Biogeochemical Elemental Cycling (BEC) Model Update

I. Recent model improvements

II. Preliminary CCSM4 results

III. Planned future model development

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Improved sedimentary iron source and scavenging (Moore and Braucher, 2008)

Improved phytoplankton dynamic Si/C and Fe/C ratios

Modifications to phytoplankton loss terms, allows for more phytoplankton blooms

Incorporation of atmospheric N, P, and Si deposition (in addition to Fe)
  - N has modest impacts, and deposition is changing rapidly since preindustrial
  - P and Si from the atmosphere have very small impacts on C cycle

Diazotroph utilization of fixed N sources (nitrate, ammonium) (Moore, submitted)

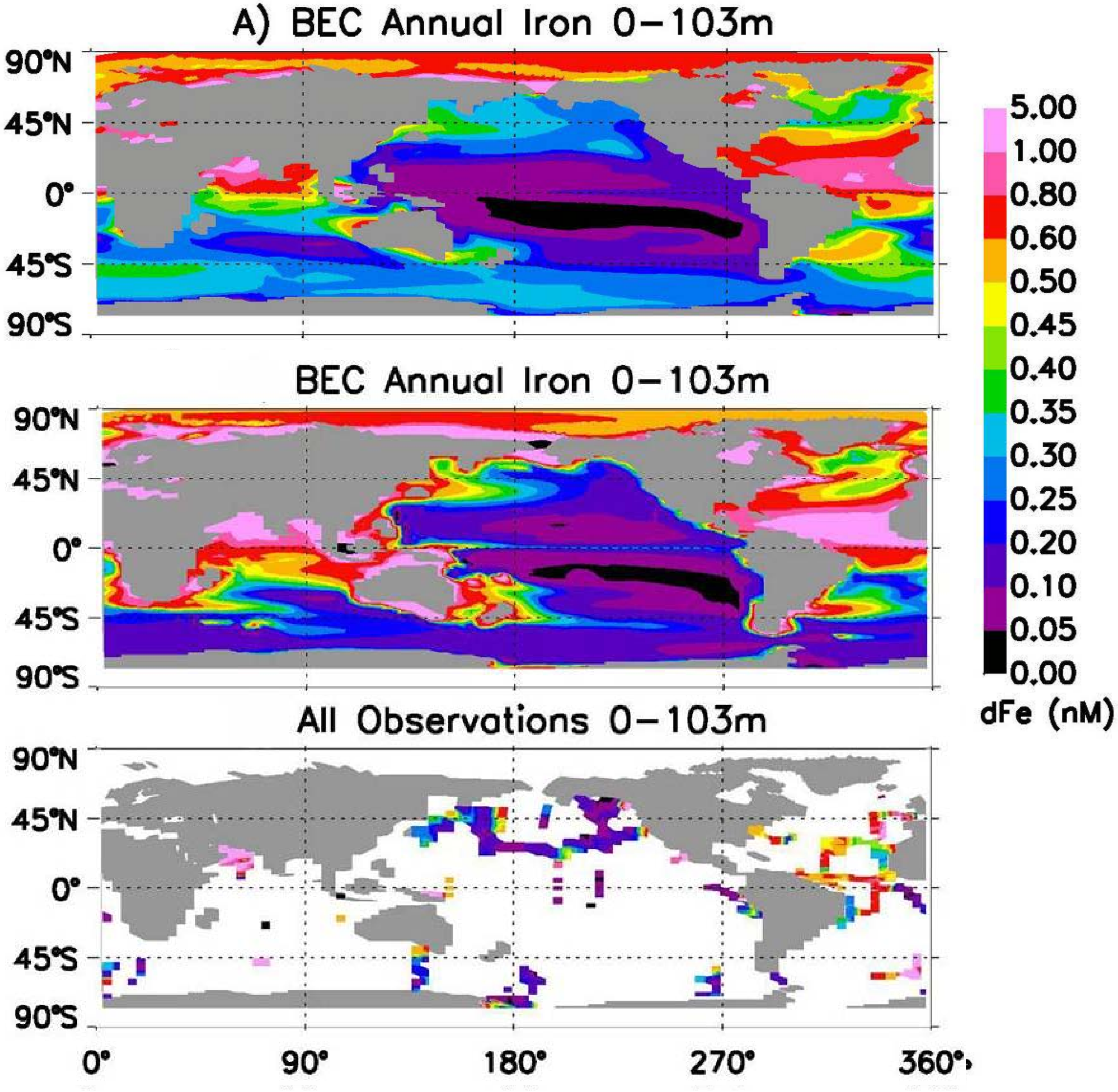
Development of Newton-Krylov solver technique for fast model spin up (Lindsay)

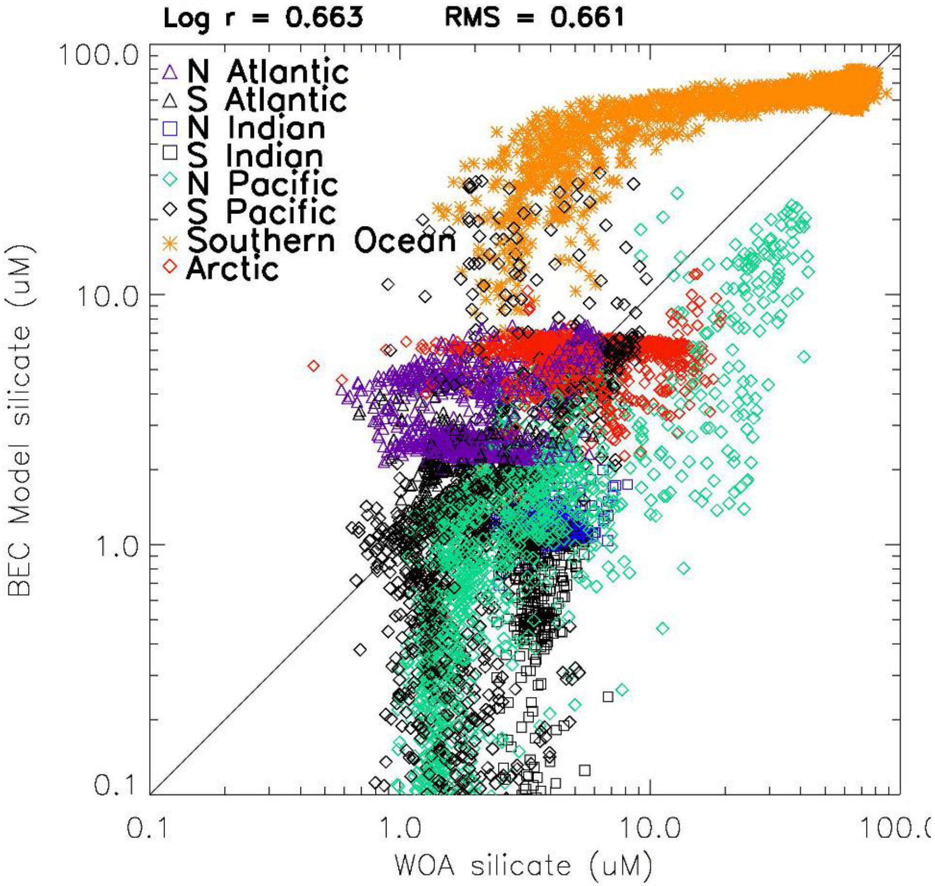
Development of extensive package for model evaluation and validation against a diverse set of observations (Doney et al., 2009)

Addition of a phytoplankton functional group based on *Phaeocystis antarctica* (Wang and Moore)

