Impacts on Marine Biogeochemistry After Four Centuries of Climate Warming

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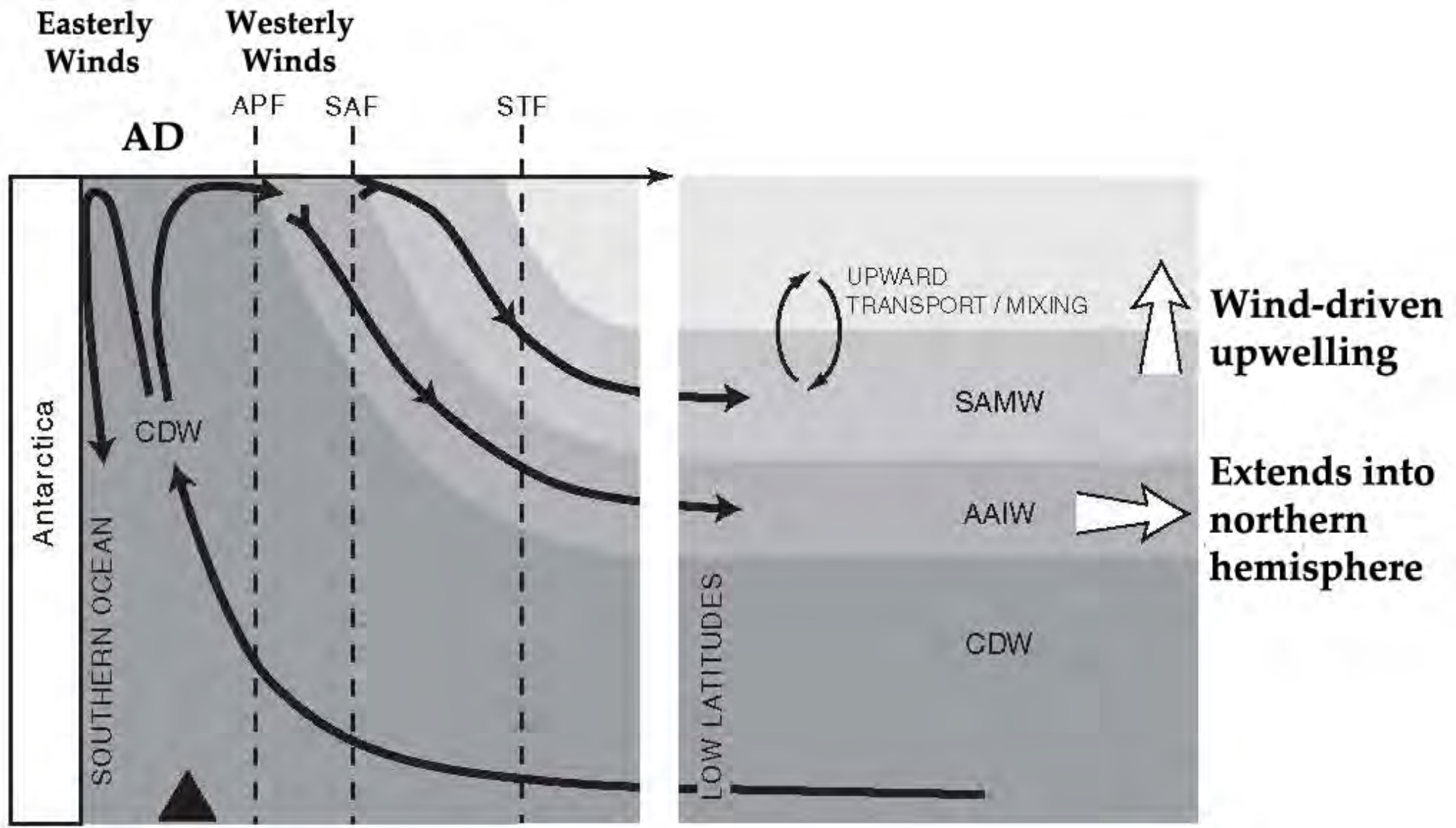
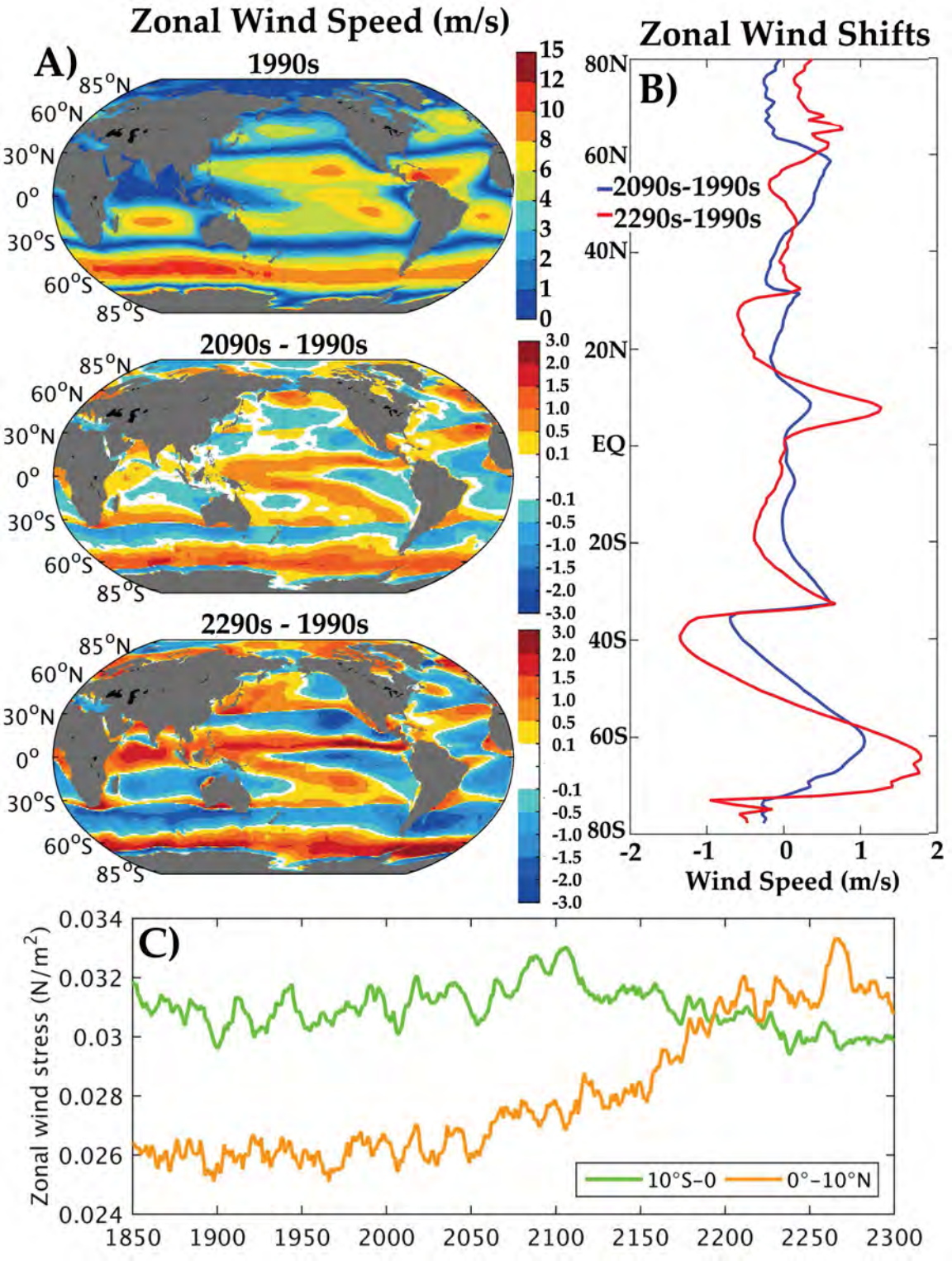
