Benchmarking Ocean Biogeochemical Fields in GFDL's ESMs

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Project objective # 1

The current generation of fully coupled ESMs represent a variety of biogeochemical fields and processes.

Need For Diagnostics

There are relatively few collections of computerized analysis routines aimed at diagnosing these processes in ESMs

How are diagnostics useful to scientists at GFDL?

- Generalized analysis scripts to help see model biases, how the model is behaving and its characteristics.
- Plots can be generated automatically when experiments are run

Determining Biogeochemical Vital Signs

Initial research: What are the key biogeochemical variables in ESMs that should be monitored on a routine basis?

Ocean Topaz Tracers

- Alkalinity
- Dissolved Inorganic Carbon (DIC)
- Phosphate (PO4)
- Nitrate (NO3)
- Silica (SiO4)
- Oxygen (O2)
- Iron (Fe)
- Chlorophyll

Global Data Analysis Project (GLODAP)

World Ocean Atlas (WOA)

Methods

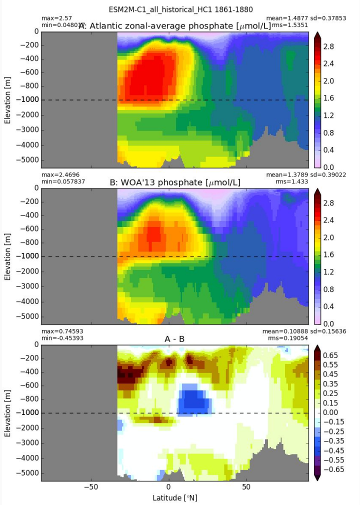
Development of diagnostic tool:

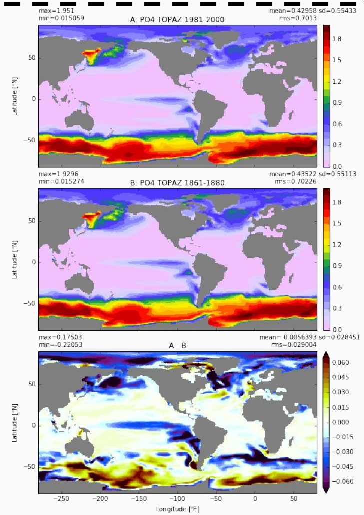
- Regrid World Ocean Atlas (2013) data to the ESM2M model grid
  - FMS “horiz_interp” bilinear interpolation
  - Vertical remapping using ALE -- 102 vertical levels to 50 levels
  - Regridding performed via MIDAS (Matt Harrison)
- Analysis scripts based on common Python packages:
  - netCDF4
  - Numpy
- Makefile available for running and testing the scripts
- Scripts can easily be updated to work with ESM4
  - Variables names similar between TOPAZ and COBALT

Output:

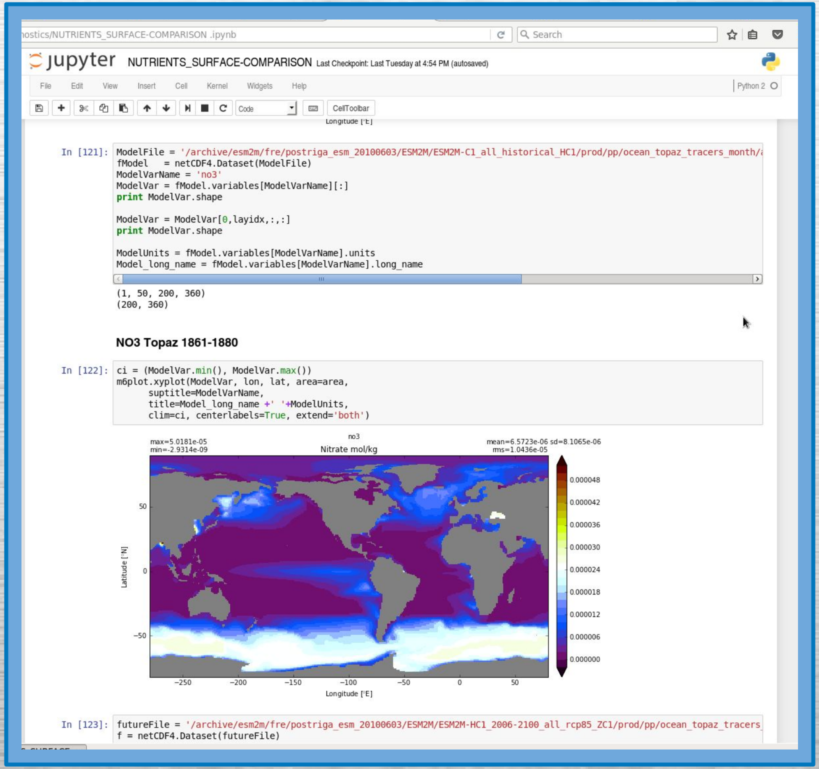
“Three Panel Plots” generated using “m6plot” (Alistair Adcroft)

- Generates surface and zonal mean vs. depth plots
- Basin masking for Atlantic, Pacific, and Indian Oceans



