Update on Ocean BGC Spinup

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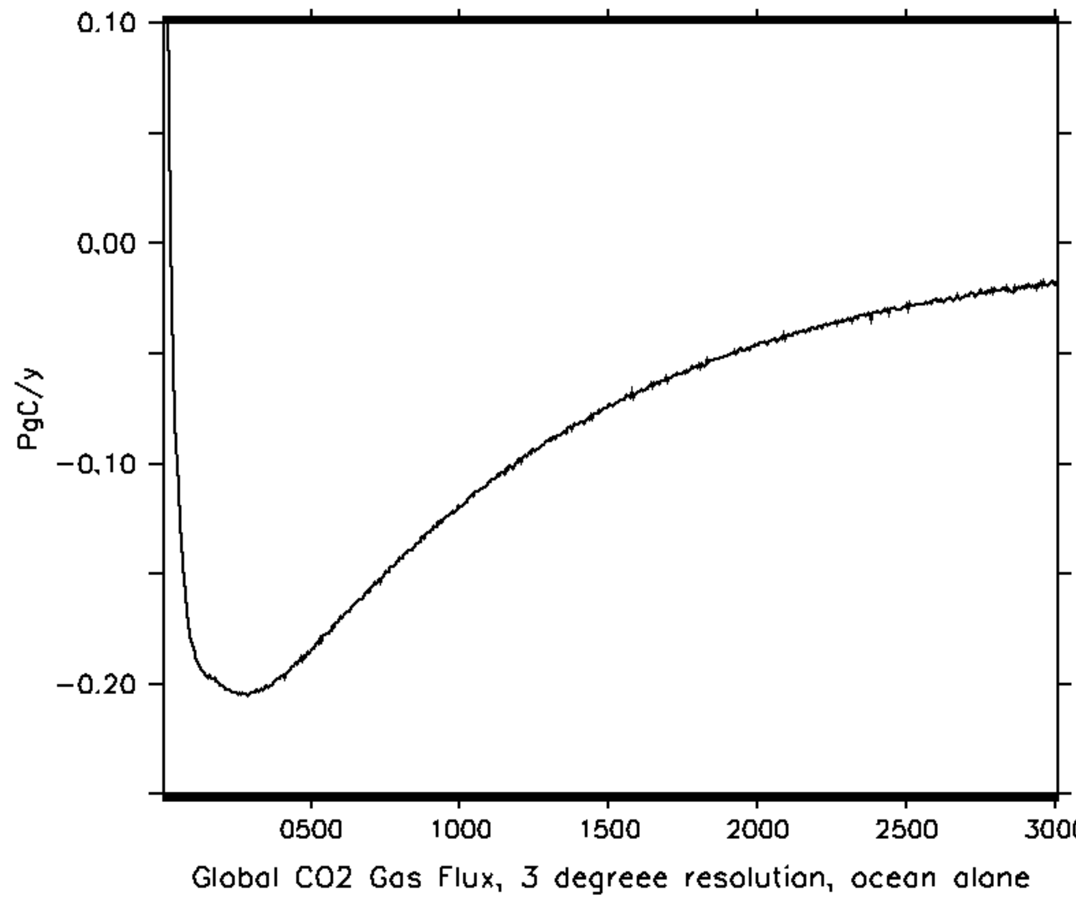
Ocean BGC Spinup

BGC tracers in the ocean, such as dissolved inorganic carbon, take thousands of years to equilibriate when run directly forward in time. Assuming a throughput rate of 20 years per day, running the model for 2000 years would take over 3 months.



