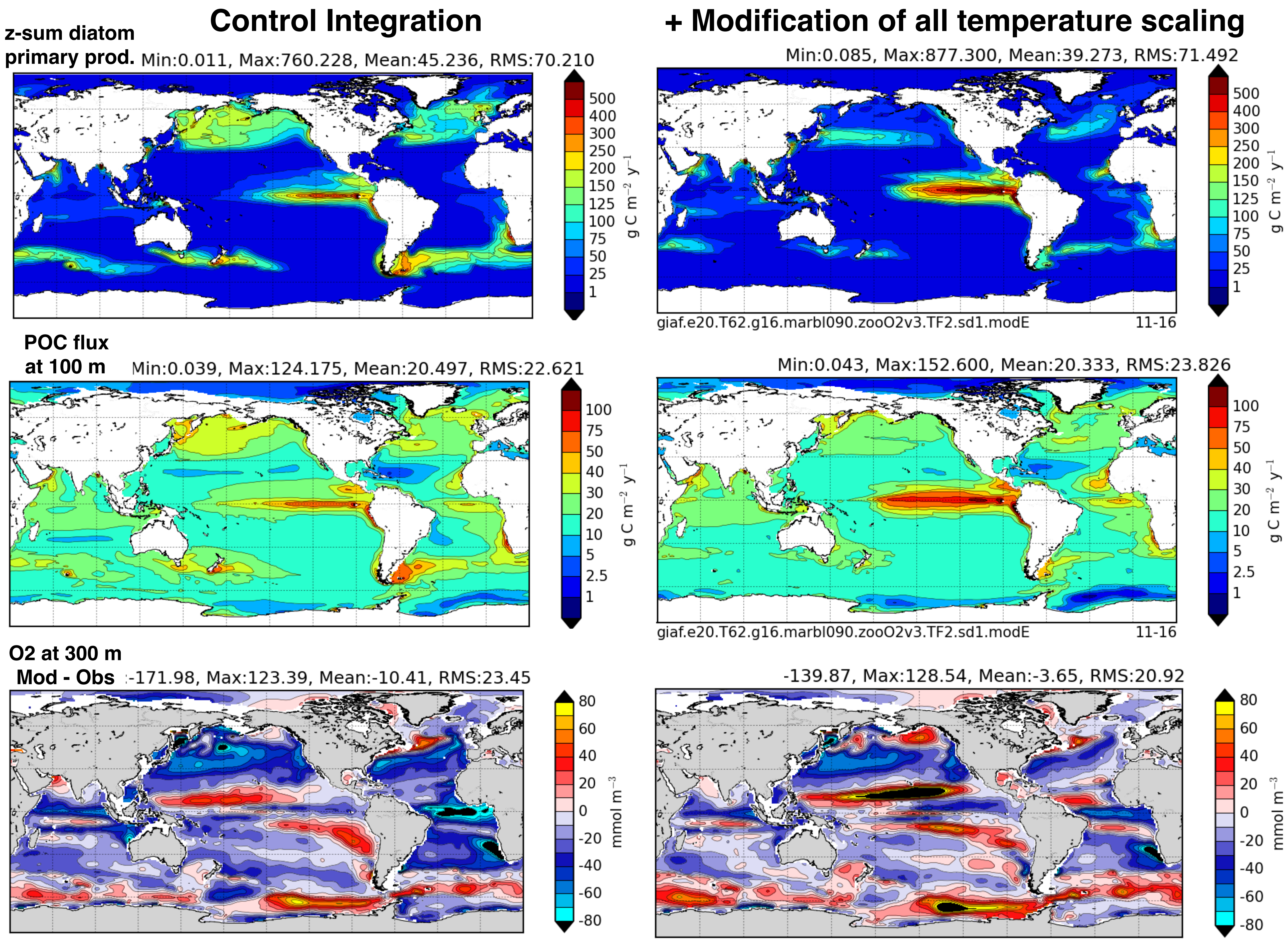


$$\mathrm{MI} = cM^{x}\frac{[O_2]}{Q10^{\frac{T}{10}}} \begin{array}{l} \nearrow \mathrm{MI}_{sm} \\ \searrow \mathrm{MI}_{lg} \end{array}$$