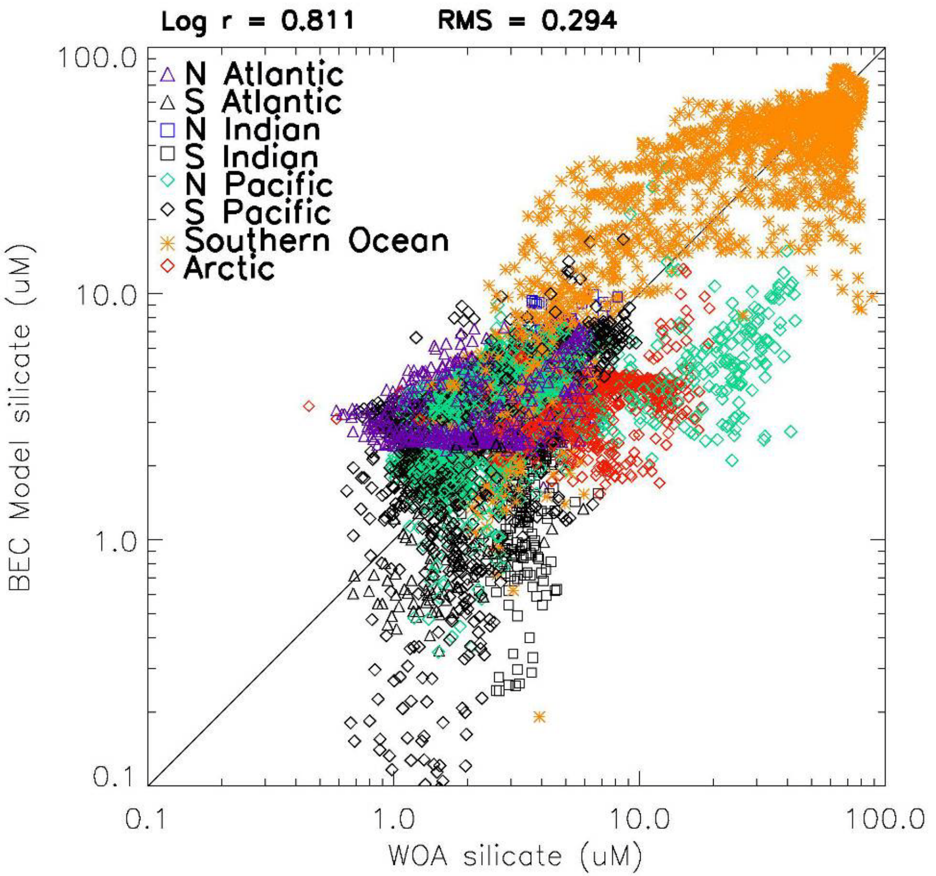
Original BEC

Improved BEC
  sediment Fe source
  Fe scavenging



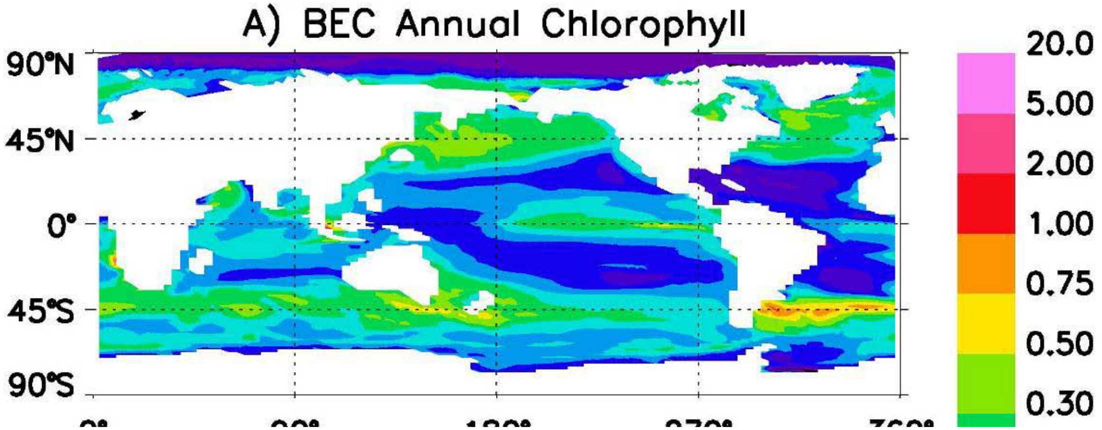


Original BEC - Si vs. Obs.

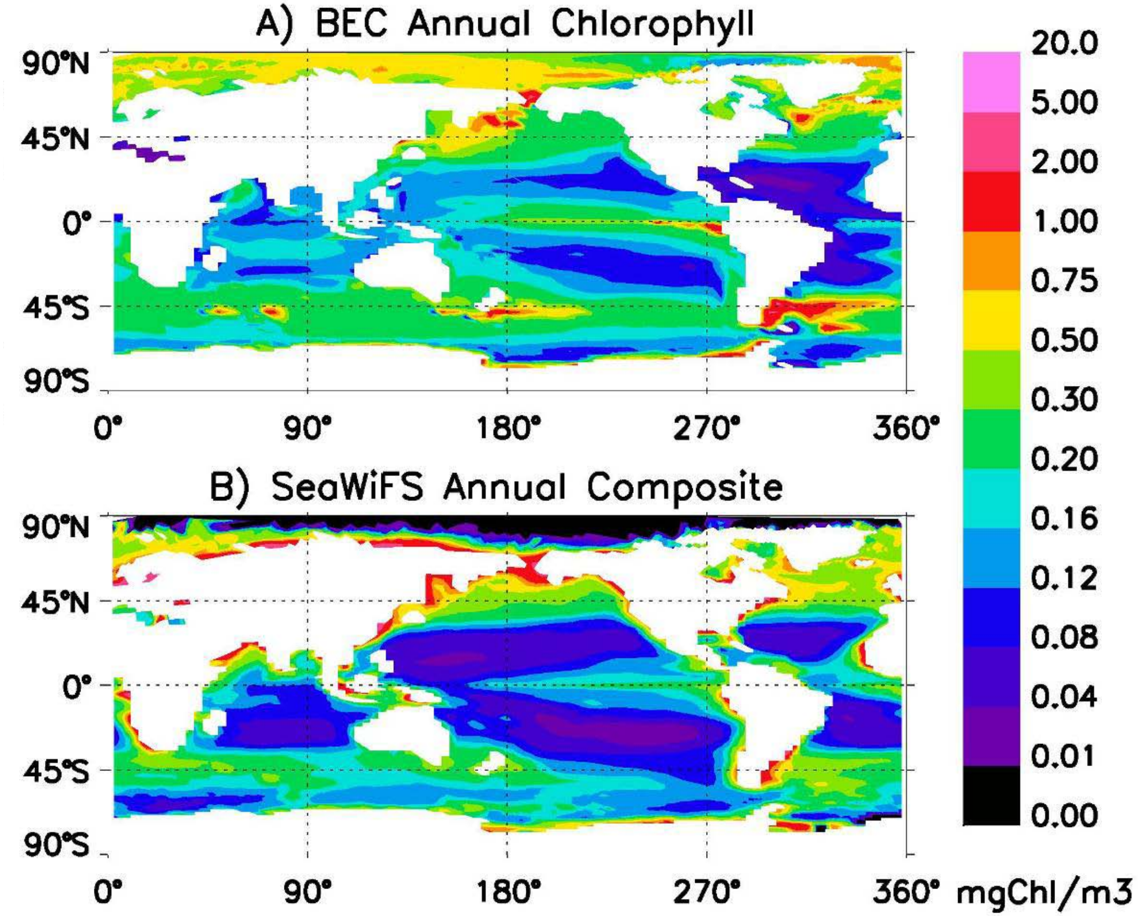


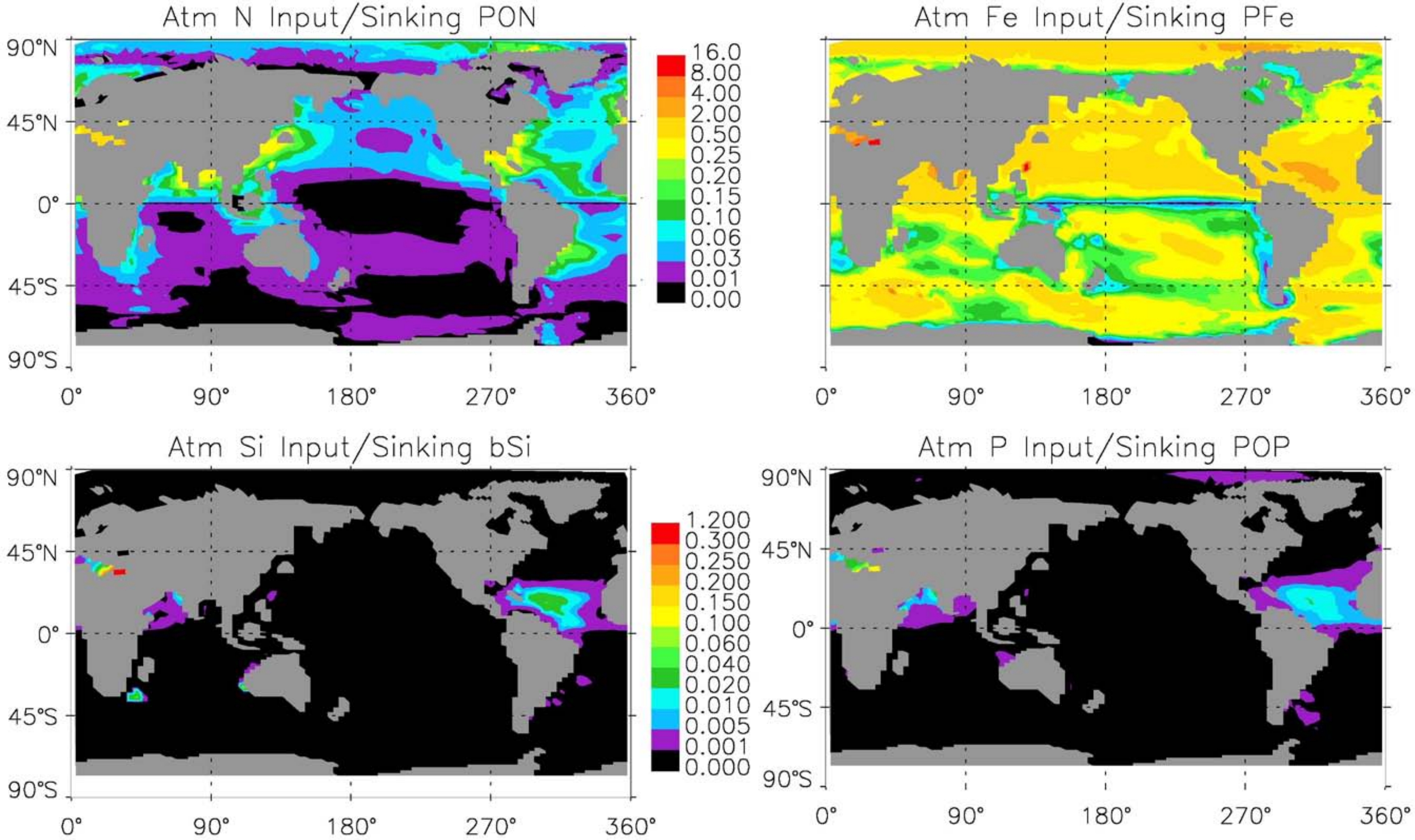
Improved BEC - Si vs. Obs.