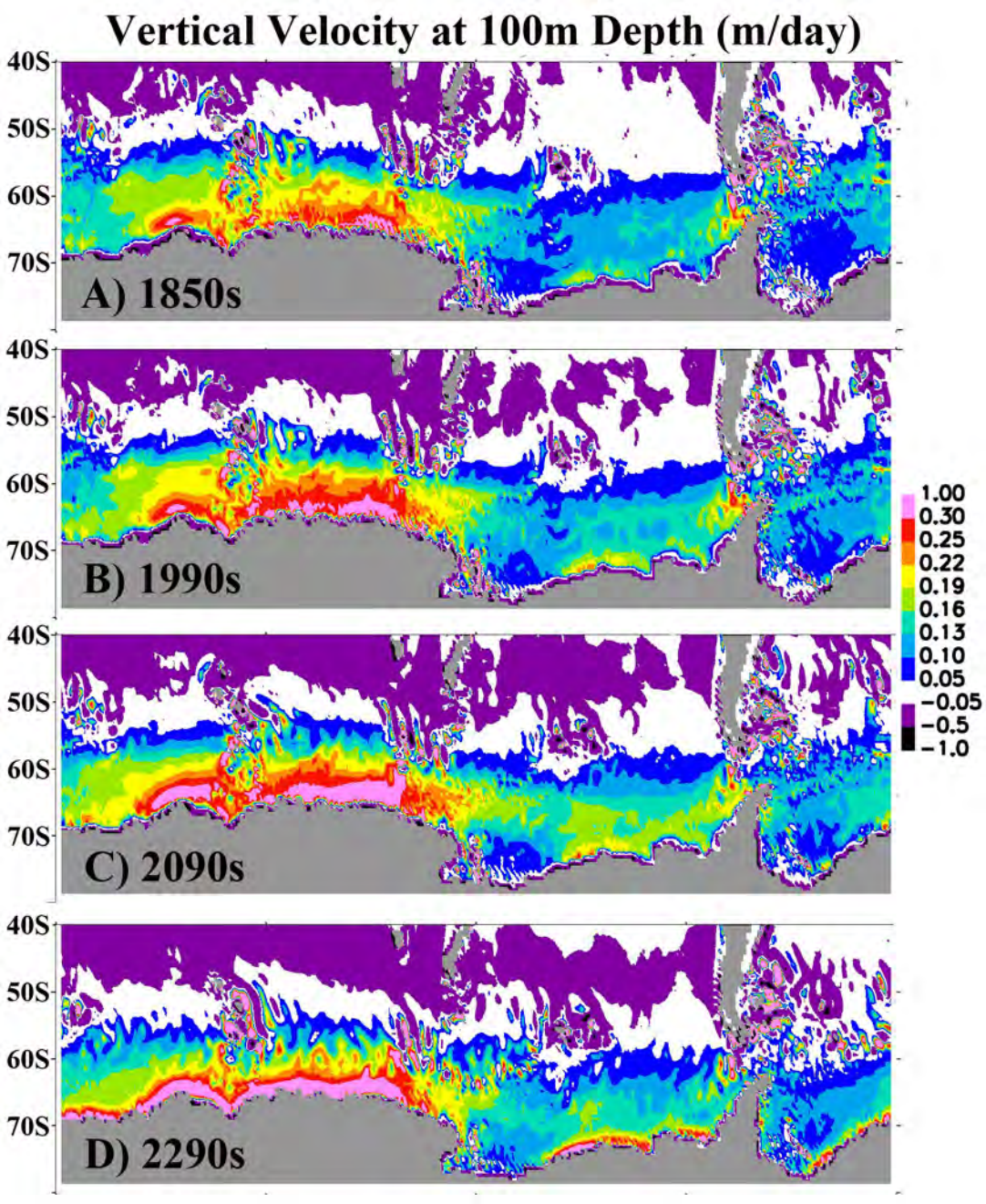
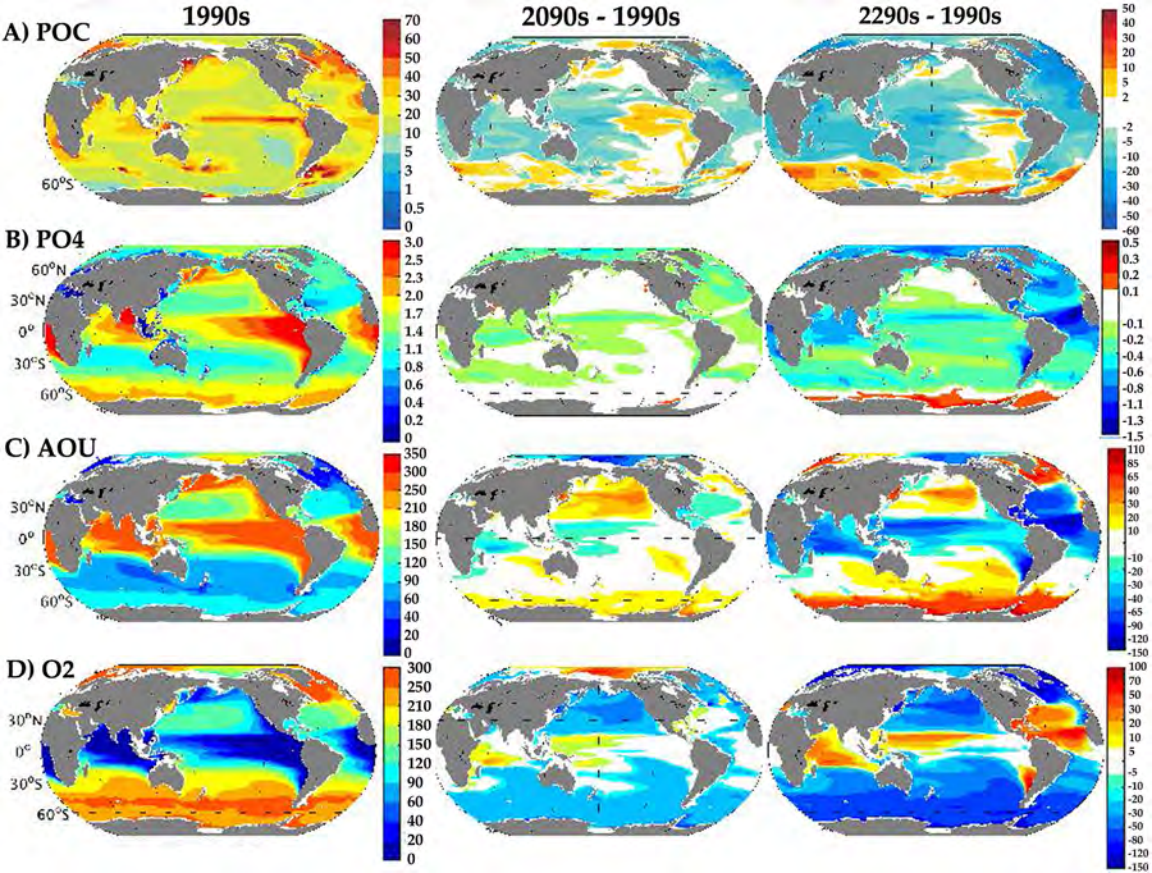
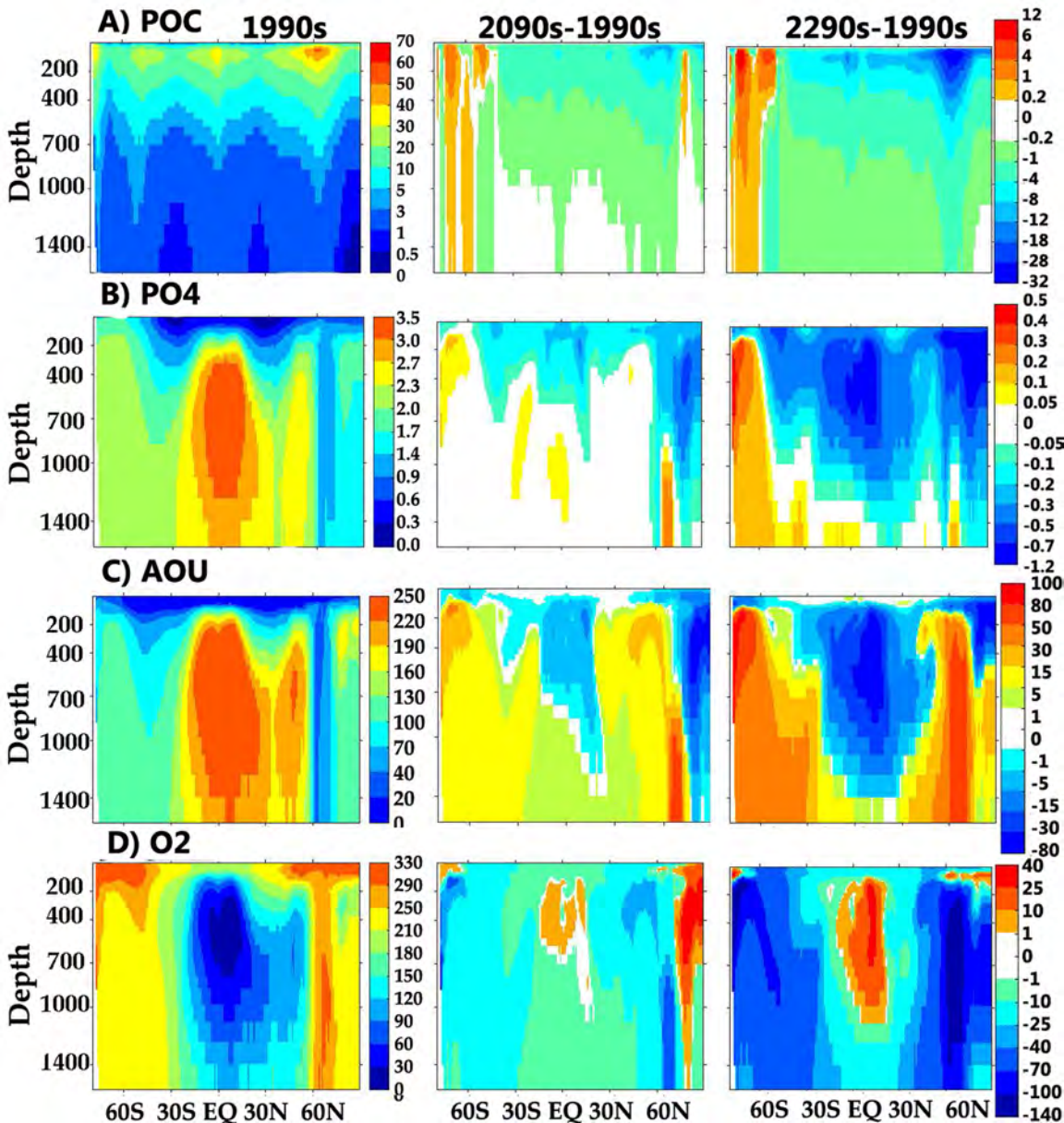
NCAR