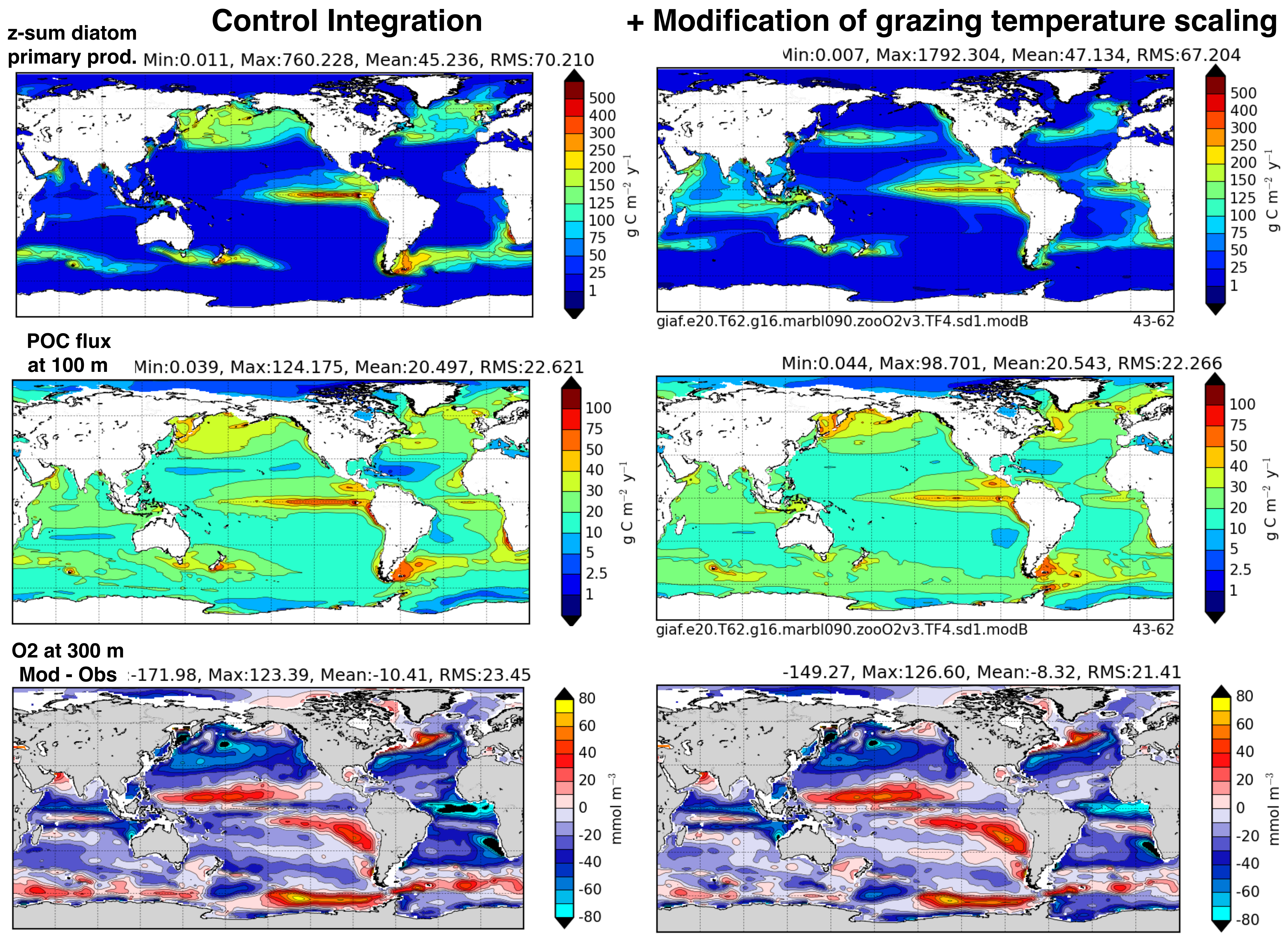
$$\mathrm{MIfunc} = \frac{\mathrm{MI}}{1.5 + \mathrm{MI}}$$