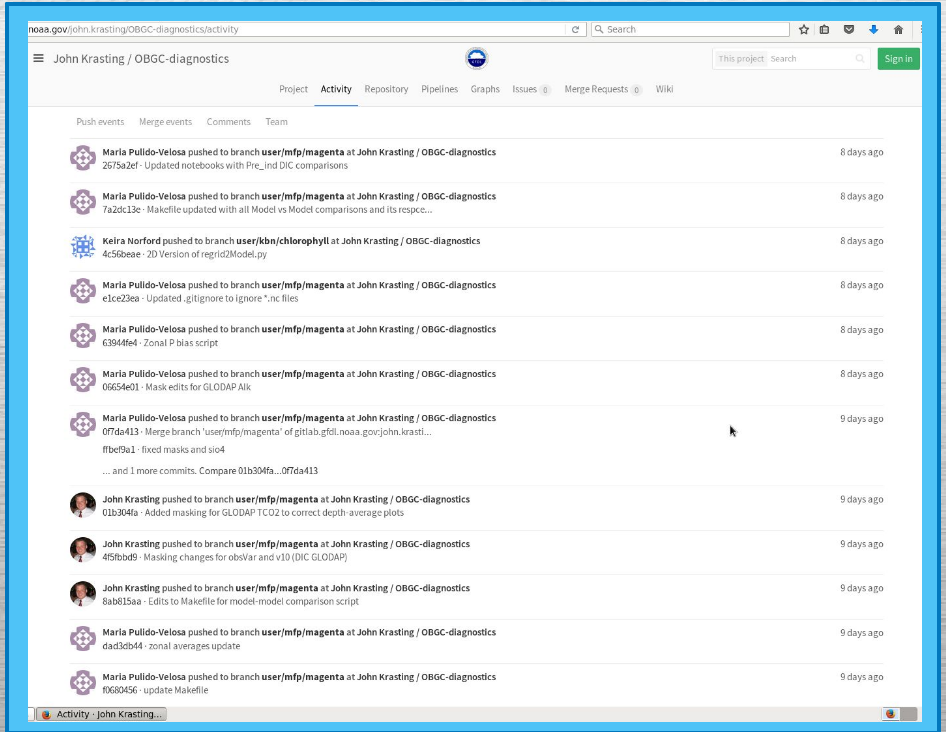


Python & Jupyter Notebooks



Methods

GitLab

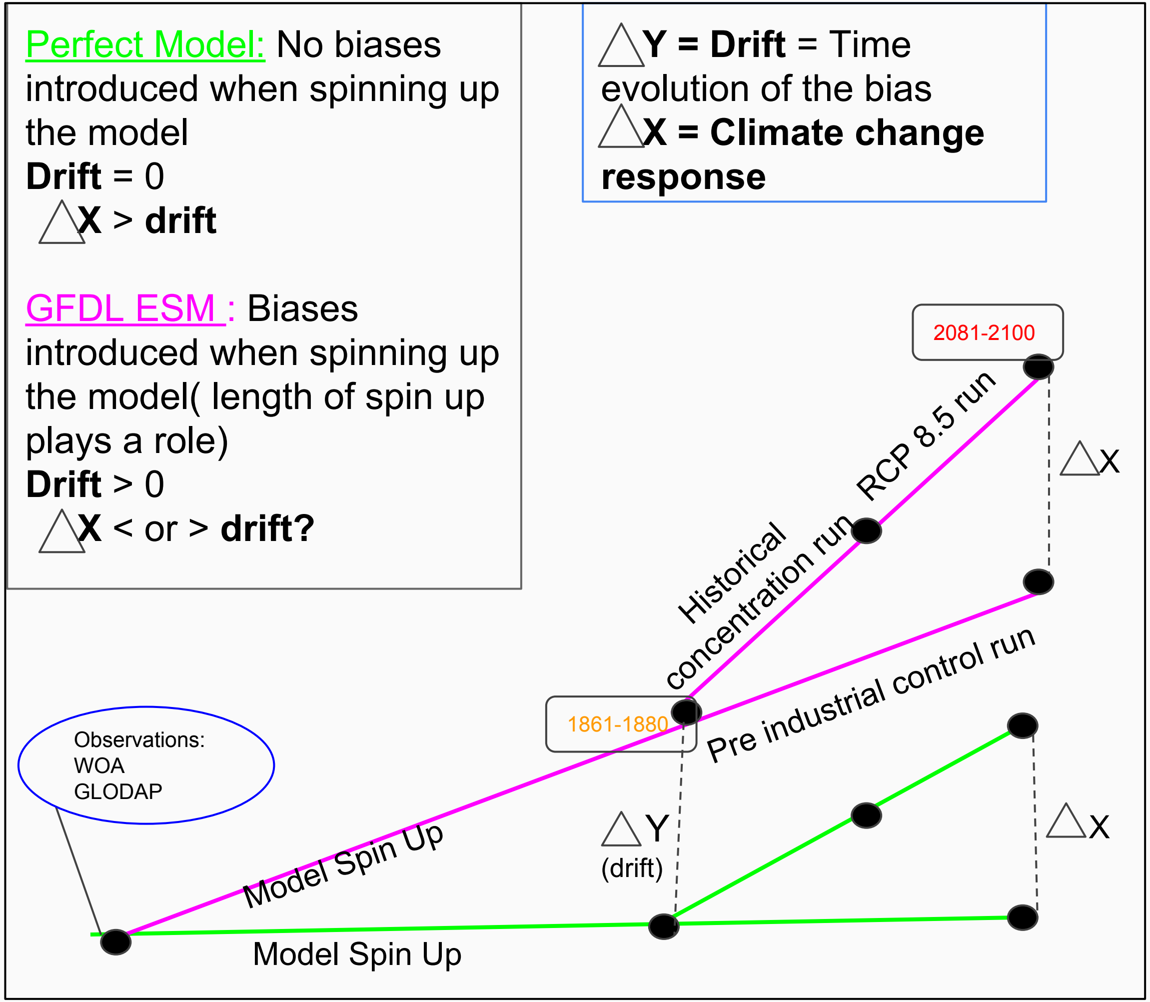


Project objective # 2

Application of the diagnostic tool

Use the diagnostic tool created to:

Understand the changes to the biogeochemical fields under a climate change scenario relative to how much the model drifts.



-To obtain 1860 initial conditions, biogeochemical tracers were initialized from **World Ocean Atlas observations** for **NO3,PO4,SIO4,O2** and the **Global Data Analysis** project for **DIC and Alkalinity**.

△**Y (drift)** = 1861-1880 - observations

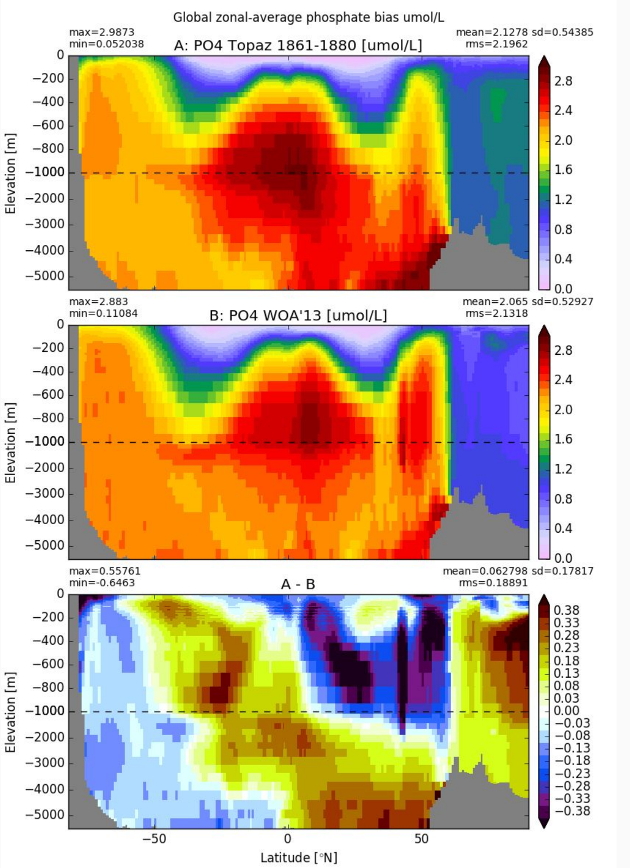
△**X (Clim. change)** = 2081-2100 - p.i control

What is △X (climate change response) relative to △Y (drift) in each of the biogeochemical fields?

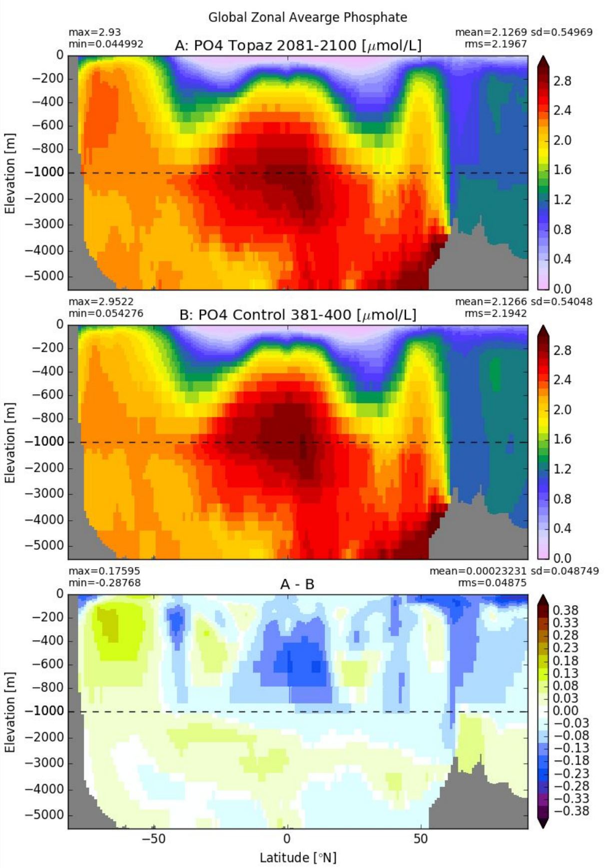
- if drift is larger than the climate change response, it makes it harder to interpret results of climate change experiments.