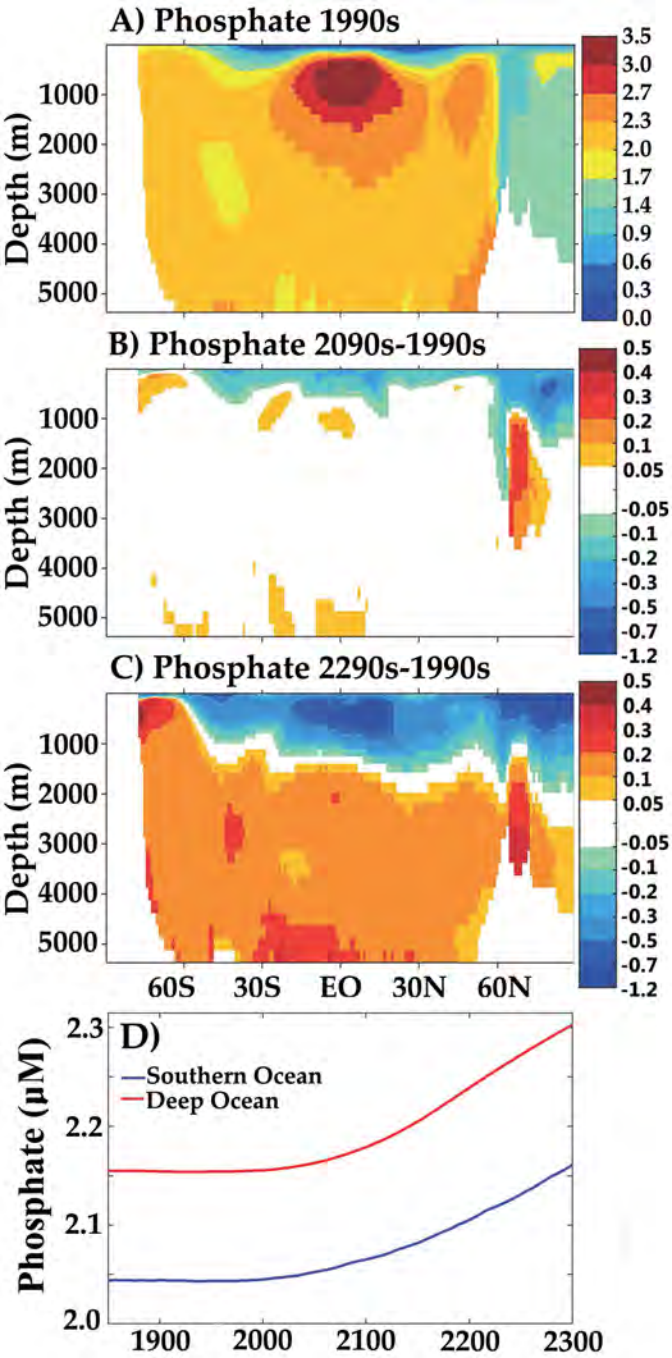

Easterly Winds
Westerly Winds
APF
SAF
STF
AD
Antarctica
CDW
SOUTHERN OCEAN
UPWARD TRANSPORT / MIXING
SAMW
AAIW
CDW
LOW LATITUDES
Wind-driven upwelling
Extends into northern hemisphere

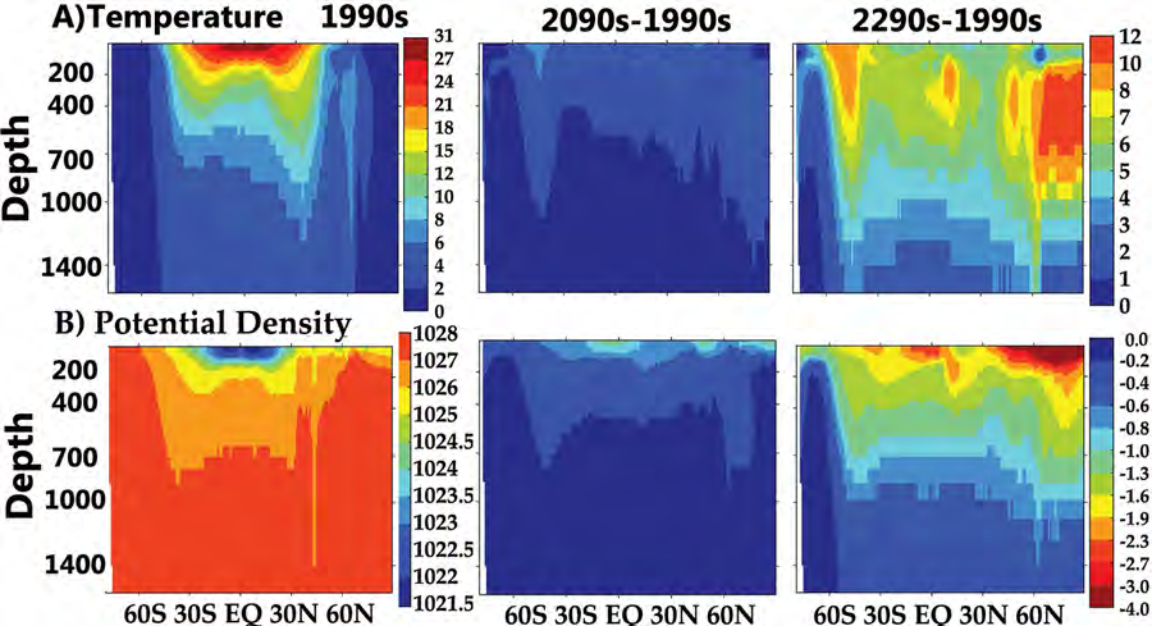

Zonal Wind Speed (m/s)
A)
1990s
2090s - 1990s
2290s - 1990s
85°N
60°N
30°N
0°
30°S
60°S
85°S
15
12
10
8
6
4
3
2
1
0
3.0
2.0
1.5
1.0
0.5
0.1
-0.1
-0.5
-1.0
-1.5
-2.0
-3.0
Zonal Wind Shifts
B)
2090s-1990s
2290s-1990s
80N
60N
40N
20N
EQ
20S
40S
60S
80S
-2
-1
0
1
2
Wind Speed (m/s)
C)
Zonal wind stress (N/m²)
0.034
0.032
0.03
0.028
0.026
0.024
1850
1900
1950
2000
2050
2100
2150
2200
2250
2300
10°S-0
0°-10°N