$$\dot{g} = \mu_{max} Z \frac{P}{K_m + P} * \mathrm{Tfunc} * \mathrm{MIfunc}$$

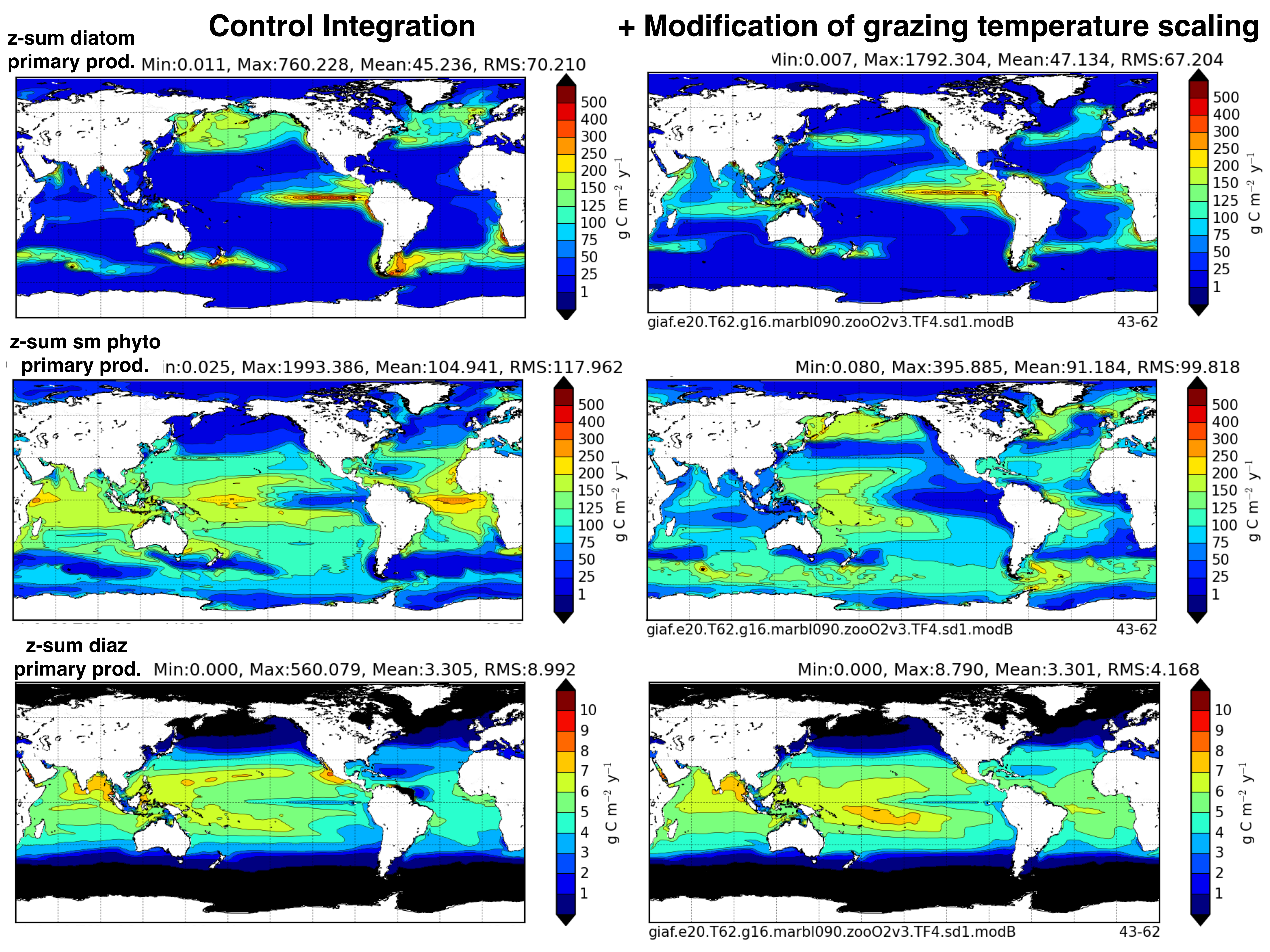
$$\mathrm{Tfunc} = Q10^{\frac{T - T_{ref}}{10}}$$