Original BEC



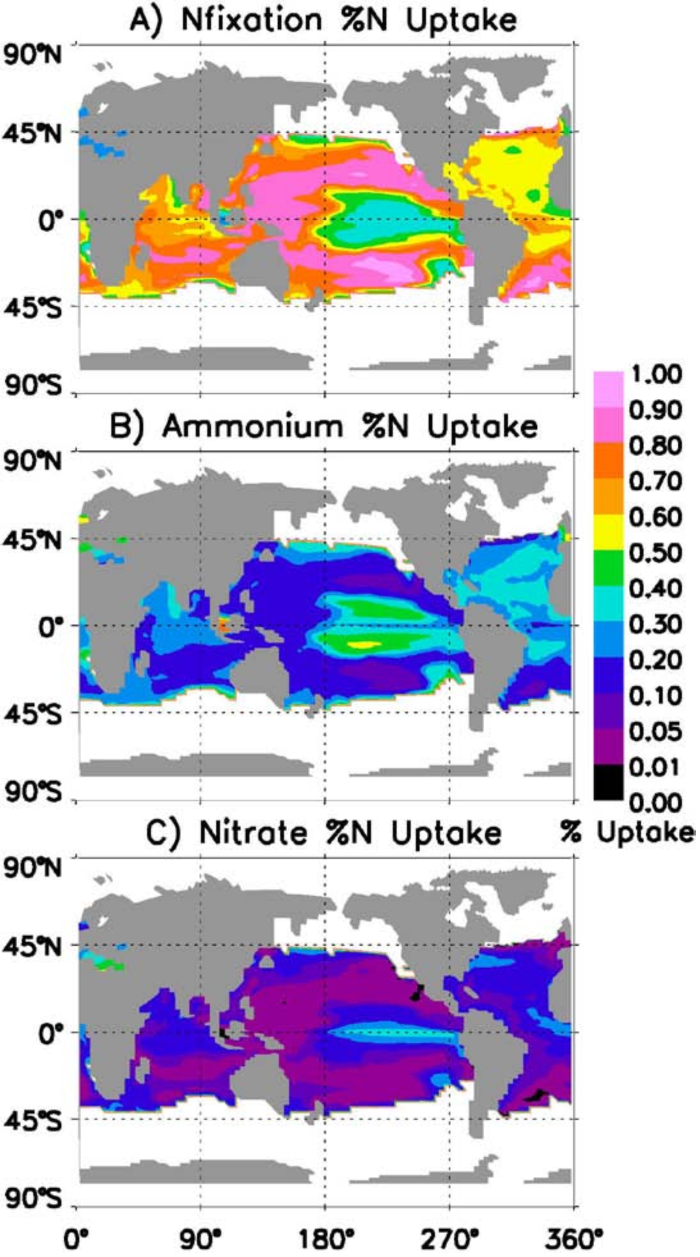
Improved BEC





Plots show the fraction of export production potentially supported by nutrient inputs from the atmosphere (using variable aerosol Fe solubility plus the combustion Fe source from Luo et al. (2008), from Krishnamurthy et al., in preparation).

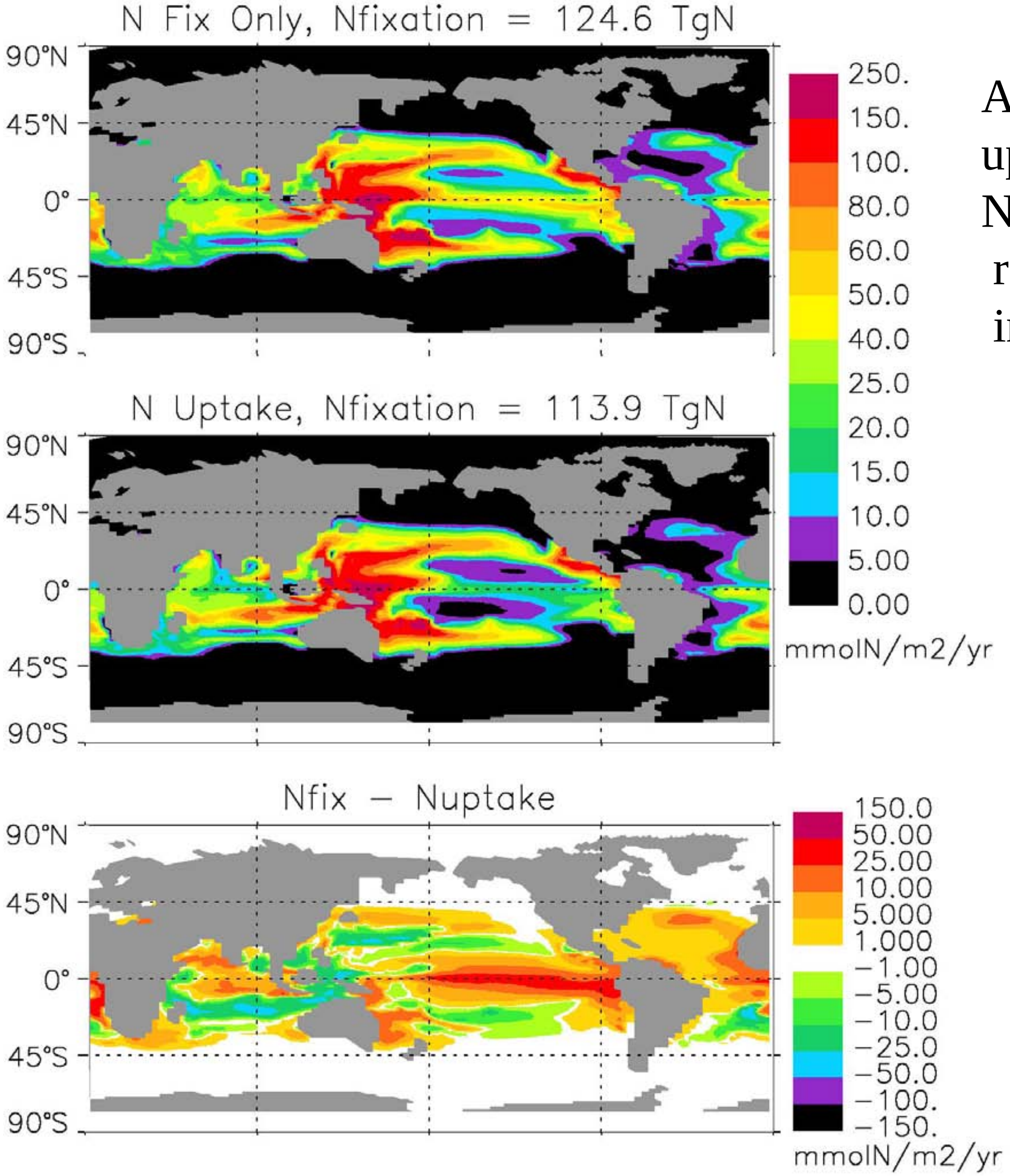
Note atmospheric P and Si inputs account for << 1% of export production (Krishnamurthy, et al, in prep.).



The diazotroph phytoplankton group can now take up fixed N (nitrate, ammonium) when available, with any unmet N demand then met by N_2 fixation.

Uptake kinetics set conservatively to be the same as the diatoms, small phytoplankton are much more efficient taking up fixed N.