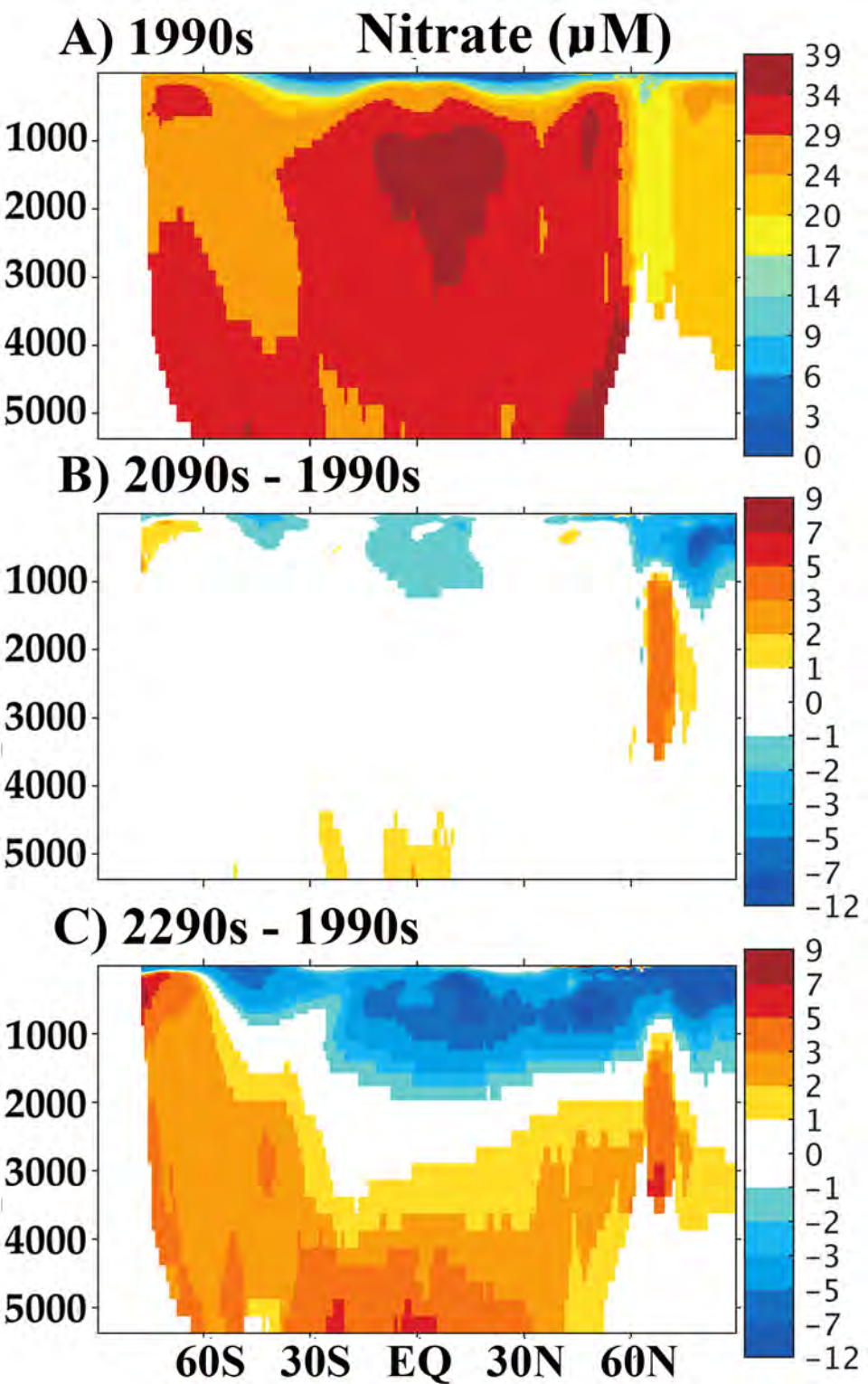

Vertical Velocity at 100m Depth (m/day)
40S
50S
60S
70S
A) 1850s
B) 1990s
C) 2090s
D) 2290s
1.00
0.30
0.25
0.22
0.19
0.16
0.13
0.10
0.05
−0.05
−0.5
−1.0

