Dissolution of olivine (potential, side effects) in simulated CO_2 removal experiments

—

enhanced weathering, ocean alkalinization, ocean fertilization

Peter Köhler, Judith Hauck
Christoph Völker, Dieter A. Wolf-Gladrow

Oxford Greenhouse Gas Removal Conference (30 Sep - 02 Oct 2015)

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

(0) Basics: Olivine

foto: H Grobe (AWI)

Olivine is:

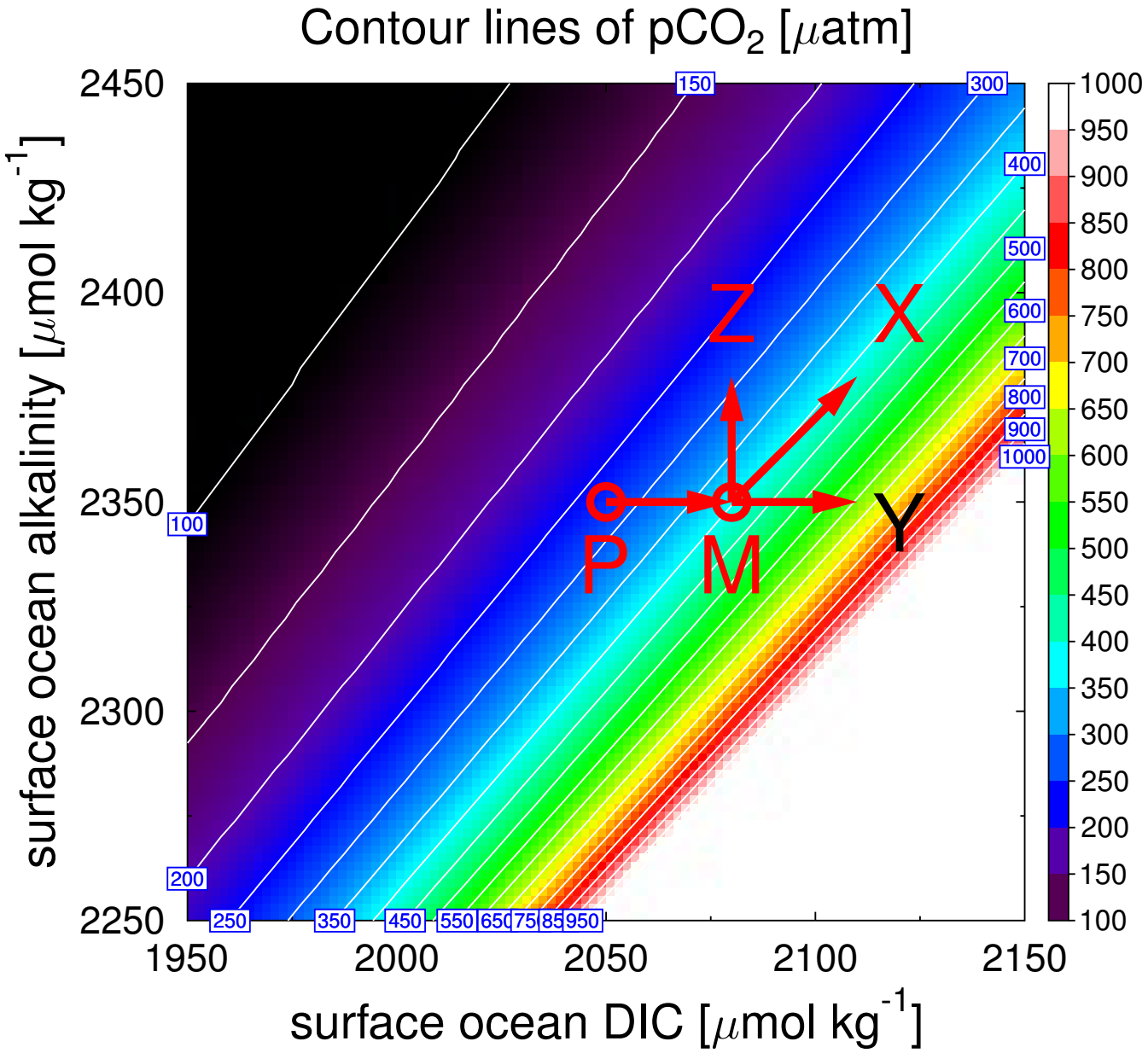
- a silicate (Si) containing mineral ($(Mg,Fe)_2SiO_4$).
- found in dunite, one of the major constituents of the Earth's upper mantle and accessible at the Earth's surface.
- highly dissolvable compared to other silicate minerals.
- dissolves within 1-2 yr if grinded to 10–30 μm.
- contains a Mg:Fe molar ratio of about 9:1.