Phosphate Global Zonal Average vs. depth

DRIFT



CLIMATE CHANGE RESPONSE

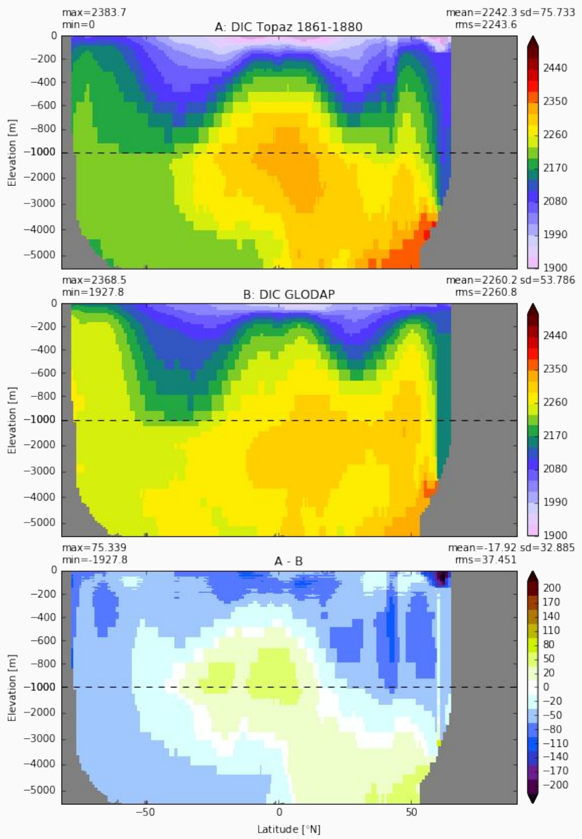


Drift:
rms=0.189
Climate change response:
rms= 0.049

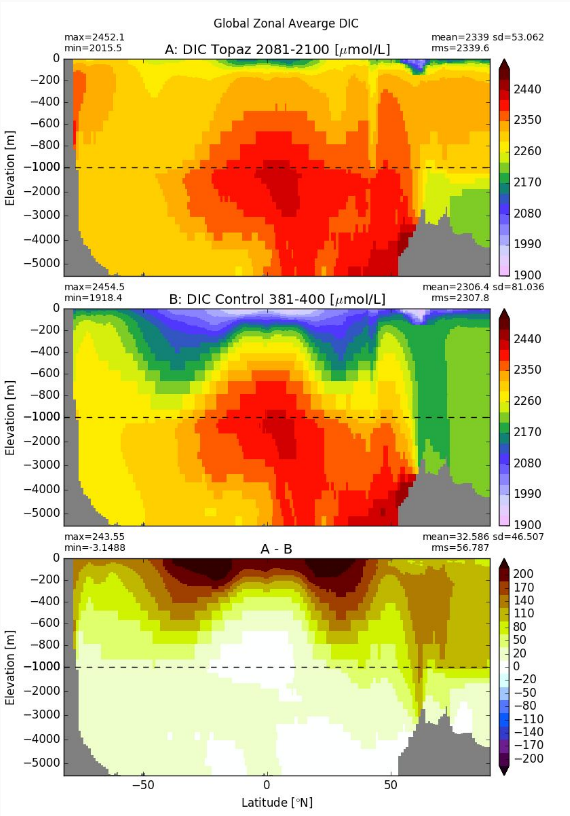
Drift > clim. change response for PO4, NO3, SIO4, O2 and Alkalinity

Dissolved Inorganic Carbon Zonal Average vs. depth

DRIFT



CLIMATE CHANGE RESPONSE

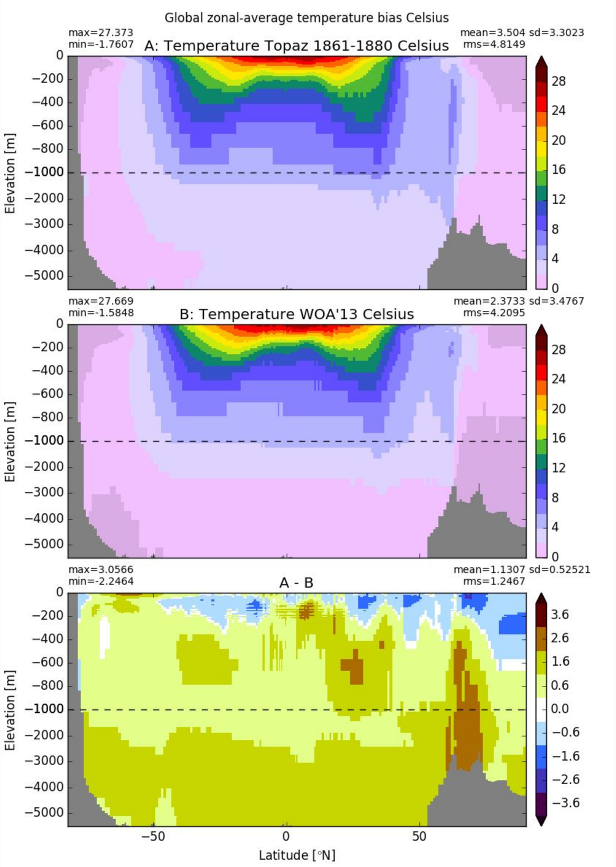


Drift:
rms=37.451
Climate change response:
rms= 56.787

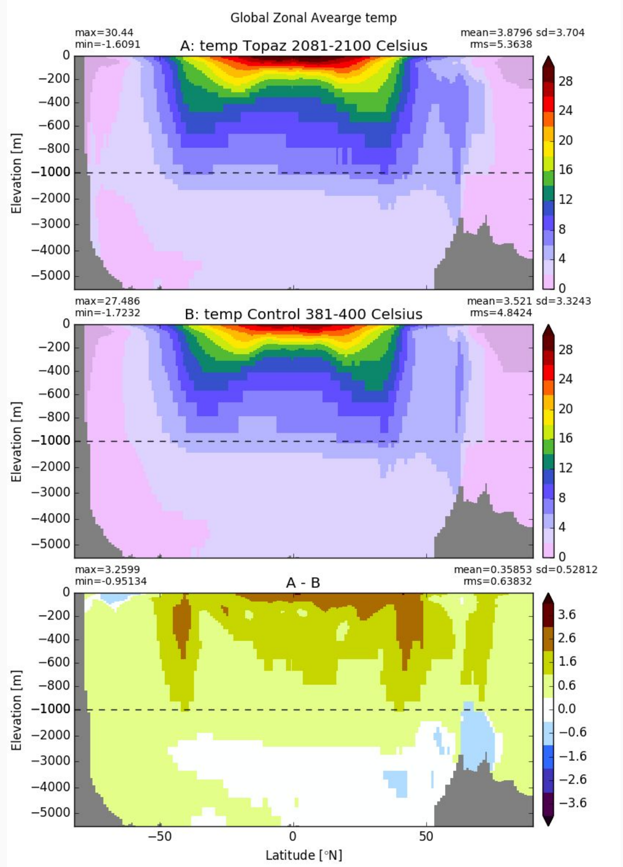
Clim. change response > Drift

Temperature Global Zonal Average vs Depth

DRIFT



CLIMATE CHANGE RESPONSE



Drift:
rms=1.2467
Climate change response:
rms=0.638

Drift > Climate Change Response

Normalized RMS		
Variable	Drift *(Model vs. Obs)*	Climate Change Response *(RCP8.5 vs. Control)*
PO4	0.09	0.02
NO3	0.08	0.02
SIO4	0.19	0.05
O2	0.11	0.05
DIC	0.017	0.025
Alkalinity	0.009	0.003
Temperature	0.5	0.18

Drift > Climate Change Response

Climate Change Response > Drift

$$\text{Normalized RMS} = \frac{\left(\sqrt{\sum_i^N (X_{model_i} - X_{reference_i})^2}\right)/N}{\bar{X}_{reference}}$$

Conclusions

- Over the course of the model spin up, the model has drifted and changed more than the climate change response

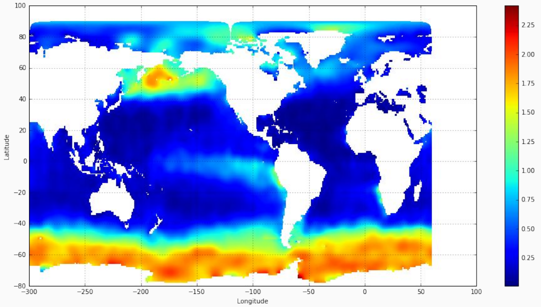
- For a higher resolution model (CM4) that is more computationally expensive, it would be beneficial **to reduce the spin-up time in order to minimize the drift and bias**.

- As strategies emerge to shorten the spin up time of the coupled model, a useful next question would be:

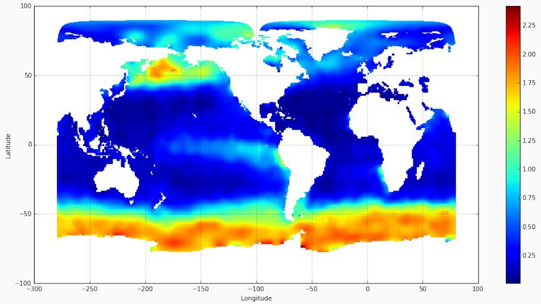
  At what time in the spin up does the drift equal the climate change response for the biogeochemical fields in other versions of GFDL ESMs?