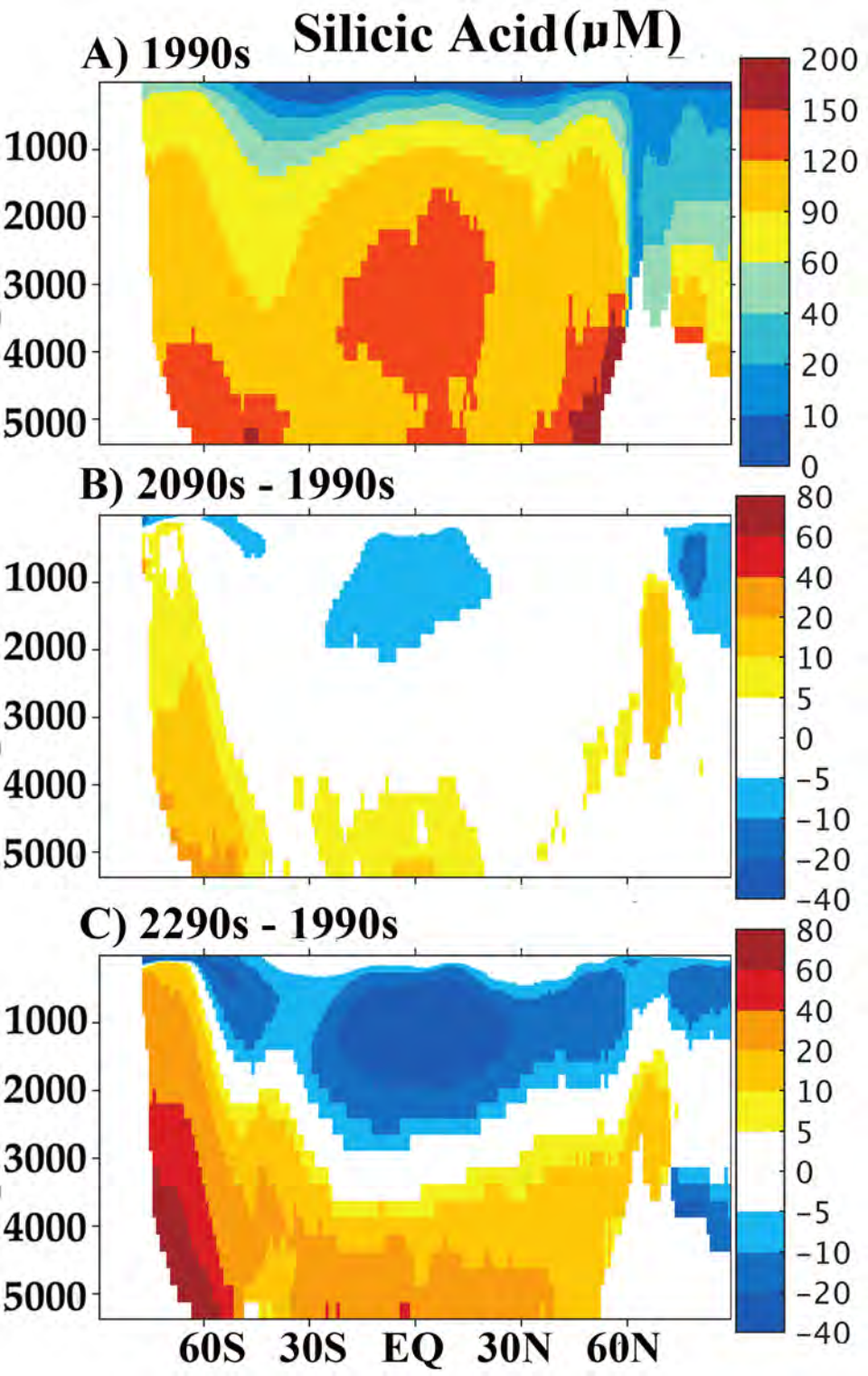

1990s
2090s - 1990s
2290s - 1990s
A) POC
B) PO4
C) AOU
D) O2
60°S
60°N
30°N
0°
30°S
70 60 50 40 30 20 10 5 3 1 0.5 0
50 40 30 20 10 5 2 -2 -5 -10 -20 -30 -40 -50 -60
3.0 2.5 2.3 2.0 1.7 1.4 1.1 0.8 0.6 0.4 0.2 0
0.5 0.3 0.2 0.1 -0.1 -0.2 -0.4 -0.6 -0.8 -1.1 -1.3 -1.5
350 300 250 210 180 150 120 90 60 40 20 0
110 85 65 40 30 20 10 -10 -20 -30 -40 -65 -90 -120 -150
300 250 210 180 150 120 90 60 40 20 0
100 70 50 30 20 10 5 -5 -10 -20 -30 -50 -80 -120 -150

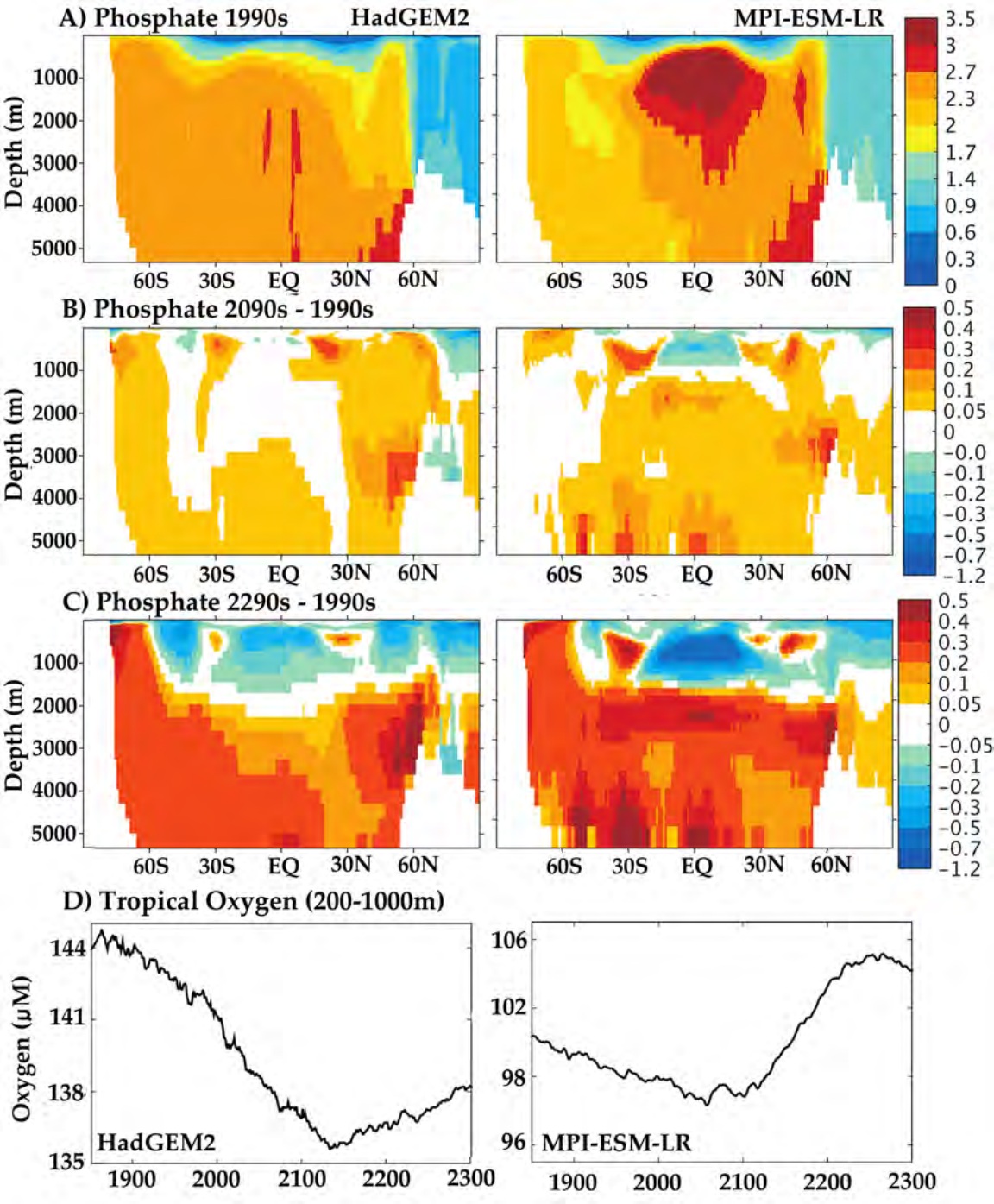

A) POC
1990s
2090s-1990s
2290s-1990s
B) PO4
C) AOU
D) O2
Depth
200
400
700
1000
1400
70 60 50 40 30 20 10 5 3 1 0.5 0
12 6 4 1 0.2 0 -0.2 -1 -4 -8 -12 -18 -28 -32
3.5 3.0 2.7 2.3 2.0 1.7 1.4 0.9 0.6 0.3 0.0
0.5 0.4 0.3 0.2 0.1 0.05 0 -0.05 -0.1 -0.2 -0.3 -0.5 -0.7 -1.2
250 220 190 160 130 100 70 40 20 0
100 80 50 30 15 5 1 0 -1 -5 -15 -30 -80
330 290 250 210 180 150 120 90 60 30 0
40 25 10 1 0 -1 -10 -25 -40 -70 -100 -140
60S 30S EQ 30N 60N
60S 30S EQ 30N 60N
60S 30S EQ 30N 60N