Control Integration
+ Modification of all temperature scaling
z-sum diatom primary prod.
Min:0.011, Max:760.228, Mean:45.236, RMS:70.210
Min:0.085, Max:877.300, Mean:39.273, RMS:71.492
500 400 300 250 200 150 125 100 75 50 25 1
g C m^{-2} y^{-1}
giaf.e20.T62.g16.marbl090.zooO2v3.TF2.sd1.modE
11-16
POC flux at 100 m
Min:0.039, Max:124.175, Mean:20.497, RMS:22.621
Min:0.043, Max:152.600, Mean:20.333, RMS:23.826
100 75 50 40 30 20 10 5 2.5 1
g C m^{-2} y^{-1}
giaf.e20.T62.g16.marbl090.zooO2v3.TF2.sd1.modE
11-16
O2 at 300 m
Mod - Obs
:-171.98, Max:123.39, Mean:-10.41, RMS:23.45
-139.87, Max:128.54, Mean:-3.65, RMS:20.92
80 60 40 20 0 -20 -40 -60 -80
mmol m^{-3}



Control Integration
+ Modification of grazing temperature scaling
z-sum diatom primary prod.
Min:0.011, Max:760.228, Mean:45.236, RMS:70.210
Min:0.007, Max:1792.304, Mean:47.134, RMS:67.204
500
400
300
250
200
150
125
100
75
50
25
1
g C m⁻² y⁻¹
giaf.e20.T62.g16.marbl090.zooO2v3.TF4.sd1.modB
43-62
POC flux at 100 m
Min:0.039, Max:124.175, Mean:20.497, RMS:22.621
Min:0.044, Max:98.701, Mean:20.543, RMS:22.266
100
75
50
40
30
20
10
5
2.5
1
g C m⁻² y⁻¹
giaf.e20.T62.g16.marbl090.zooO2v3.TF4.sd1.modB
43-62
O2 at 300 m Mod - Obs
:-171.98, Max:123.39, Mean:-10.41, RMS:23.45
-149.27, Max:126.60, Mean:-8.32, RMS:21.41
80
60
40
20
0
-20
-40
-60
-80
mmol m⁻³


Control Integration
+ Modification of grazing temperature scaling
z-sum diatom
primary prod.
Min:0.011, Max:760.228, Mean:45.236, RMS:70.210
Min:0.007, Max:1792.304, Mean:47.134, RMS:67.204
500
400
300
250
200
150
125
100
75
50
25
1
g C m^{-2} y^{-1}
giaf.e20.T62.g16.marbl090.zooO2v3.TF4.sd1.modB
43-62
z-sum sm phyto
primary prod.
n:0.025, Max:1993.386, Mean:104.941, RMS:117.962
Min:0.080, Max:395.885, Mean:91.184, RMS:99.818
giaf.e20.T62.g16.marbl090.zooO2v3.TF4.sd1.modB
43-62
z-sum diaz
primary prod.
Min:0.000, Max:560.079, Mean:3.305, RMS:8.992
Min:0.000, Max:8.790, Mean:3.301, RMS:4.168
10
9
8
7
6
5
4
3
2
1
g C m^{-2} y^{-1}
giaf.e20.T62.g16.marbl090.zooO2v3.TF4.sd1.modB
43-62

Discussion

- Many major ocean BGC fields are highly sensitive to small changes in zooplankton grazing rates (poorly constrained, sparse datasets)

