Biogeochemical Elemental Cycling (BEC) Model Improvements for CCSM4

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Improved sedimentary iron source and scavenging parameterizations
   Reduces mismatch with observations
   Improves HNLC region distributions (Moore and Braucher, 2008)

Improved phytoplankton dynamic Si/C and Fe/C ratios
   Improves surface silicate and dissolved iron distributions

Modifications to phytoplankton loss terms
   Allows for more phytoplankton blooms
   Better seasonal nutrient drawdown at high latitudes

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

Diazotroph utilization of fixed N sources (nitrate, ammonium) (Moore, submitted)
   Diazotrophs can fix N\textsubscript{2}, but now also take up fixed N when available

Modified O\textsubscript{2}/Denitrification effect on remineralization lengths
   Length scales grow longer at low O\textsubscript{2}
   Physics/mixing improvements in CCSM4 could help with low O\textsubscript{2} problem
Original BEC

Improved BEC
sedimentary source
Fe scavenging
Original BEC - Si vs. Obs.

Improved BEC - Si vs. Obs.
Original BEC

Improved BEC

temperature effect on respiration
reduced aggregation loss
increased grazing loss
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). Note atmospheric P and Si inputs account for $<<1\%$ of export production.
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.
Original BEC
Low O$_2$ in Southern Ocean
Low O$_2$ in OMZs

Improved BEC
Increased SO mixing
Increased background turbulence
Conclusions and Future Work

1) Improved physics/mixing in CCSM4 will benefit biogeochemistry through better mixed layer depths, O$_2$ ventilation, and Oxygen Minimum Zone distributions.

2) Remaining improvements to be incorporated into the BEC, over next few years:

   Fast Solver – will greatly decrease spin up time, allow for better tuning of parameters controlling remineralization of organic matter at depth.

   River Nutrients – needs to be incorporated as nutrient sources to the oceans.

   Expanded Nitrogen Cycle – sedimentary denitrification, ocean ammonia and N$_2$O emissions, better treatment of DON/DOP, etc...

   CaCO$_3$ Dissolution – needs to tied more directly to saturation state and water column chemistry.

Sediment Biogeochemistry Module