(0) Basics: Silicate (olivine) Weathering (Ruddiman 2001)

Picture on natural weathering from Textbook
W.F. Ruddiman (2001)
"Earth's Climate, past and future" W H Freeman & Co
missing due to copyrights.

Weathering: input of HCO_3^- (+DIC, +alkalinity) and of nutrients into ocean.
All C in silicate weathering has its source in atmospheric CO_2.
(sum of C in atmosphere-ocean stays constant)
Enhance natural weathering by $\sim 10\times$: from < 0.2 to > 1 Pg C yr^{-1}

(0) Basics: CO_2 in Seawater (following Zeebe & Wolf-Gladrow 2001)



P: preindustrial
M: modern

Y: future

X: pure weathering input of HCO_3^-

Z: net weathering no change in DIC

(1) **Potential:** Process changes carbonate system
$\Rightarrow$ CO_2 removal potential $\sim$ 20% smaller

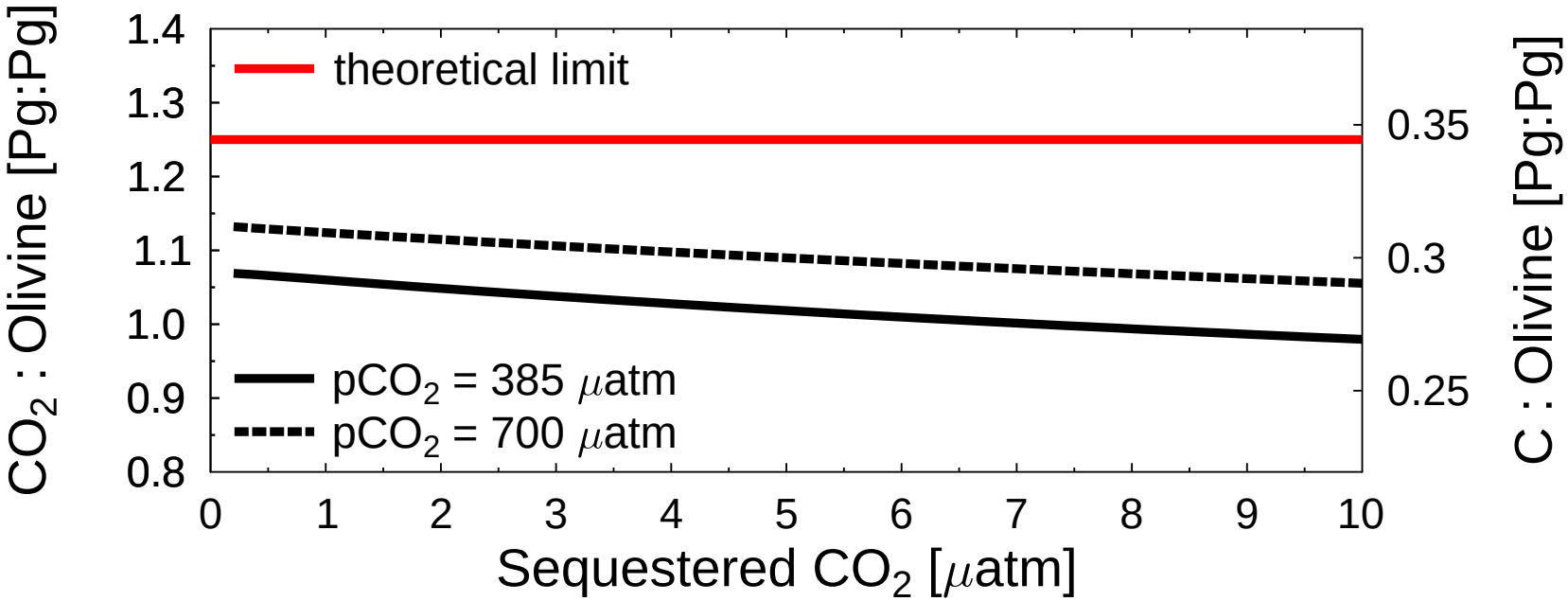
$$(Mg,Fe)_2SiO_4 + 4\,CO_2 + 4H_2O \Rightarrow 2\,(Mg,Fe)^{2+} + 4\,HCO_3^- + H_4SiO_4$$

olivine + carbonic acid $\Rightarrow$ cations + bicarbonate + silicic acid

Theoretical limit of chemical effect (no enhanced biology):