Outstanding Issues

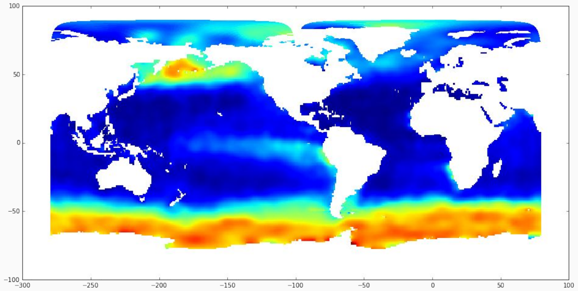
- Further validate horizontal and vertical regridding
  - Regridding in the Arctic seems sensitive to model resolution
  - Tried different regridding tools



PO_4 - MOM6 0.25 degree
GFDL FMS Horiz Interp



PO_4 - MOM4p1 1 degree
GFDL FMS Horiz Interp



PO_4 - MOM4p1 1 degree
Earth System Modeling Framework (ESMF)
(bilinear conservative)

- Uncovered bug in the MIDAS implementation of ALE
  - Piecewise-linear (plm) remapping fails on MOM4p1 output
  - Only piecewise-constant (pcm) remapping was successful

Next Steps

- Include more biogeochemical fields
- When ESM4 is ready:
  - Regrid WOA nutrients to new 0.5 degree grid
  - Double-check variable names
  - Integrate Makefile into the workflow
- Scripts are GFDL specific but eventually should be generalized (i.e. other CMIP models)

Acknowledgments:

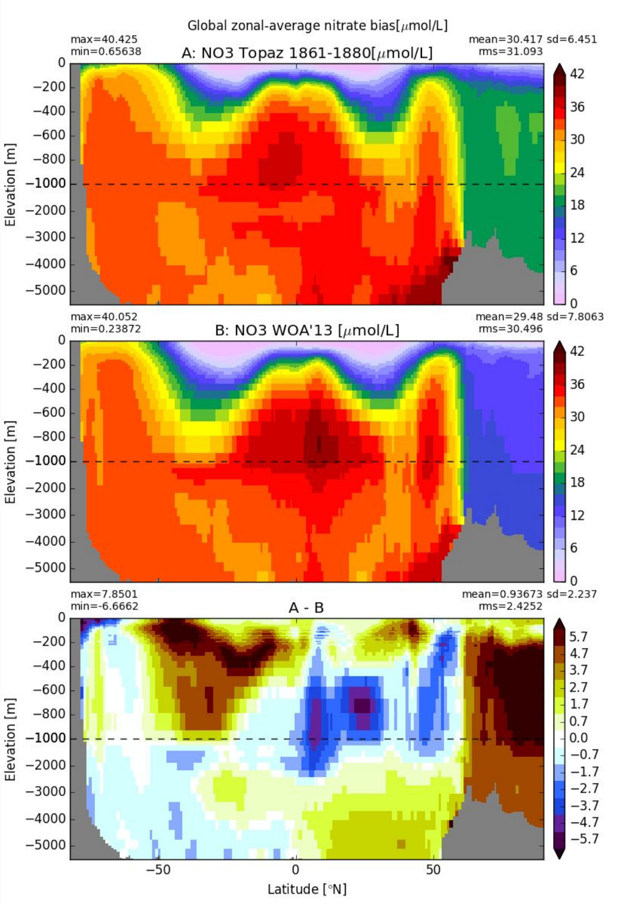
- John Krasting

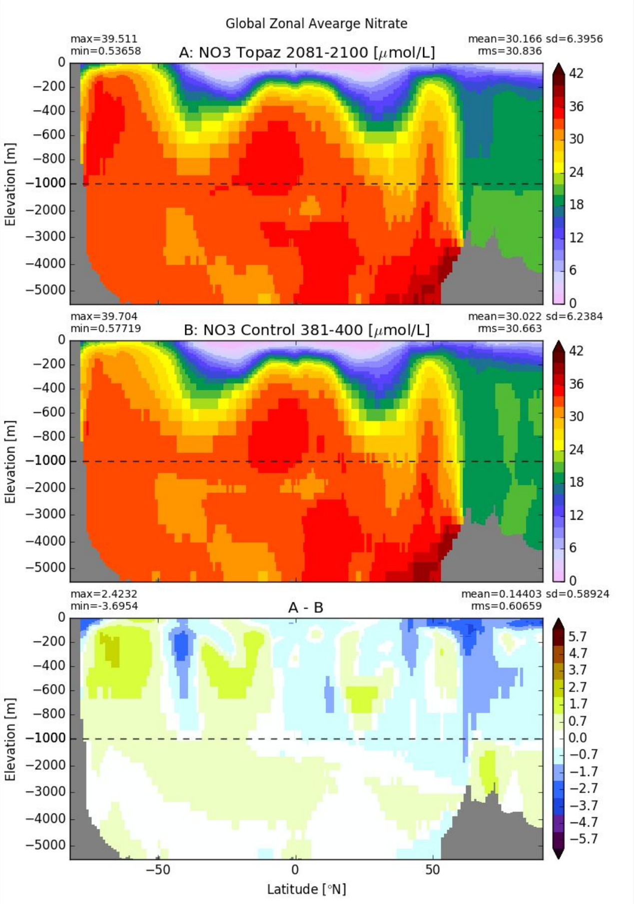
- Jasmin John, John Dunne, Charles Stock, Alistair Adcroft, and everyone in B group