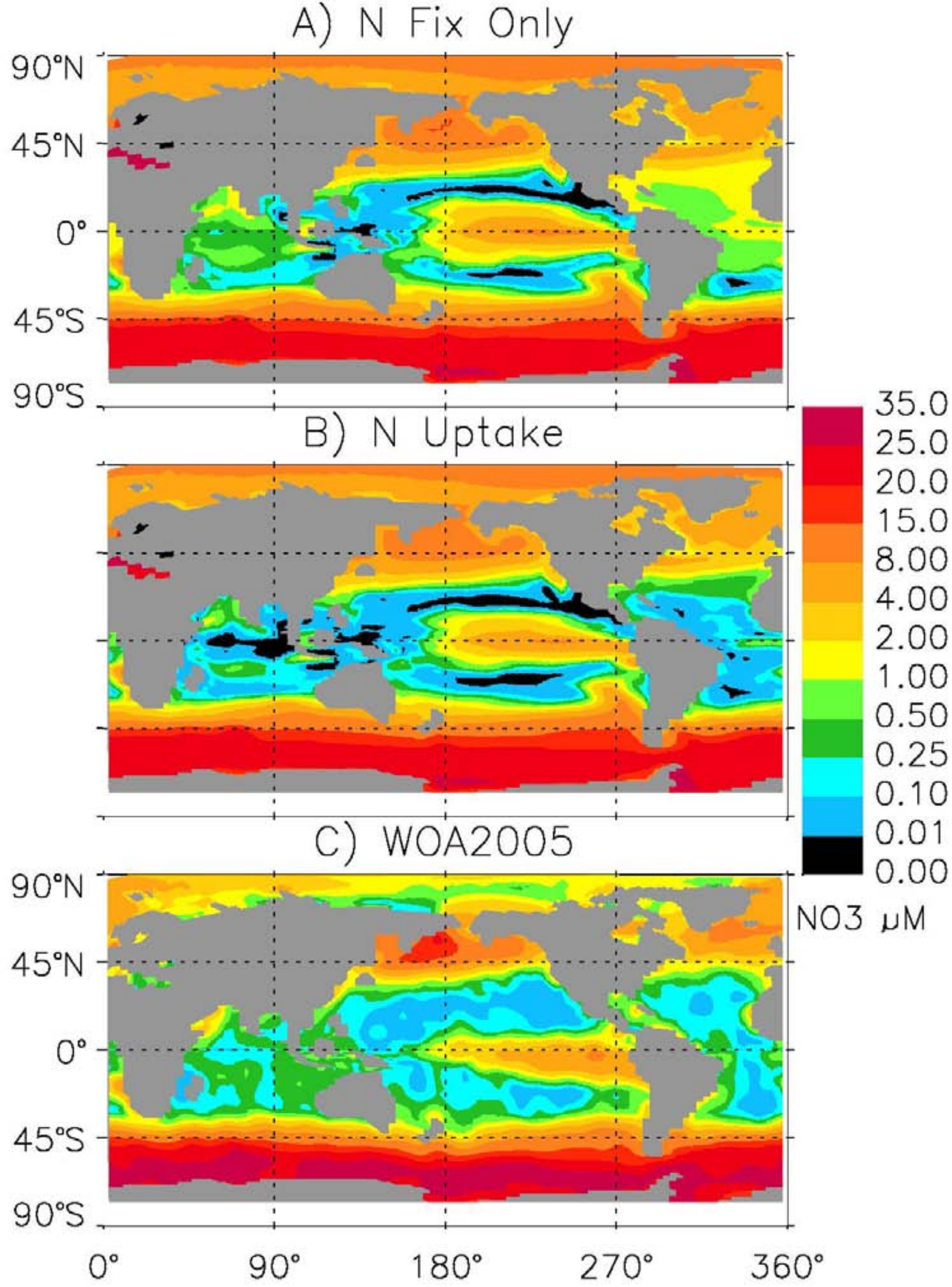
In the N-limited subtropical gyres, >80% of N uptake is still due to N-fixation. However, in the Fe-limited, equatorial Pacific most N demand met through uptake of fixed N.



Allowing diazotroph fixed-N uptake, shifts spatial patterns of N-fixation,

reduced in HNLC regions,

increased in downstream regions.



Allowing for diazotroph fixed-N uptake also maintains more realistic surface nitrate concentrations (i.e. tropical North Atlantic. Thus, this uptake seems an important feedback helping maintain surface ocean N/P ratios at close to the Redfield value.

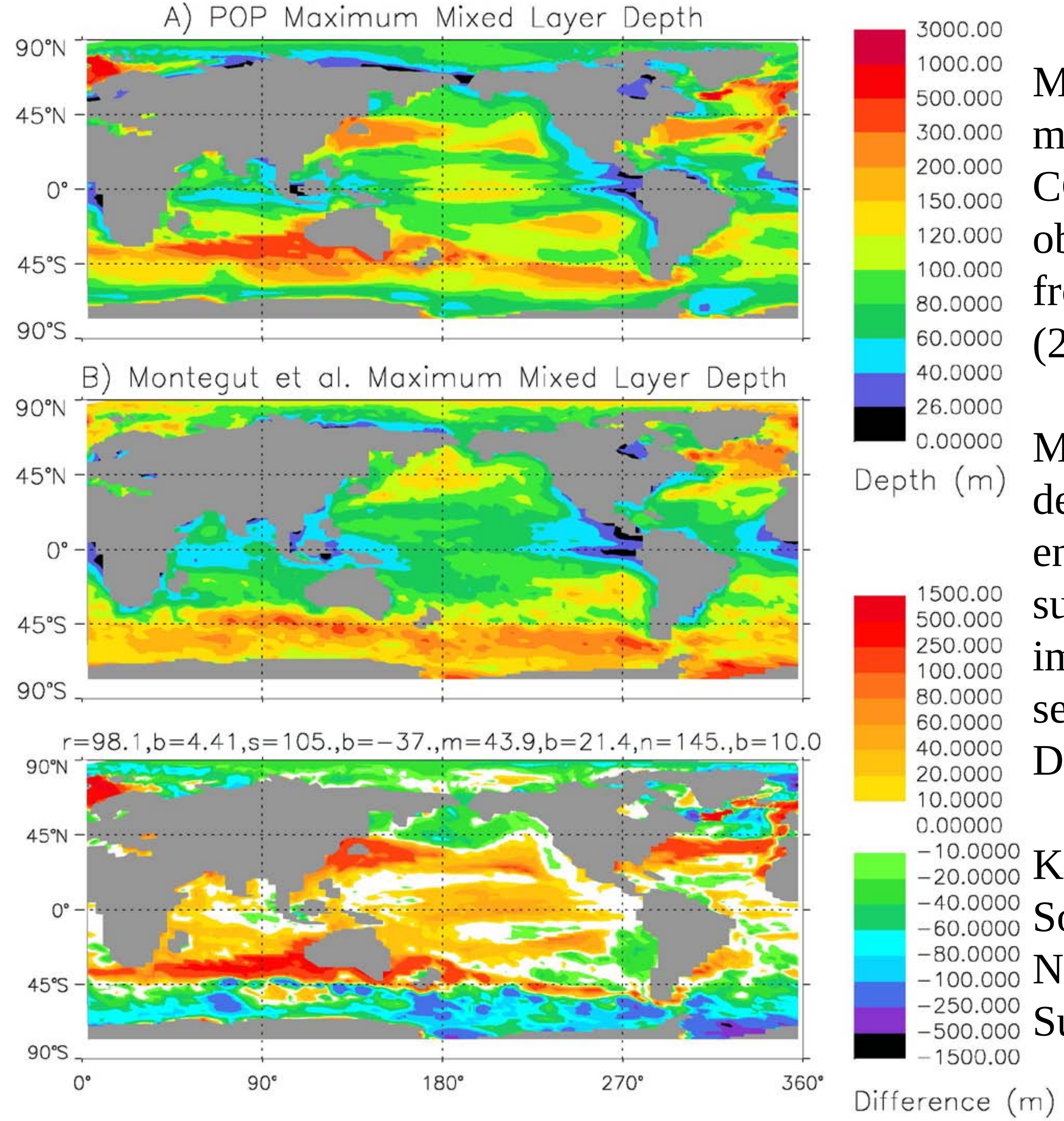
Preliminary CCSM4 Results

Key parameters controlling grazing and remineralization length scales have not been optimized for CCSM4 yet.

Model physics largely drives ocean biogeochemistry.

Biases in mixed layer depths caused problems in CCSM3.

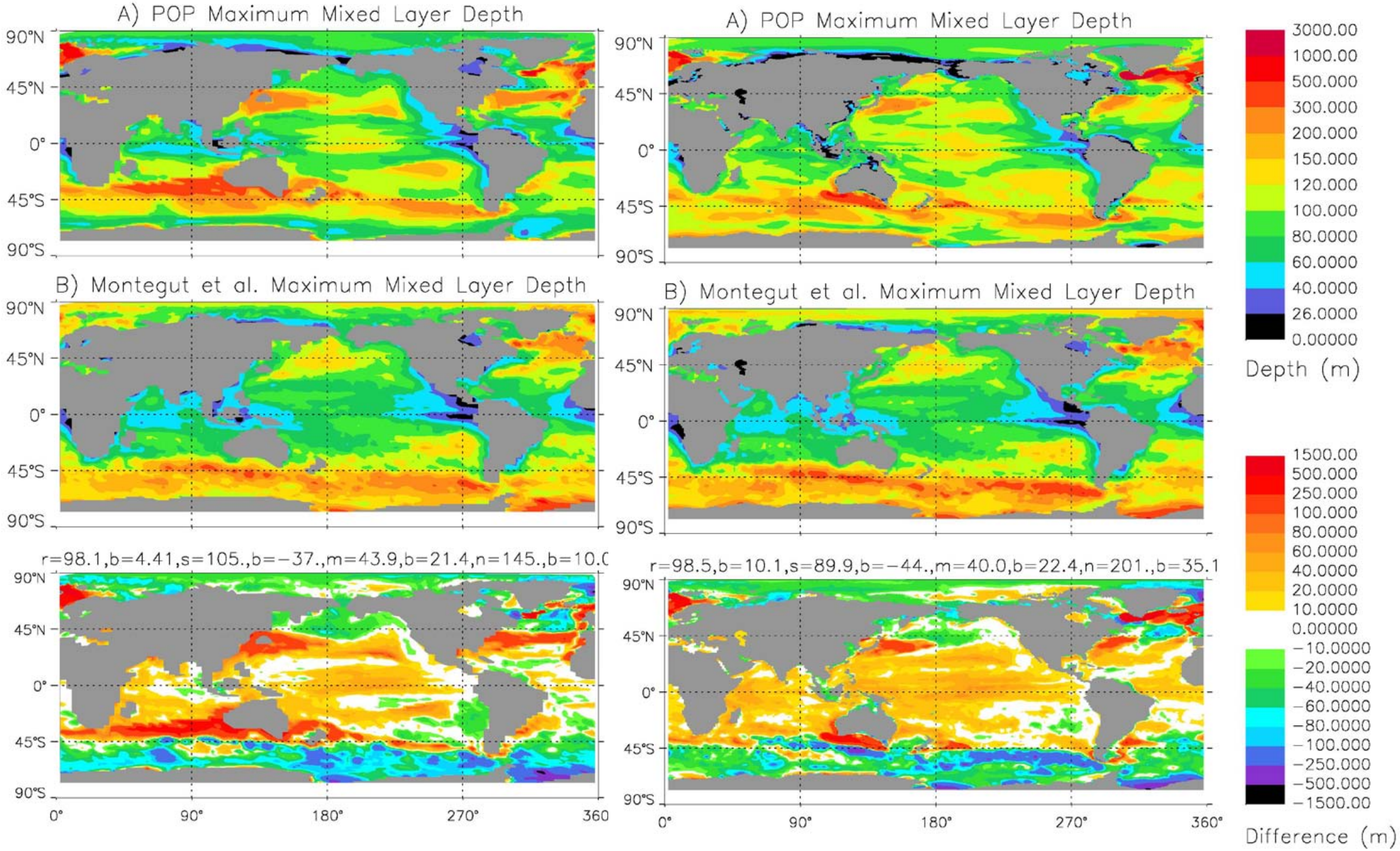
These biases are reduced, but still present in CCSM4.