Newton-Krylov Solvers

Li & Primeau (2008) , Khatiwala (2008)

- Model Map: $u(t) = \Phi(u(0),t)$, where u is the BGC state
- Solve: $\Phi(u_0,T)=u_0$ for u_0.
- Rewrite: $F(u)\equiv\Phi(u,T)-u=0$
- Newton's Method:
  $u_{k+1} = u_k - (\partial F/\partial u)^{-1} * F(u_k)$
- Use Krylov iterative method (GMRES) to solve:
  $(\partial F/\partial u)(\delta u_k)=-F(u_k)$
- Each iteration evaluates $(\partial F/\partial u)(\delta u)$
- Finite Difference Approximation
  - $(\partial F/\partial u)(\delta u) \approx (F(u+\sigma\delta u)-F(u))/\sigma$
  - note this is a forward model run of length T.
- Preconditioner is a MUST for GMRES.

Preconditioner Approach

Li & Primeau (2008) , Khatiwala (2008)

- Approximate forward model with a single backward Euler step with timestep T.
- Derive exact formula for $(\partial F/\partial u)$, assuming this approximation is exact.
- Inverting approximate $(\partial F/\partial u)$ requires inverting a 3D sparse matrix (SuperLU).
- Subtleties: appropriate velocities and mixing coefficients for backward Euler step.

Results for an Nutrient Tracer

Direct Integration

Model Years	Change per Year
500	1.4e-4
1000	5.6e-5
1500	2.2e-5
2000	7.7e-6
2500	2.8e-6

Newton-Krylov
4 iterations+2 adjustment years per Newton step

Newton Iteration	Change per Year
1	9.7e-5
2	7.2e-6
3	7.8e-7
4	1.1e-7

Nutrient conservation is not automatic and must be explicitly enforced.

Application to Full BGC Model

- BGC tracers have a variety of timescales, from days to thousands of years. Initial experiments generated unphysical values for short timescale tracers.
- Decouple slow tracers from fast tracers, apply Krylov step to slow tracers only.
- Implementation of this creates duplicate copy of each slow tracer and applies perturbations of Krylov iterations to the copy.
- Replace original slow tracers w/ duplicates after Krylov step and run a few years to allow fast tracers to adjust.
- Subtlety: source-sink terms for duplicate tracers