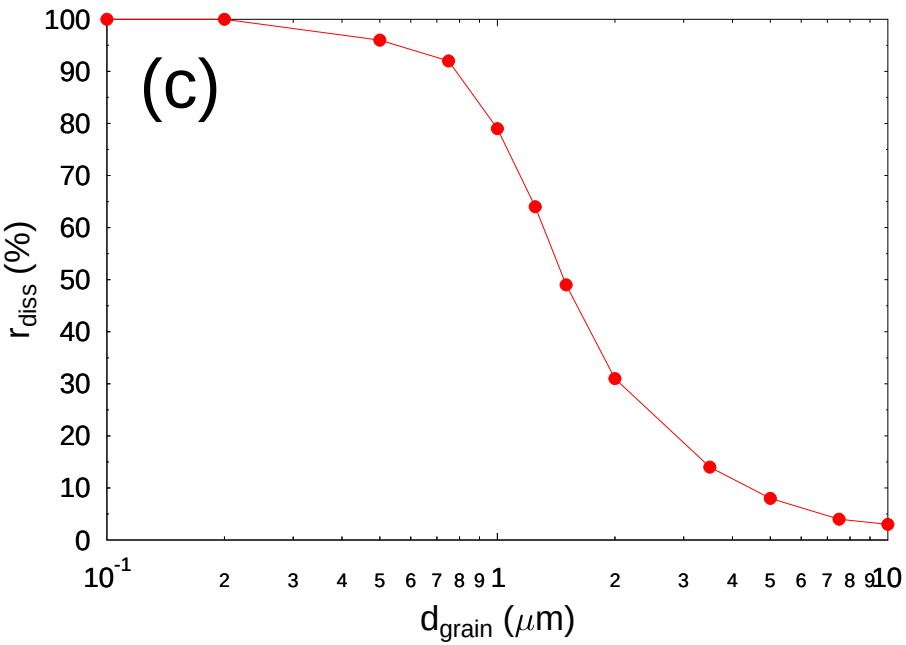
1 mol olivine removes 4 mol CO_2 (1 t olivine = 1.25 t CO_2 (0.34 t C))

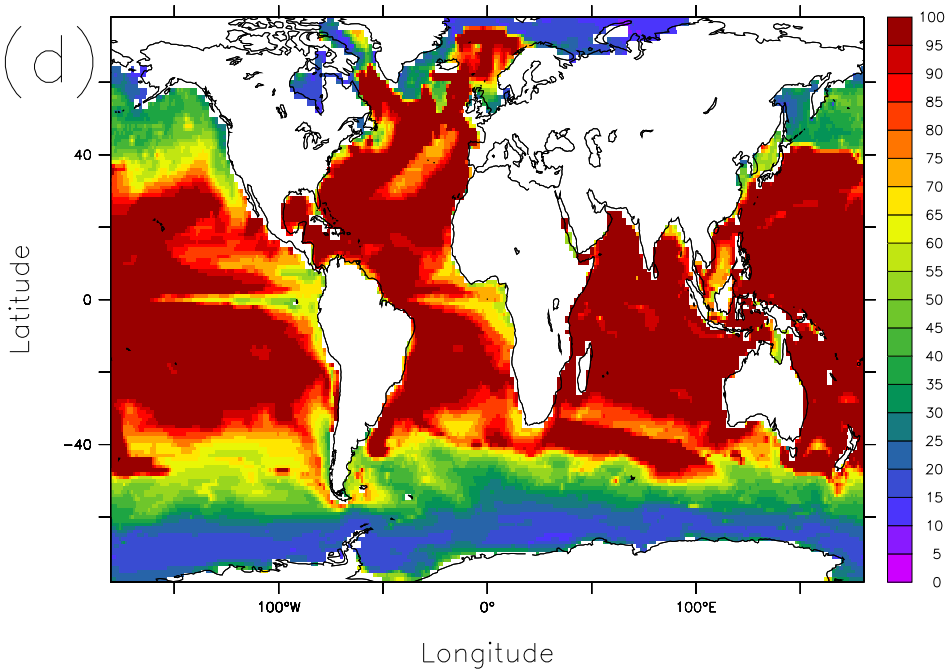
Realization: about 20% smaller depending on carbonate chemistry



(Köhler et al., 2010)

(2) Dissolution Kinetics: Only particles of 1μm sink slow enough for surface dissolution.