Maximum monthly mean mixed layer depth from CCSM3 compared with observational estimates from Montegut et al. (2004).

Maximum mixed layer depths control the annual entrainment of nutrients to surface waters and are also important in terms of air-sea gas exchange (O_2, DIC…).

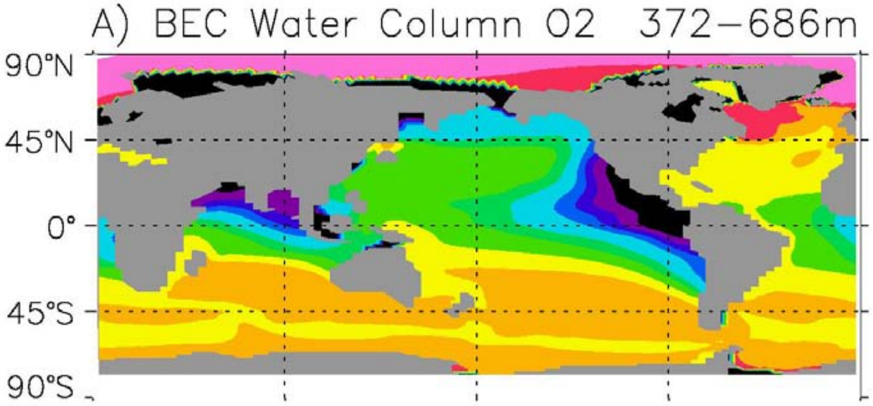
Key regions:
Southern Ocean
NW Pacific
Subtropical Gyres



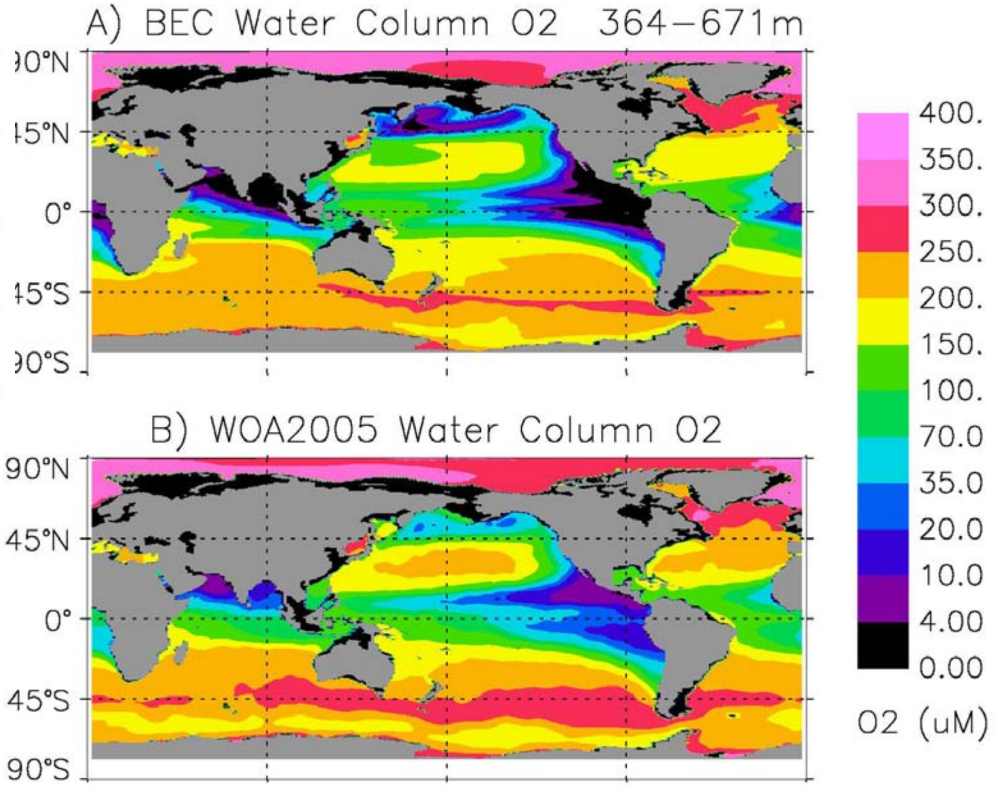
CCSM3 CCSM4

Southern ocean mixed layers still too shallow, but the bias reduced in many areas. NW Pacific mixed layers much improved. Low latitudes still mix too deeply, entraining nutrients that lead to elevated phytoplankton biomass.

CCSM3

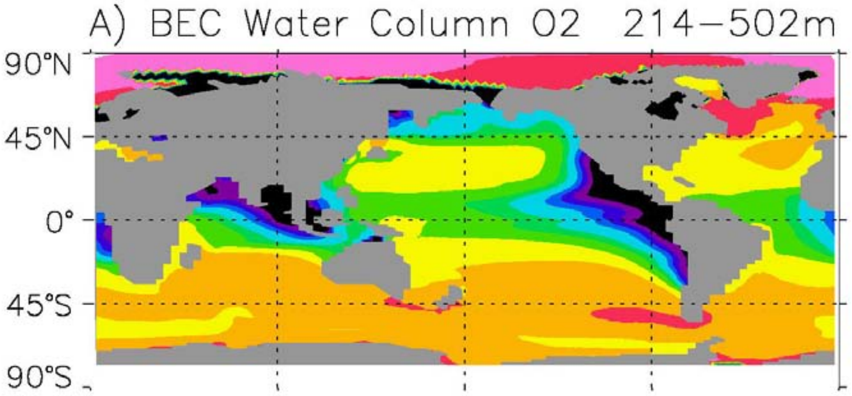


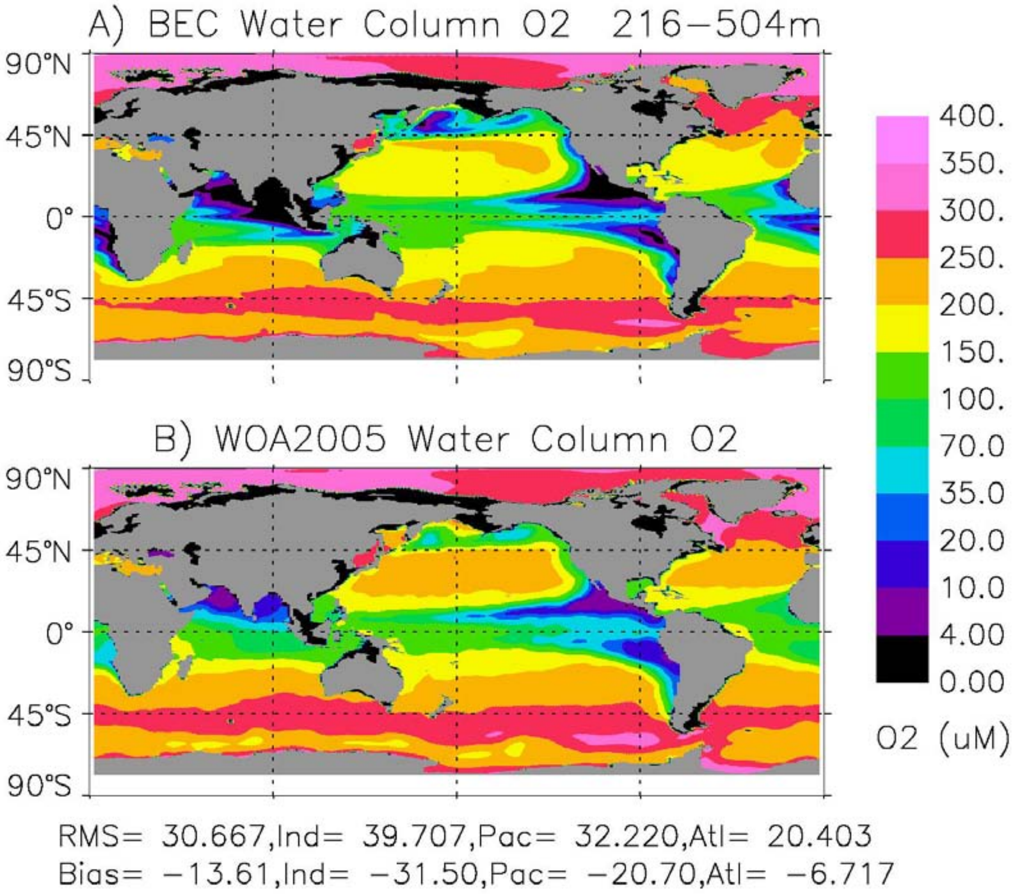
CCSM4



RMS= 25.682,Ind= 33.347,Pac= 25.303,Atl= 19.090
Bias= −11.02,Ind= −25.01,Pac= −19.41,Atl= −3.754