Measures of Convergence

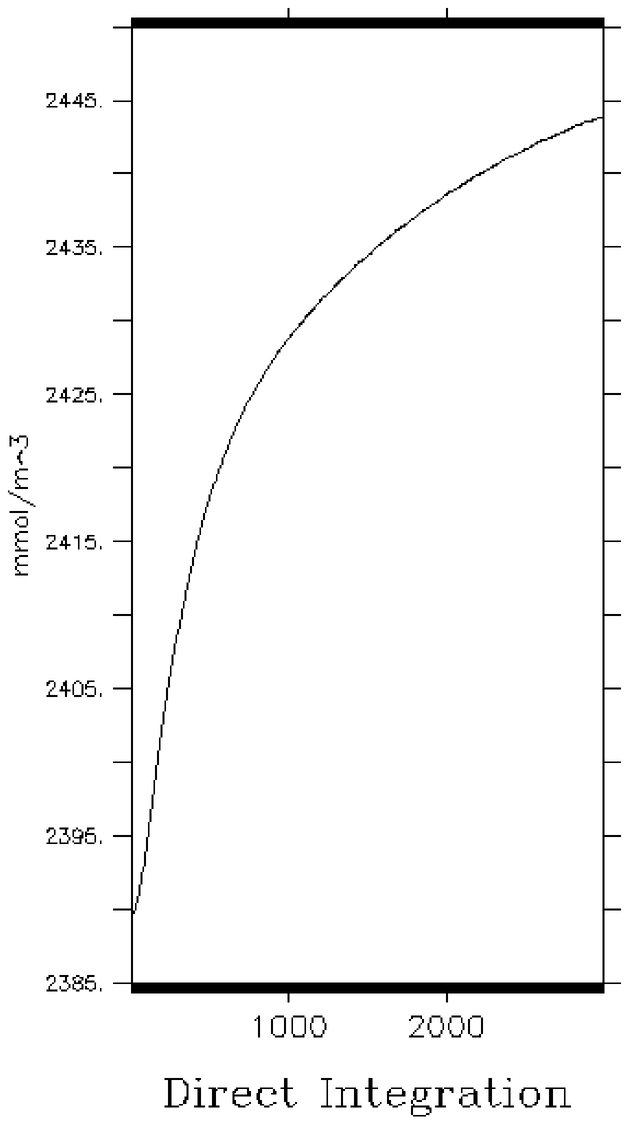
Direct Integration

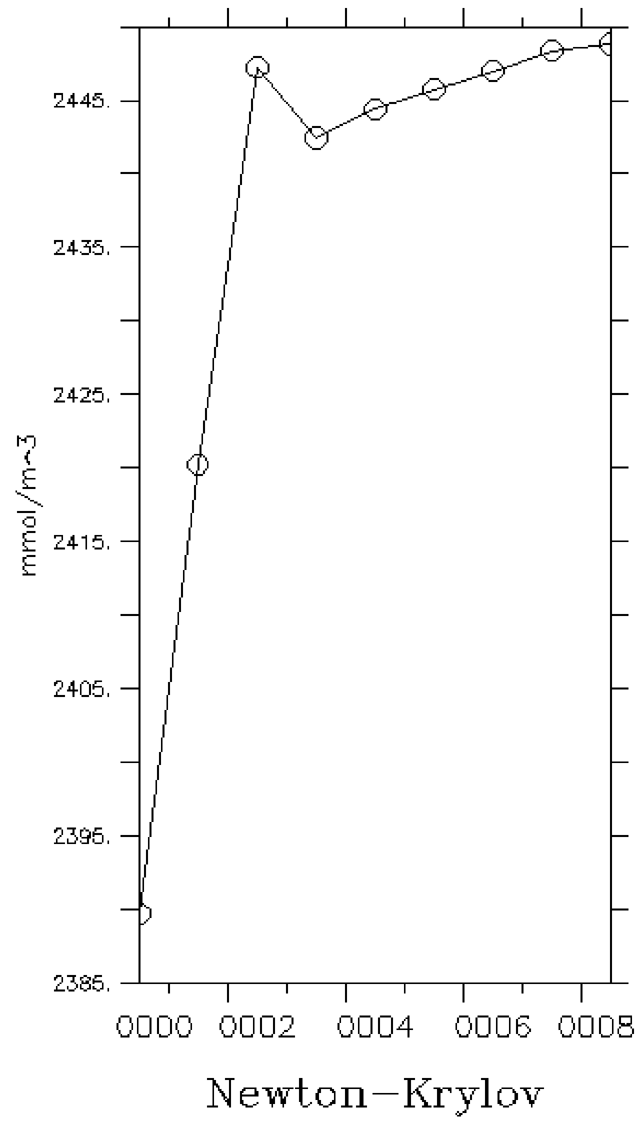
Model Years	CO_2 Gas Flux (PgC/y)
500	0.1477
1000	0.0964
1500	0.0636
2000	0.0404
2500	0.0269
3000	0.0181

Newton-Krylov
4 iterations+5 adjustment years per Newton step

Newton Iteration	RMS Tracer Change per year	CO_2 Gas Flux (PgC/y)
0	0.11486	0.1240
1	0.09034	0.1658
2	0.06261	0.2131
3	0.03683	0.2821
4	0.02593	0.1596
5	0.02295	0.1333
6	0.01297	0.0805
7	0.01050	0.0717
8	0.00750	0.0446

DIC @ 45N, 215E, 2500m





However, …

- Convergence is spatially variable
- N cycle is not coming into balance
- Further iterations of Newton-Krylov are not reducing the imbalance
- Some global N metrics, such as nitrogen fixation and denitrification, from state computed with Newton-Krylov solver differ from solution obtained by running for 3000 years

What's Next?

- Better quantify performance of Newton-Krylov
- What is inhibiting convergence of N cycle?
- Transition to x1
  - Is explicit treatment of overflows necessary?
  - Is SuperLU adequate for x1 grid?
- Use Newton-Krylov with interannually varying coupled model forcing