- Matt Harrison

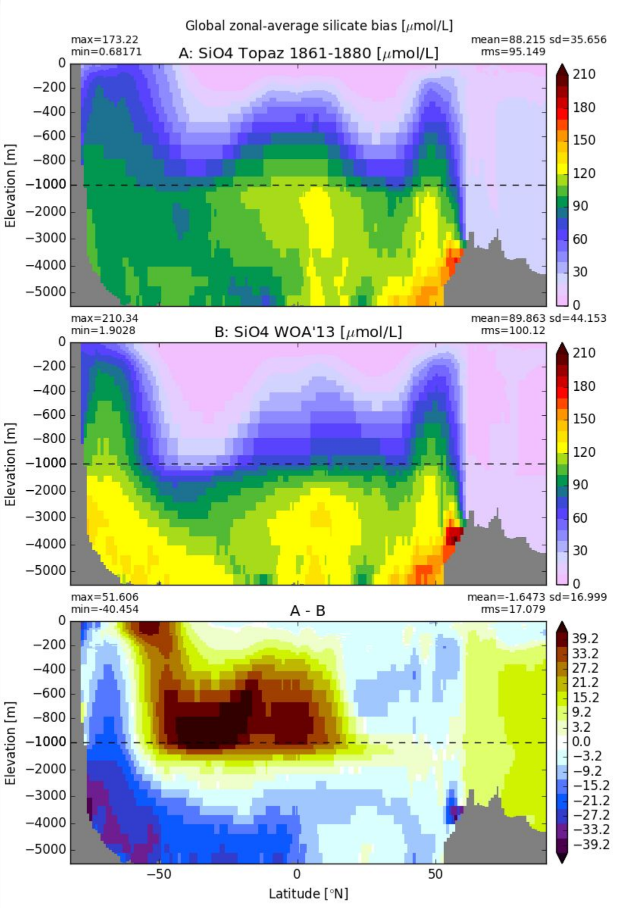
Supplemental Materials

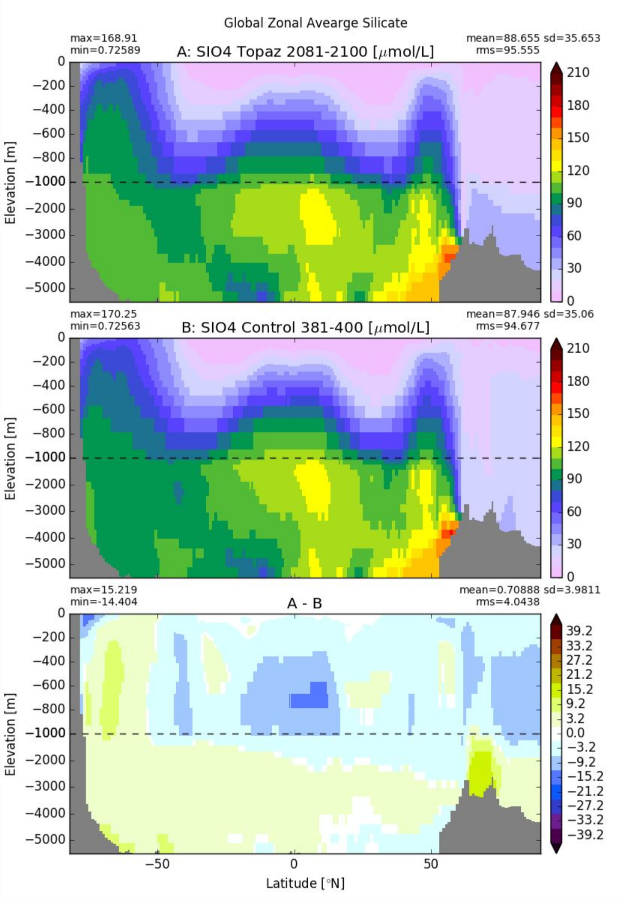
NO3


Global zonal-average nitrate bias[μmol/L]
max=40.425
min=0.65638
A: NO3 Topaz 1861-1880[μmol/L]
mean=30.417 sd=6.451
rms=31.093
max=40.052
min=0.23872
B: NO3 WOA'13 [μmol/L]
mean=29.48 sd=7.8063
rms=30.496
max=7.8501
min=-6.6662
A - B
mean=0.93673 sd=2.237
rms=2.4252
Elevation [m]
Latitude [°N]

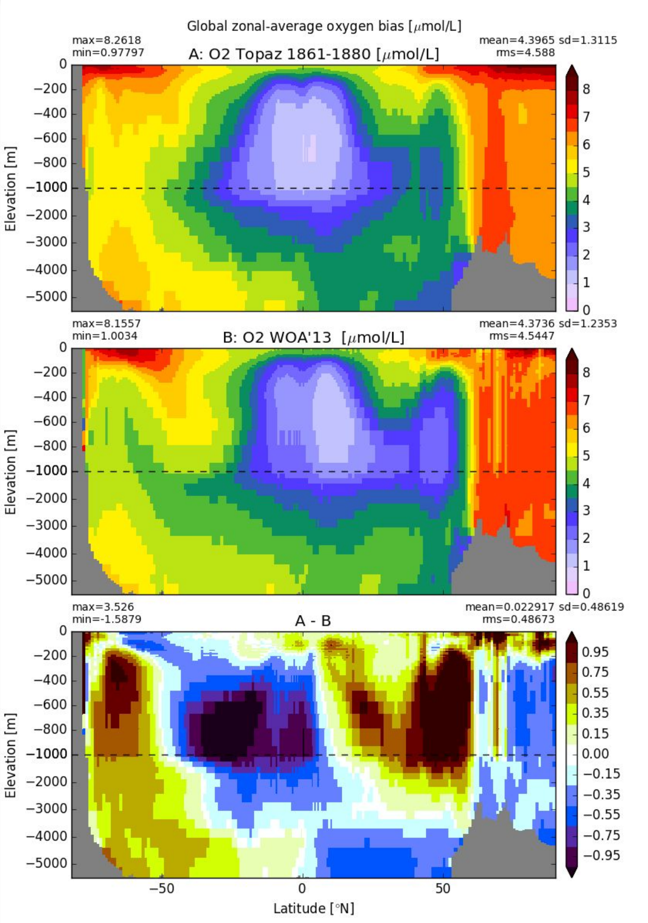

Global Zonal Avearge Nitrate
max=39.511
min=0.53658
A: NO3 Topaz 2081-2100 [μmol/L]
mean=30.166 sd=6.3956
rms=30.836
max=39.704
min=0.57719
B: NO3 Control 381-400 [μmol/L]
mean=30.022 sd=6.2384
rms=30.663
max=2.4232
min=-3.6954
A - B
mean=0.14403 sd=0.58924
rms=0.60659
Elevation [m]
Latitude [°N]

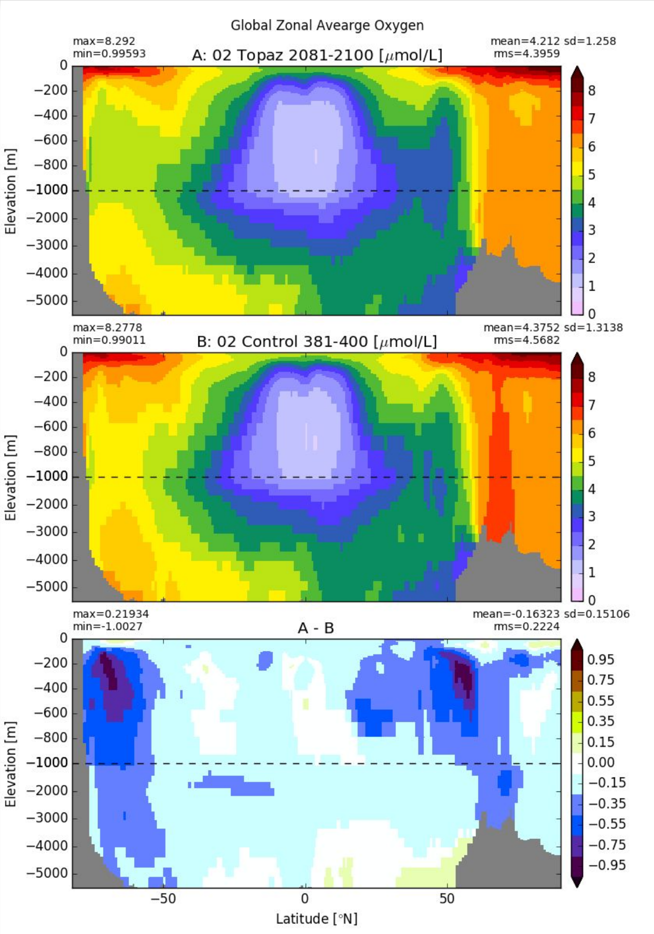
SiO4


Global zonal-average silicate bias [μmol/L]
max=173.22
min=0.68171
A: SiO4 Topaz 1861-1880 [μmol/L]
mean=88.215 sd=35.656
rms=95.149
max=210.34
min=1.9028
B: SiO4 WOA'13 [μmol/L]
mean=89.863 sd=44.153
rms=100.12
max=51.606
min=-40.454
A - B
mean=-1.6473 sd=16.999
rms=17.079
Elevation [m]
Latitude [°N]
−50
0
50
210
180
150
120
90
60
30
0
39.2
33.2
27.2
21.2
15.2
9.2
3.2
0.0
−3.2
−9.2
−15.2
−21.2
−27.2
−33.2
−39.2

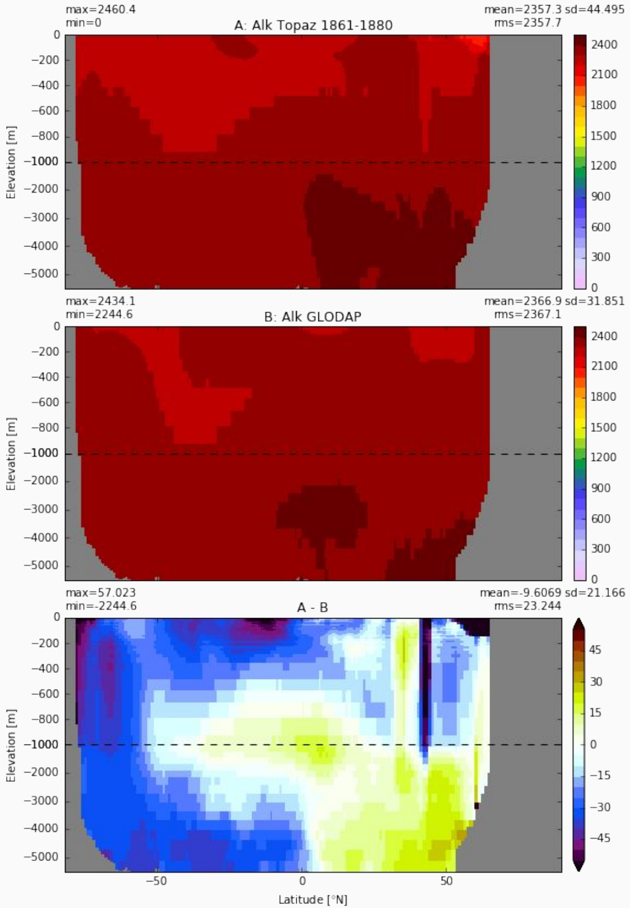

Global Zonal Avearge Silicate
max=168.91
min=0.72589
A: SIO4 Topaz 2081-2100 [μmol/L]
mean=88.655 sd=35.653
rms=95.555
max=170.25
min=0.72563
B: SIO4 Control 381-400 [μmol/L]
mean=87.946 sd=35.06
rms=94.677
max=15.219
min=-14.404
A - B
mean=0.70888 sd=3.9811
rms=4.0438
Elevation [m]
Latitude [°N]
−50
0
50