The shallow Southern Ocean mixed layers in the model mean not enough O_2 is entrained at depth. Eventually this contributes to Oxygen Minimum Zones (OMZ) in the tropic that are much too large, which causes excessive denitrification.





CCSM3

CCSM4

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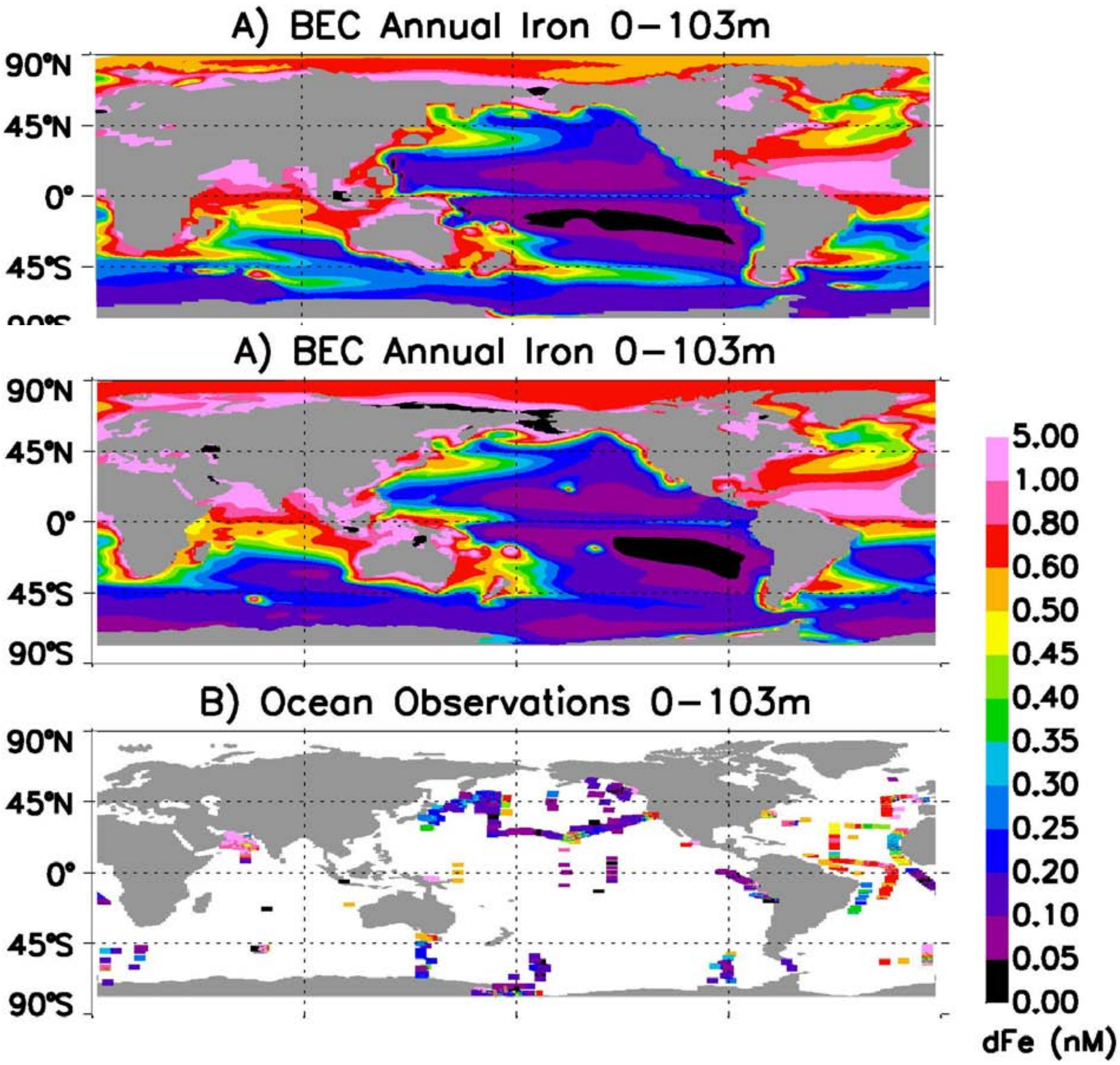
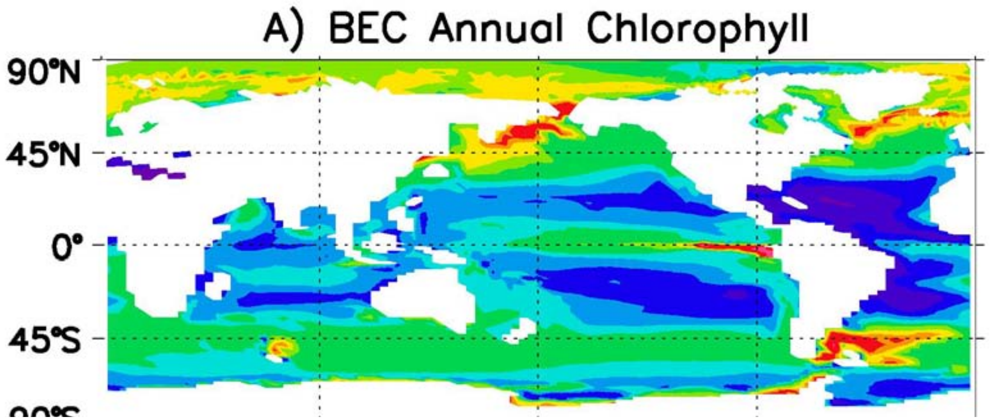
CCSM3