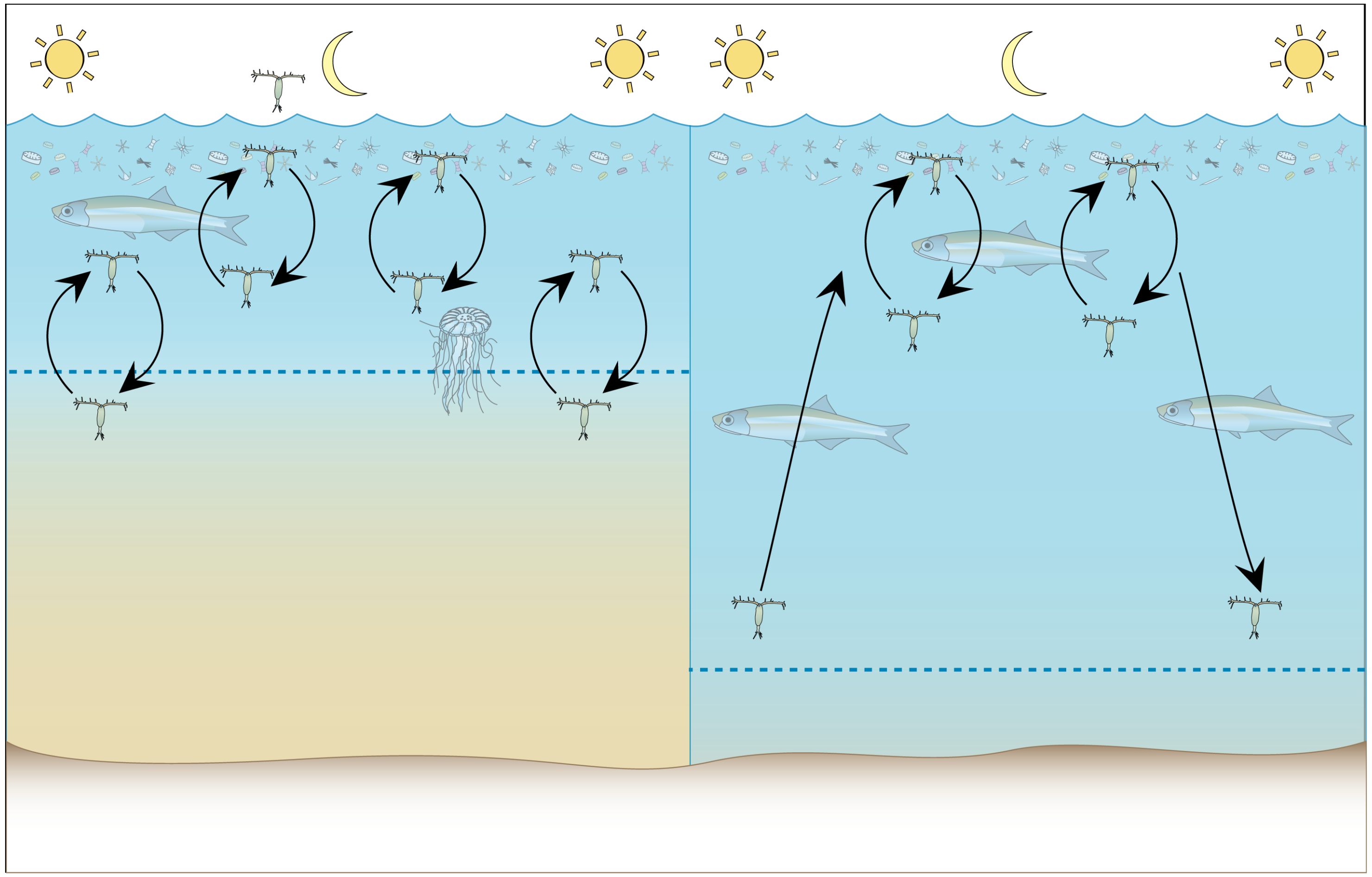
- Grazing modifications must account for differences in grazing on diatoms vs. small phytoplankton

- Parameterizations and functional scalings (e.g. Tfunc) often encompasses multiple processes that are difficult to separate

- Next: climate change experiments — 21st century transient with zooplankton grazing modifications

Future directions

- **Would the rise of OMZs lead to areas dominated by small (micro-) zooplankton?**
    - Implementation of multiple zooplankton size classes (micro-, meso-, and macro-)
- **How does zooplankton vertical migratory behavior in OMZs affect plankton community composition in multiple trophic levels? How will it feedback on the size of the OMZs?**
    - Implementation of vertical migration behavior in MARBL (allows for avoidance of low O_2 areas)



Pierson, Roman et al. *unpublished*