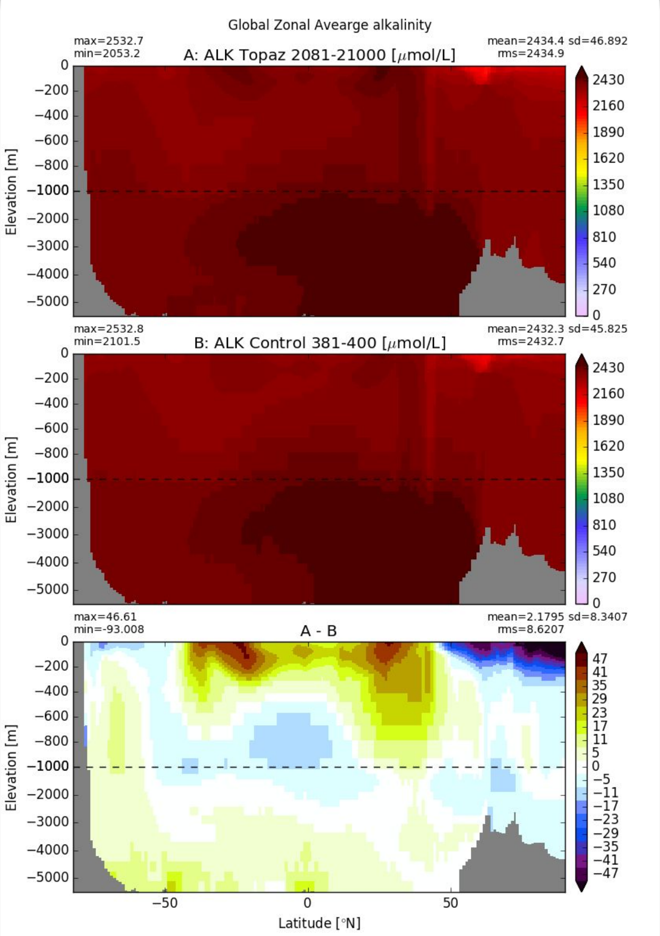
O2


Global zonal-average oxygen bias [μmol/L]
max=8.2618
min=0.97797
A: O2 Topaz 1861-1880 [μmol/L]
mean=4.3965 sd=1.3115
rms=4.588
max=8.1557
min=1.0034
B: O2 WOA'13 [μmol/L]
mean=4.3736 sd=1.2353
rms=4.5447
max=3.526
min=-1.5879
A - B
mean=0.022917 sd=0.48619
rms=0.48673
Elevation [m]
Latitude [°N]

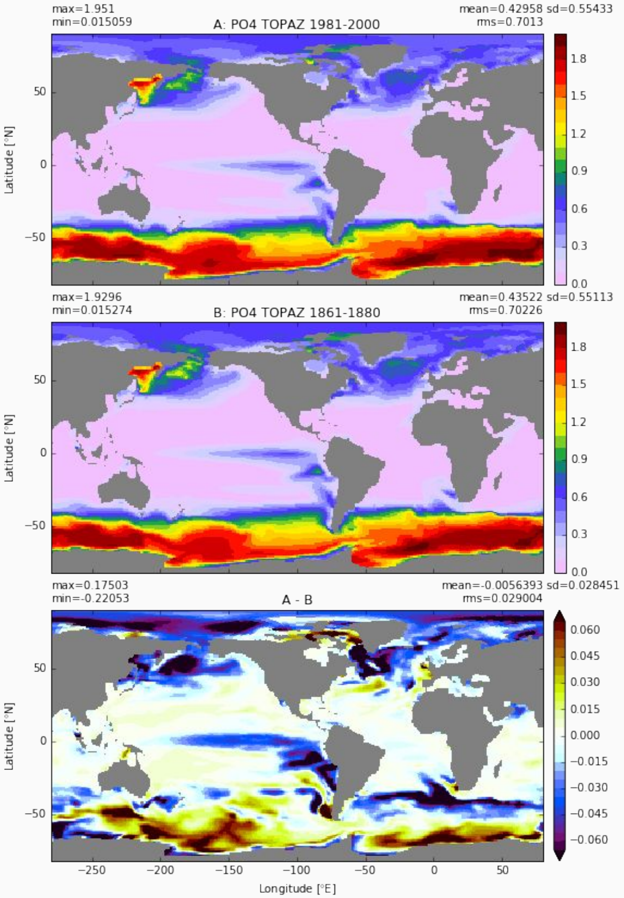

Global Zonal Avearge Oxygen
max=8.292
min=0.99593
A: 02 Topaz 2081-2100 [μmol/L]
mean=4.212 sd=1.258
rms=4.3959
max=8.2778
min=0.99011
B: 02 Control 381-400 [μmol/L]
mean=4.3752 sd=1.3138
rms=4.5682
max=0.21934
min=-1.0027
A - B
mean=-0.16323 sd=0.15106
rms=0.2224
Elevation [m]
Latitude [°N]

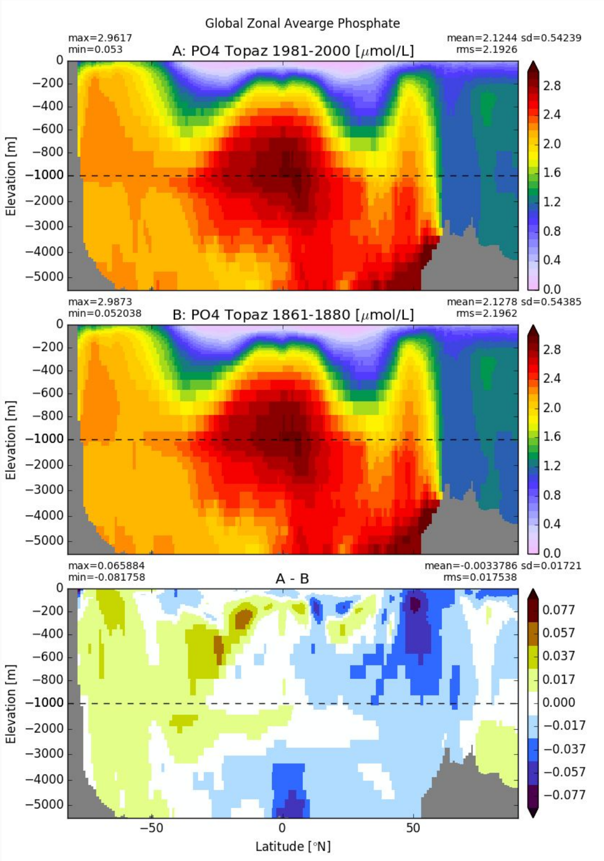
Alkalinity


max=2460.4
min=0
A: Alk Topaz 1861-1880
mean=2357.3 sd=44.495
rms=2357.7
max=2434.1
min=2244.6
B: Alk GLODAP
mean=2366.9 sd=31.851
rms=2367.1
max=57.023
min=-2244.6
A - B
mean=-9.6069 sd=21.166
rms=23.244
Elevation [m]
Latitude [°N]