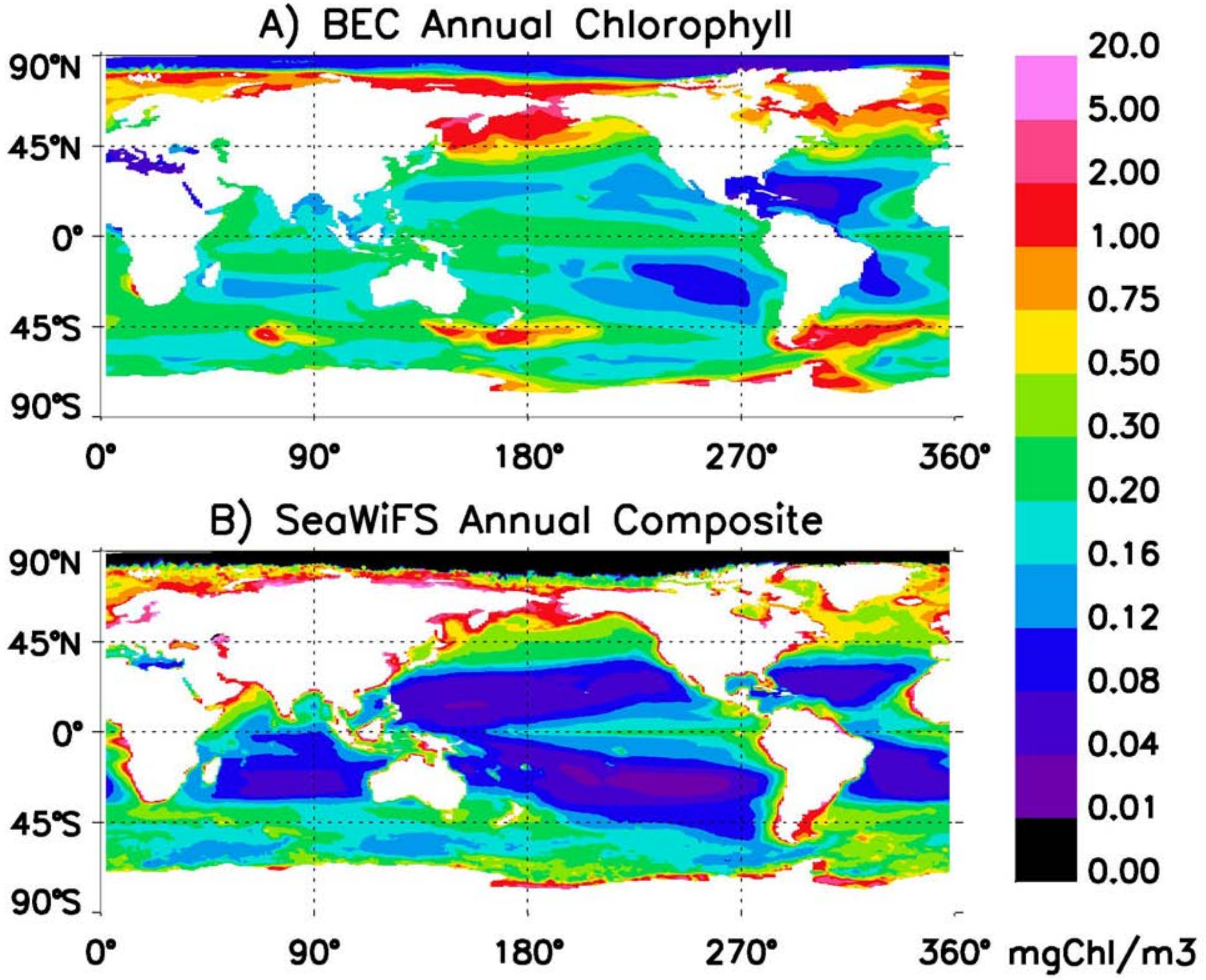
CCSM4


A) BEC Annual Iron 0–103m
A) BEC Annual Iron 0–103m
B) Ocean Observations 0–103m
90°N
45°N
0°
45°S
90°S
5.00
1.00
0.80
0.60
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.10
0.05
0.00
dFe (nM)

CCSM3


A) BEC Annual Chlorophyll
90°N
45°N
0°
45°S
90°S

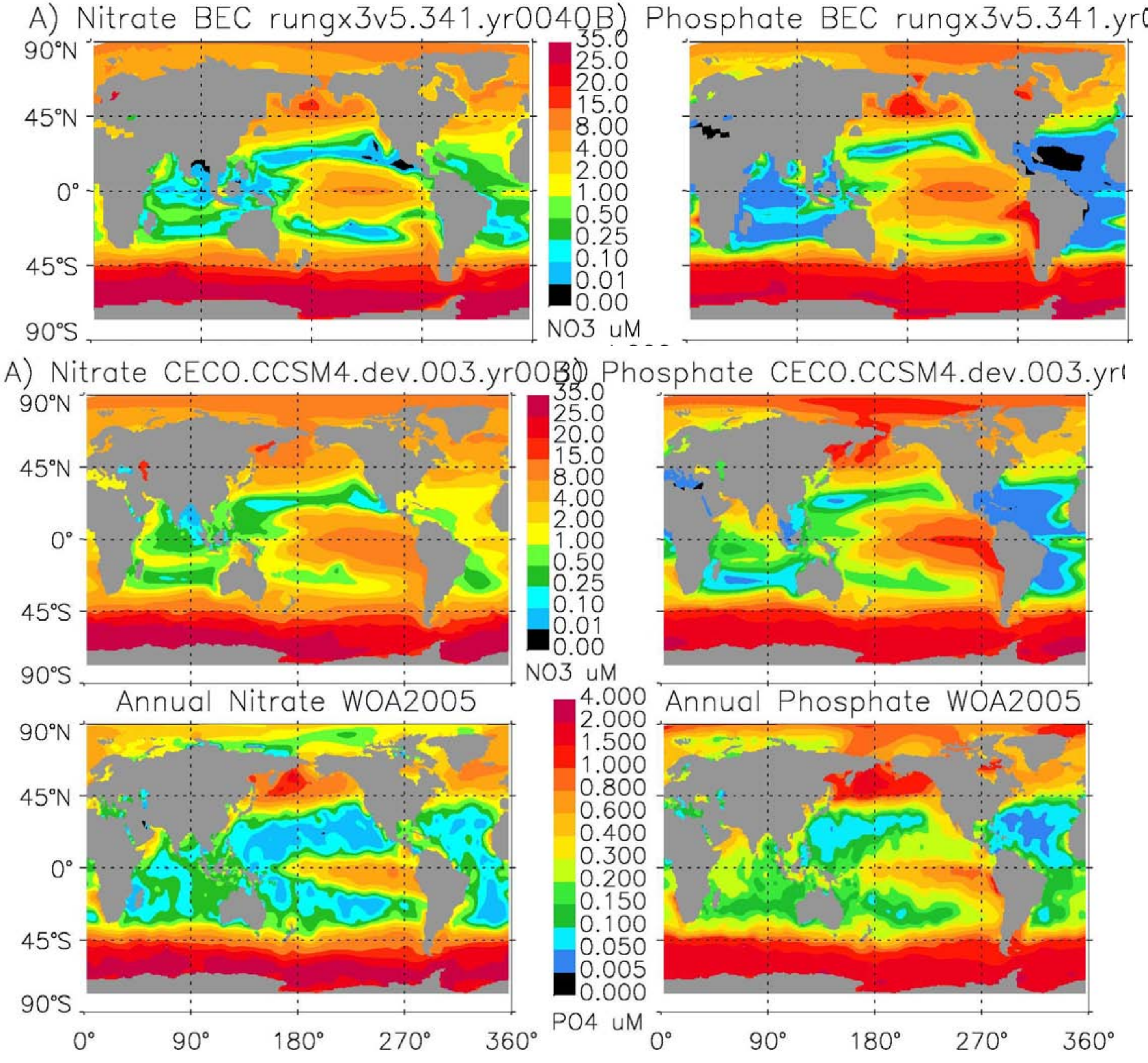
CCSM4

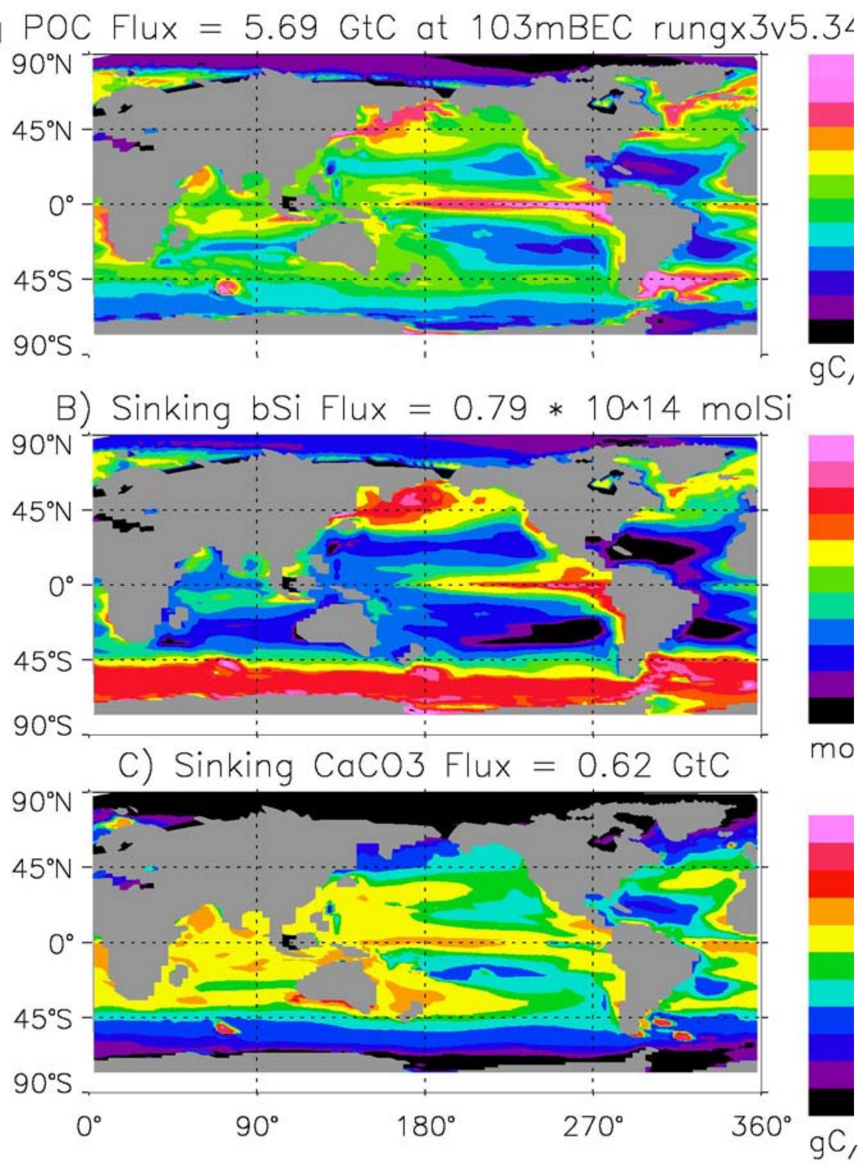

A) BEC Annual Chlorophyll
90°N
45°N
0°
45°S
90°S
0°
90°
180°
270°
360°
B) SeaWiFS Annual Composite
90°N
45°N
0°
45°S
90°S
0°
90°
180°
270°
360°
mgChl/m3
20.0
5.00
2.00
1.00
0.75
0.50
0.30
0.20
0.16
0.12
0.08
0.04
0.01
0.00