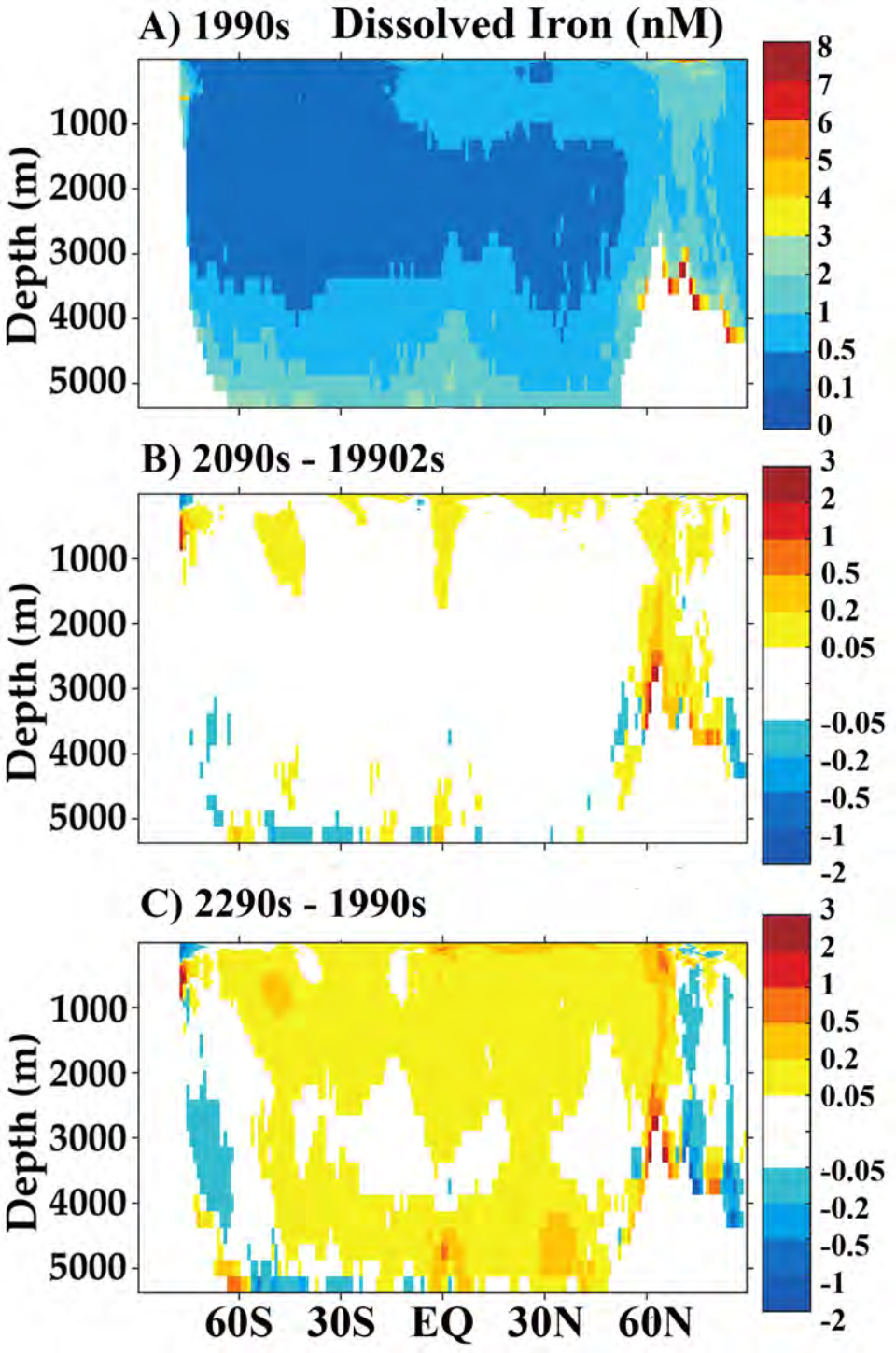

A) Phosphate 1990s
Depth (m)
1000
2000
3000
4000
5000
3.5
3.0
2.7
2.3
2.0
1.7
1.4
0.9
0.6
0.3
0.0
B) Phosphate 2090s-1990s
Depth (m)
1000
2000
3000
4000
5000
0.5
0.4
0.3
0.2
0.1
0.05
-0.05
-0.1
-0.2
-0.3
-0.5
-0.7
-1.2
C) Phosphate 2290s-1990s
Depth (m)
1000
2000
3000
4000
5000
0.5
0.4
0.3
0.2
0.1
0.05
-0.05
-0.1
-0.2
-0.3
-0.5
-0.7
-1.2
60S
30S
EO
30N
60N
D)
Southern Ocean
Deep Ocean
Phosphate (μM)
2.3
2.2
2.1
2.0
1900
2000
2100
2200
2300