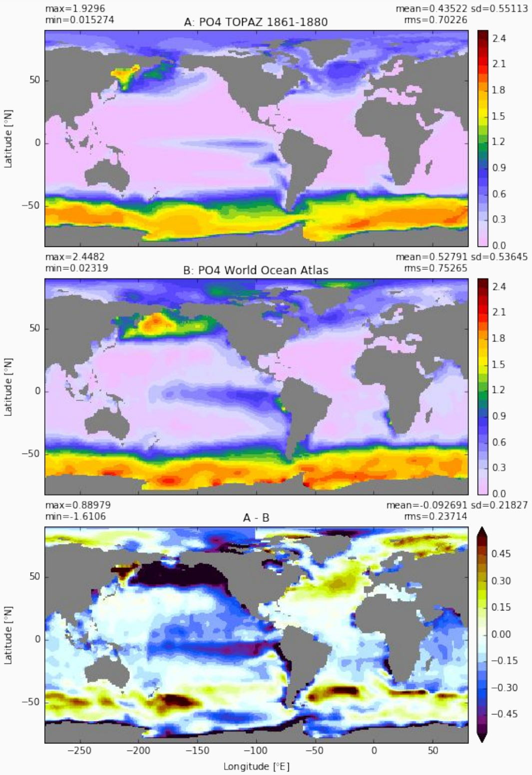

Global Zonal Avearge alkalinity
max=2532.7
min=2053.2
A: ALK Topaz 2081-21000 [μmol/L]
mean=2434.4 sd=46.892
rms=2434.9
max=2532.8
min=2101.5
B: ALK Control 381-400 [μmol/L]
mean=2432.3 sd=45.825
rms=2432.7
max=46.61
min=-93.008
A - B
mean=2.1795 sd=8.3407
rms=8.6207
Elevation [m]
Latitude [°N]

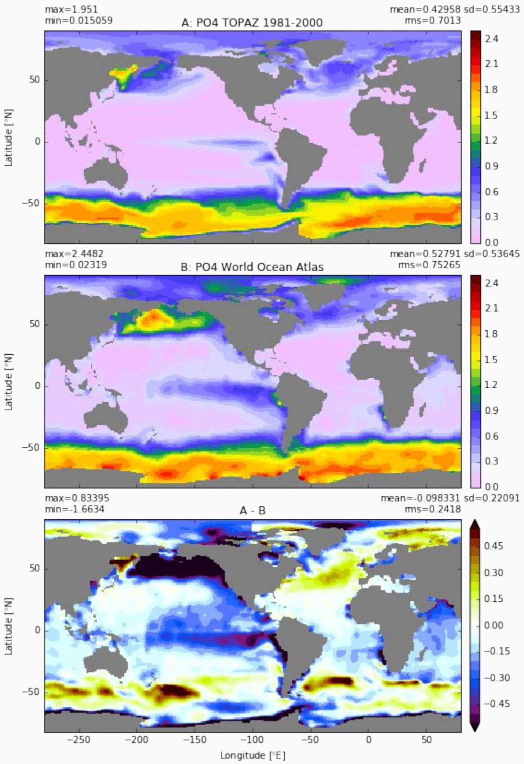
Differences between start and end of the historical run



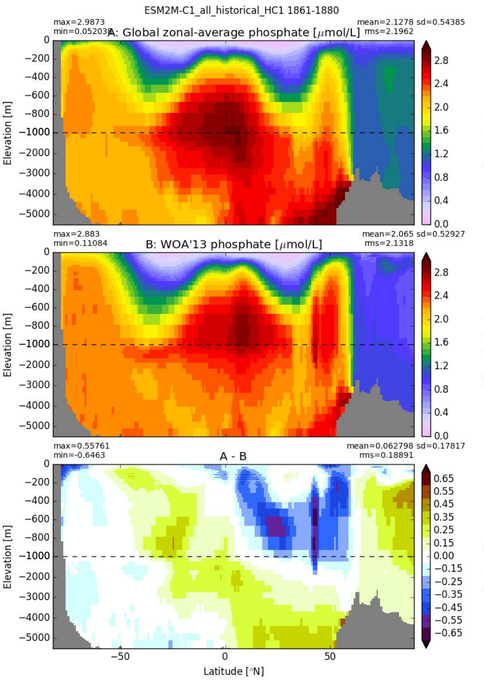


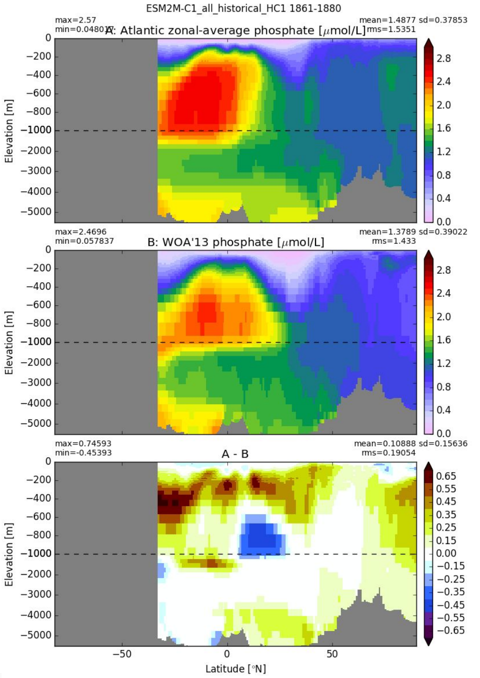
Phosphate Drift: 1861-1880 & 1981-2000 vs. WOA