CCSM3

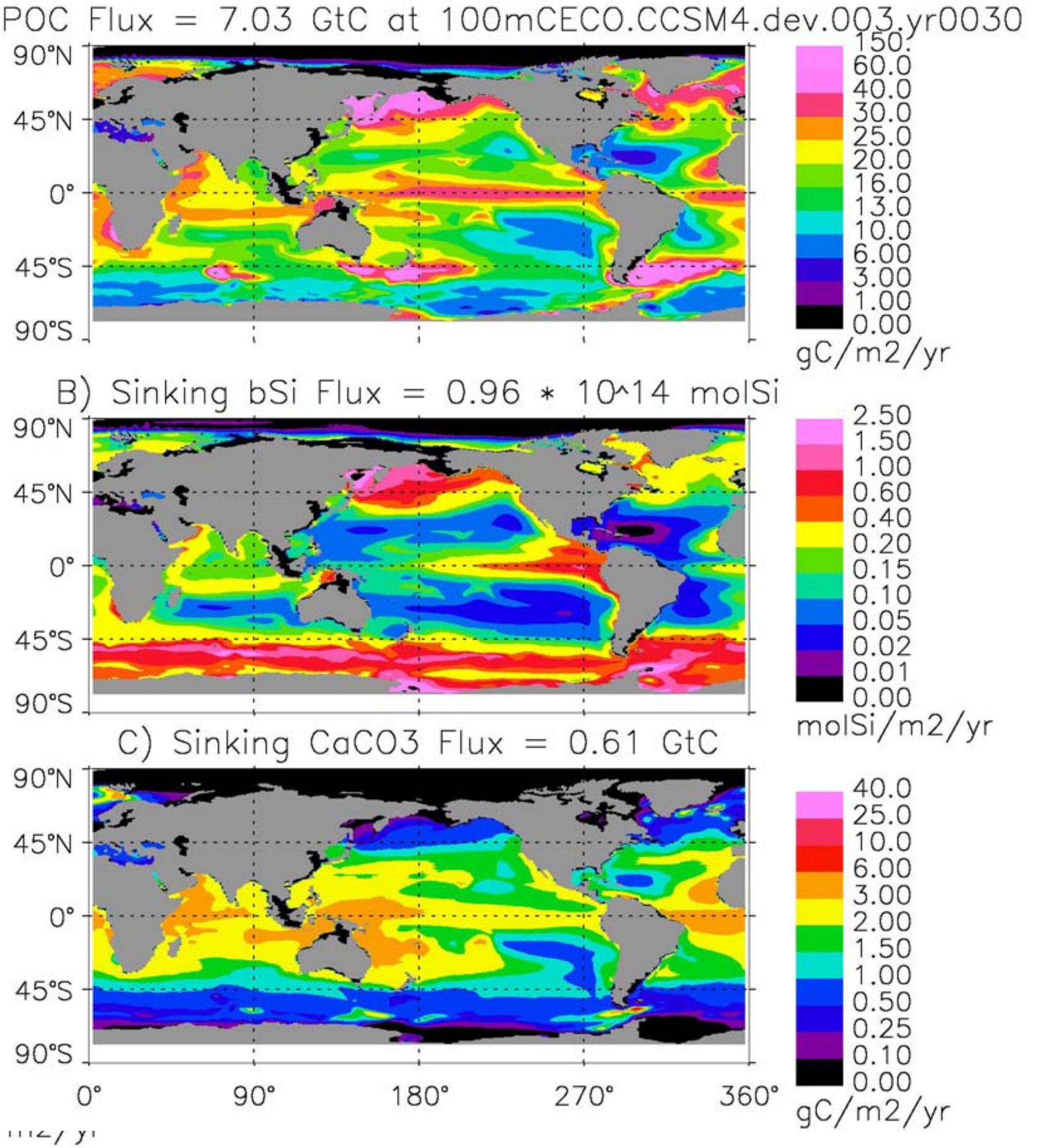
CCSM4

Observed

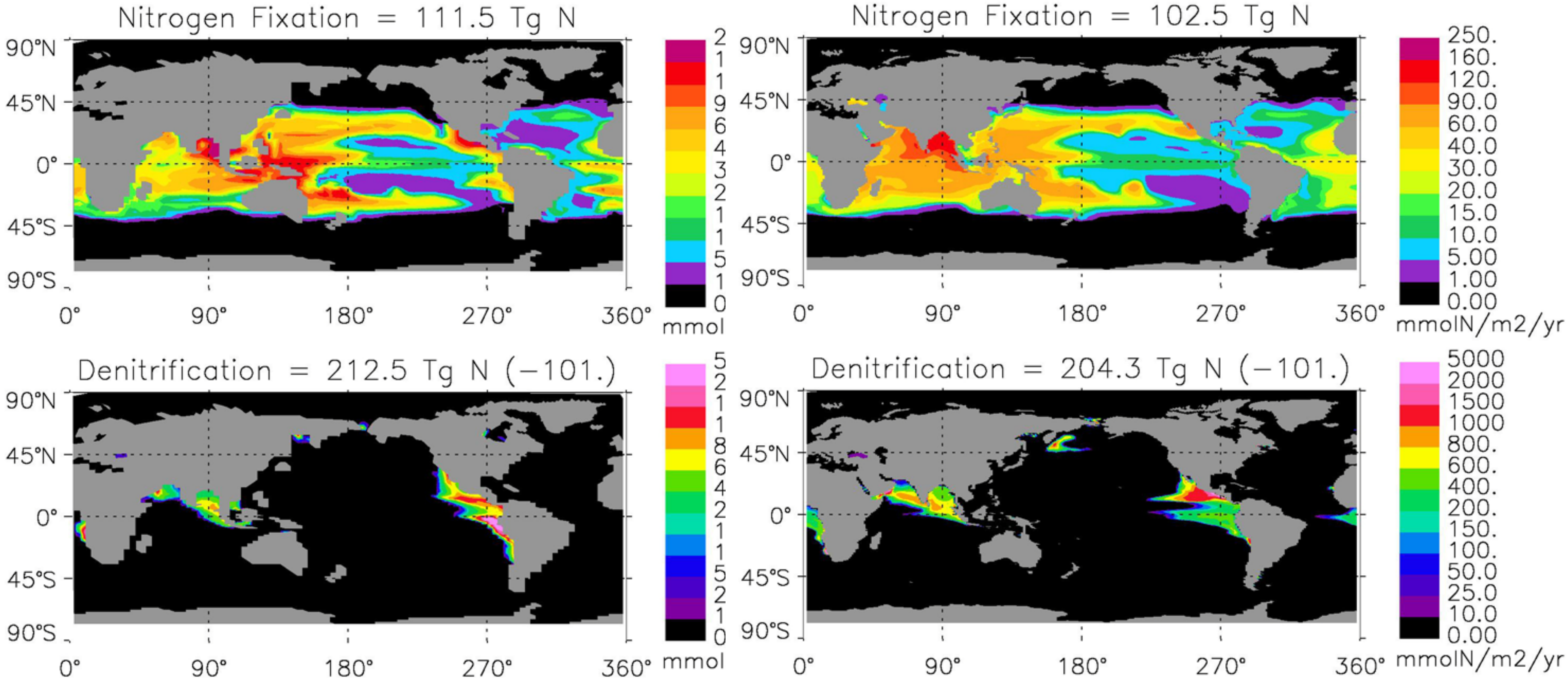



POC Flux = 5.69 GtC at 103mBEC rungx3v5.34
90°N
45°N
0°
45°S
90°S
gC/
B) Sinking bSi Flux = 0.79 * 10^14 molSi
90°N
45°N
0°
45°S
90°S
mo
C) Sinking CaCO3 Flux = 0.62 GtC
90°N
45°N
0°
45°S
90°S
0°
90°
180°
270°
360°
gC/

CCSM3


POC Flux = 7.03 GtC at 100mCECO.CCSM4.dev.003.yr0030
90°N
45°N
0°
45°S
90°S
150.
60.0
40.0
30.0
25.0
20.0
16.0
13.0
10.0
6.00
3.00
1.00
0.00
gC/m2/yr
B) Sinking bSi Flux = 0.96 * 10^14 molSi
90°N
45°N
0°
45°S
90°S
2.50
1.50
1.00
0.60
0.40
0.20
0.15
0.10
0.05
0.02
0.01
0.00
molSi/m2/yr
C) Sinking CaCO3 Flux = 0.61 GtC
90°N
45°N
0°
45°S
90°S
0°
90°
180°
270°
360°
40.0
25.0
10.0
6.00
3.00
2.00
1.50
1.00
0.50
0.25
0.10
0.00
gC/m2/yr

CCSM4



Nitrogen Fixation = 111.5 Tg N

Nitrogen Fixation = 102.5 Tg N

Denitrification = 212.5 Tg N (−101.)

Denitrification = 204.3 Tg N (−101.)

CCSM3

CCSM4

Planned BEC model development efforts over the next 1-2 years:

River Nutrients – key nutrient source to oceans (Moore).

Expanded Nitrogen Cycle – sedimentary denitrification, ocean ammonia and N_2O emissions, (Moore, Doney)

$CaCO_3$ Dissolution – needs to tied more directly to saturation state and water column chemistry (Lindsay).

Continued development of model metrics package (Doney)

Additional phytoplankton functional groups (Moore)

Improved microbial loop implementation (Doney)