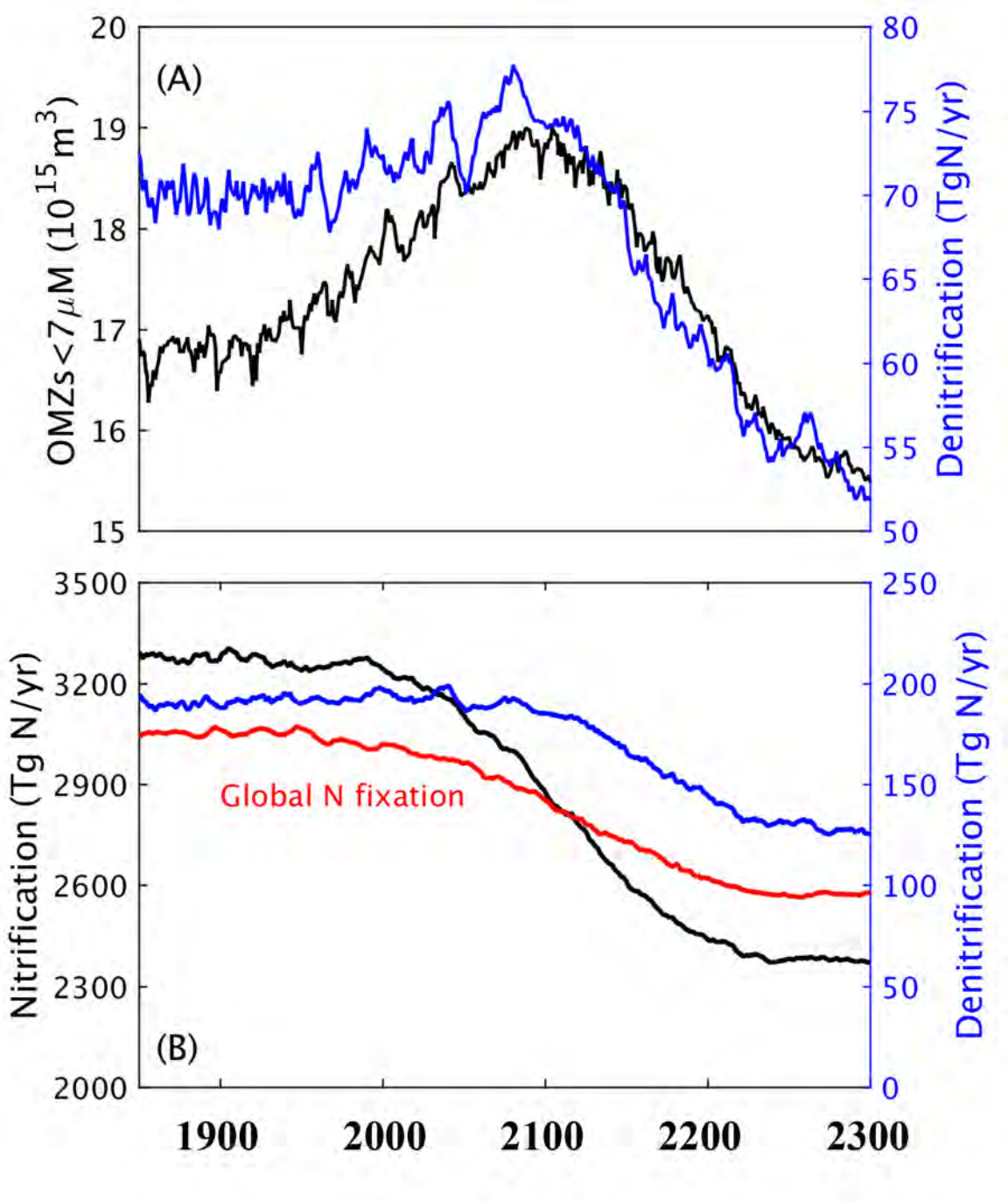

A)Temperature 1990s
2090s-1990s
2290s-1990s
Depth
200
400
700
1000
1400
31
27
24
21
18
15
12
10
8
6
4
2
0
12
10
8
7
6
5
4
3
2
1
0
B) Potential Density
1028
1027
1026
1025
1024.5
1024
1023.5
1023
1022.5
1022
1021.5
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.3
-1.6
-1.9
-2.3
-2.7
-3.0
-4.0
60S 30S EQ 30N 60N
60S 30S EQ 30N 60N
60S 30S EQ 30N 60N


A) 1990s
Nitrate (μM)
1000
2000
3000
4000
5000
39
34
29
24
20
17
14
9
6
3
0
B) 2090s - 1990s
1000
2000
3000
4000
5000
9
7
5
3
2
1
0
-1
-2
-3
-5
-7
-12
C) 2290s - 1990s
1000
2000
3000
4000
5000
9
7
5
3
2
1
0
-1
-2
-3
-5
-7
-12
60S
30S
EQ
30N
60N


Silicic Acid (μM)
A) 1990s
1000
2000
3000
4000
5000
200
150
120
90
60
40
20
10
0
B) 2090s - 1990s
1000
2000
3000
4000
5000
80
60
40
20
10
5
0
-5
-10
-20
-40
C) 2290s - 1990s
1000
2000
3000
4000
5000
80
60
40
20
10
5
0
-5
-10
-20
-40
60S
30S
EQ
30N
60N


A) Phosphate 1990s
HadGEM2
MPI-ESM-LR
Depth (m)
1000
2000
3000
4000
5000
60S
30S
EQ
30N
60N
3.5
3
2.7
2.3
2
1.7
1.4
0.9
0.6
0.3
0
B) Phosphate 2090s - 1990s
0.5
0.4
0.3
0.2
0.1
0.05
0
−0.0
−0.1
−0.2
−0.3
−0.5
−0.7
−1.2
C) Phosphate 2290s - 1990s
−0.05
D) Tropical Oxygen (200-1000m)
Oxygen (μM)
144
141
138
135
106
102
98
96
1900
2000
2100
2200
2300


A) 1990s Dissolved Iron (nM)
Depth (m)
1000
2000
3000
4000
5000
8
7
6
5
4
3
2
1
0.5
0.1
0
B) 2090s - 19902s
Depth (m)
1000
2000
3000
4000
5000
3
2
1
0.5
0.2
0.05
-0.05
-0.2
-0.5
-1
-2
C) 2290s - 1990s
Depth (m)
1000
2000
3000
4000
5000
3
2
1
0.5
0.2
0.05
-0.05
-0.2
-0.5
-1
-2
60S
30S
EQ
30N
60N


(A)
OMZs<7μM (10^15 m^3)
Denitrification (TgN/yr)
20
19
18
17
16
15
80
75
70
65
60
55
50
(B)
Nitrification (Tg N/yr)
Denitrification (Tg N/yr)
Global N fixation
3500
3200
2900
2600
2300
2000
250
200
150
100
50
0
1900
2000
2100
2200
2300

Implications for Ice Age Climate

1. The processes that drive SO nutrient trapping in a warming climate, would work in the opposite sense in the cold, dusty glacial climate.

2. Increased sea ice cover and colder temperatures suppress high-latitude SO biological production, increasing lateral transfer of nutrients to low latitudes.

3. NPP and export would increase across the lower latitudes, contributing to the drawdown of atmospheric CO_2.

4. The response to increasing iron deposition in the HNLC regions, would be enhanced because the background concentrations of other nutrients would be higher.

Summary

1. **Multicentury climate warming increases SO high latitude biological production.**

2. **This leads to nutrients being trapped in the SO with net transfer to the global deep ocean.**

3. **Upper ocean nutrient concentrations, global NPP, and global export production decline steadily.**

4. **As these changes work their way up the food chain, global fisheries catch could decline by 50%.**

5. **The results suggest that efficient lateral nutrient transfer from the SO could contribute to the ice age drawdown in atmospheric CO_2.**