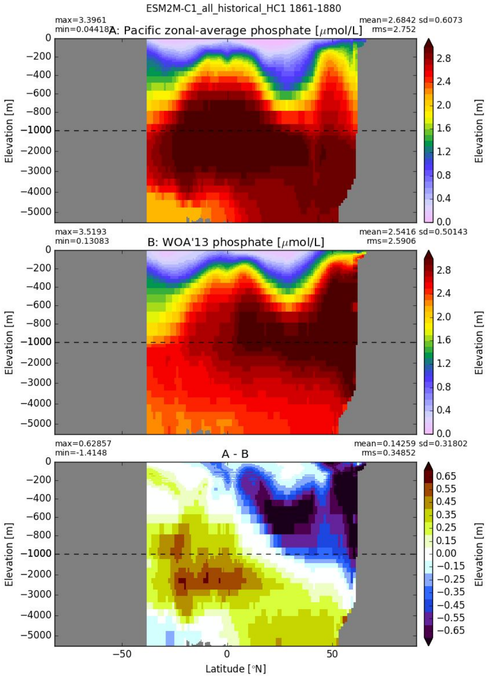


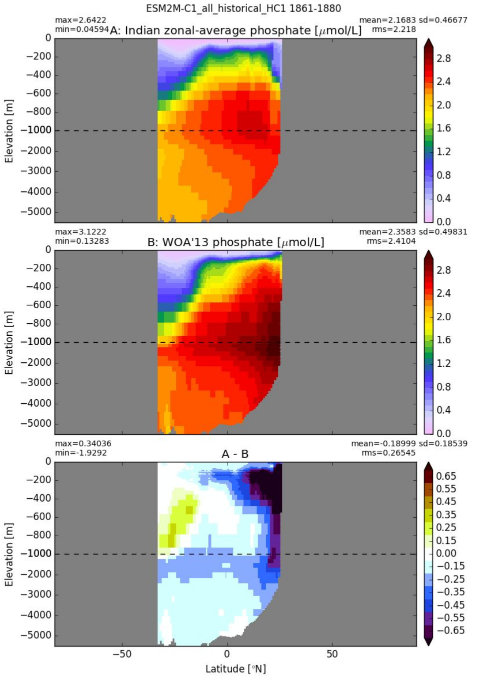


Phosphate Drift: 1861-1880 vs WOA

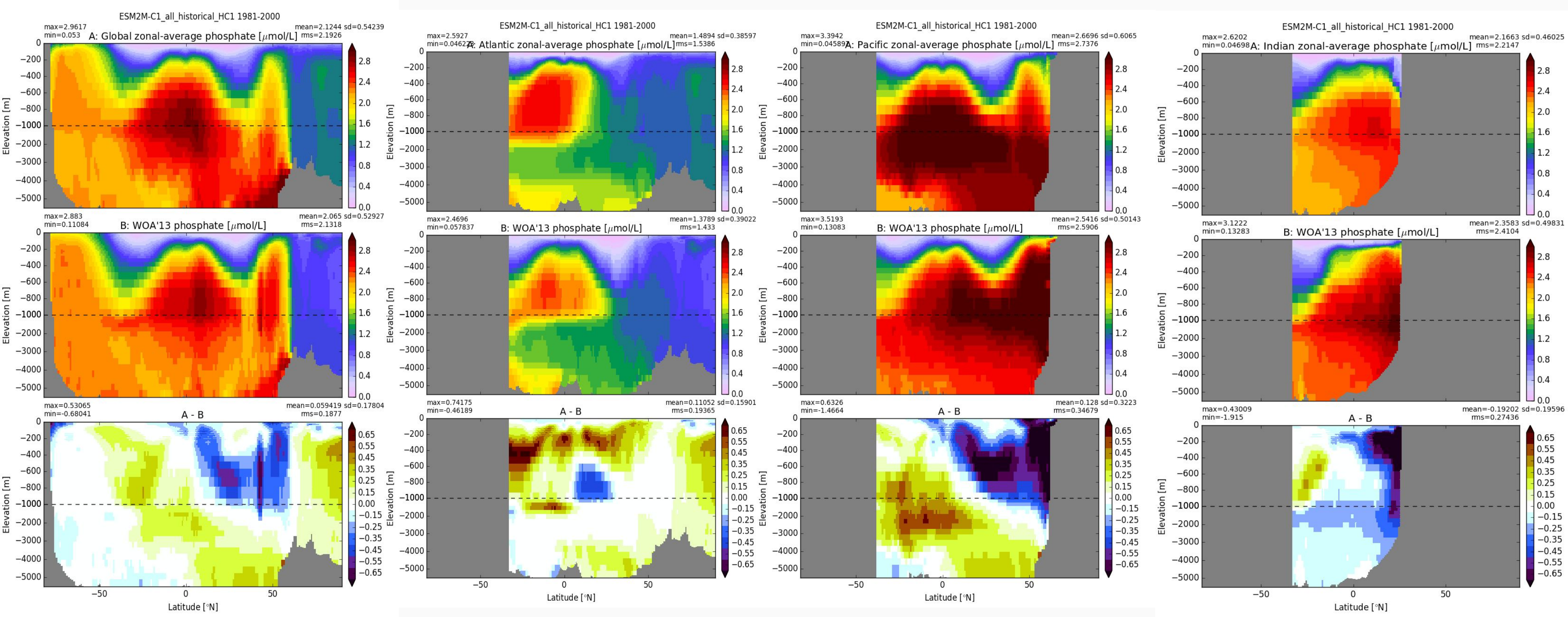


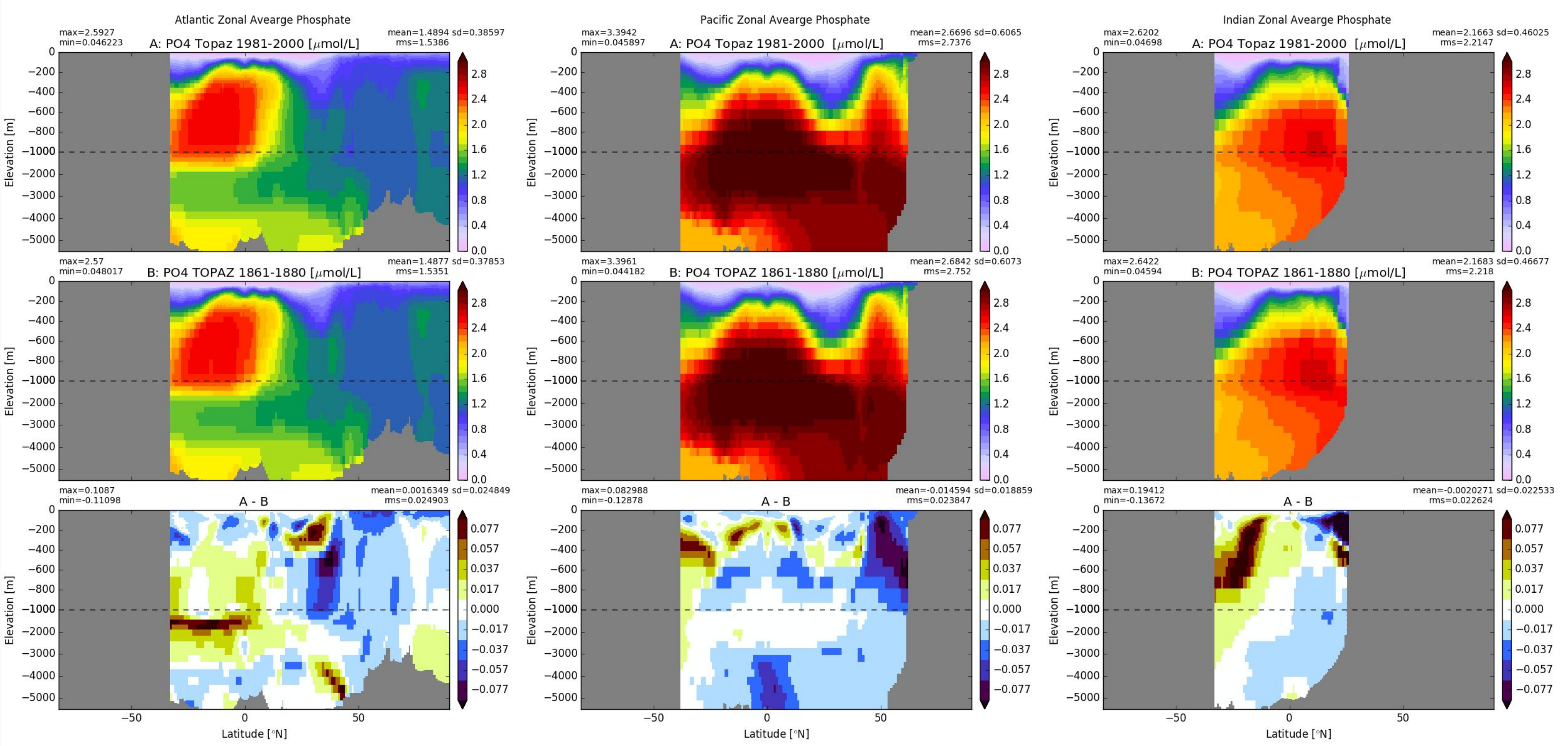






Phosphate Drift: 1981-2000 vs WOA




Atlantic Zonal Avearge Phosphate
Pacific Zonal Avearge Phosphate
Indian Zonal Avearge Phosphate
max=2.5927
min=0.046223
mean=1.4894 sd=0.38597
rms=1.5386
A: PO4 Topaz 1981-2000 [μmol/L]
max=3.3942
min=0.045897
mean=2.6696 sd=0.6065
rms=2.7376
A: PO4 Topaz 1981-2000 [μmol/L]
max=2.6202
min=0.04698
mean=2.1663 sd=0.46025
rms=2.2147
A: PO4 Topaz 1981-2000 [μmol/L]
max=2.57
min=0.048017
mean=1.4877 sd=0.37853
rms=1.5351
B: PO4 TOPAZ 1861-1880 [μmol/L]
max=3.3961
min=0.044182
mean=2.6842 sd=0.6073
rms=2.752
B: PO4 TOPAZ 1861-1880 [μmol/L]
max=2.6422
min=0.04594
mean=2.1683 sd=0.46677
rms=2.218
B: PO4 TOPAZ 1861-1880 [μmol/L]
max=0.1087
min=-0.11098
mean=0.0016349 sd=0.024849
rms=0.024903
A - B
max=0.082988
min=-0.12878
mean=-0.014594 sd=0.018859
rms=0.023847
A - B
max=0.19412
min=-0.13672
mean=-0.0020271 sd=0.022533
rms=0.022624
A - B
Elevation [m]
0
−200
−400
−600
−800
−1000
−2000
−3000
−4000
−5000
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
0.077
0.057
0.037
0.017
0.000
−0.017
−0.037
−0.057
−0.077
−50
0
50
Latitude [°N]

PO4 Climate change Scenario: 1981-2000 vs Control