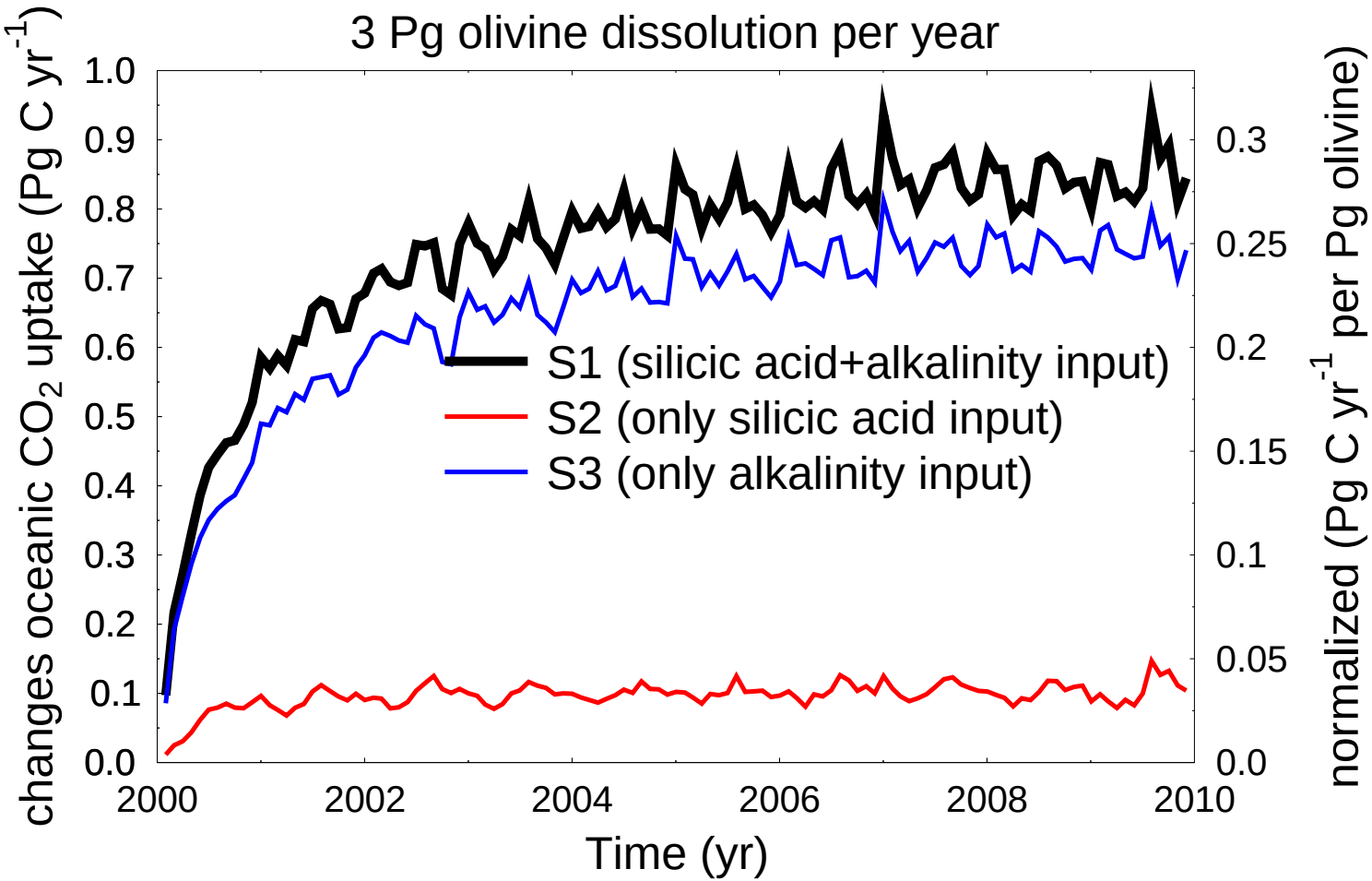


global mean dissolution as function of grain size

Dissolution $= f$(SST, mixed layer depth)
Example for grains of $\sim 1\mu$m.

(Köhler et al., 2013)

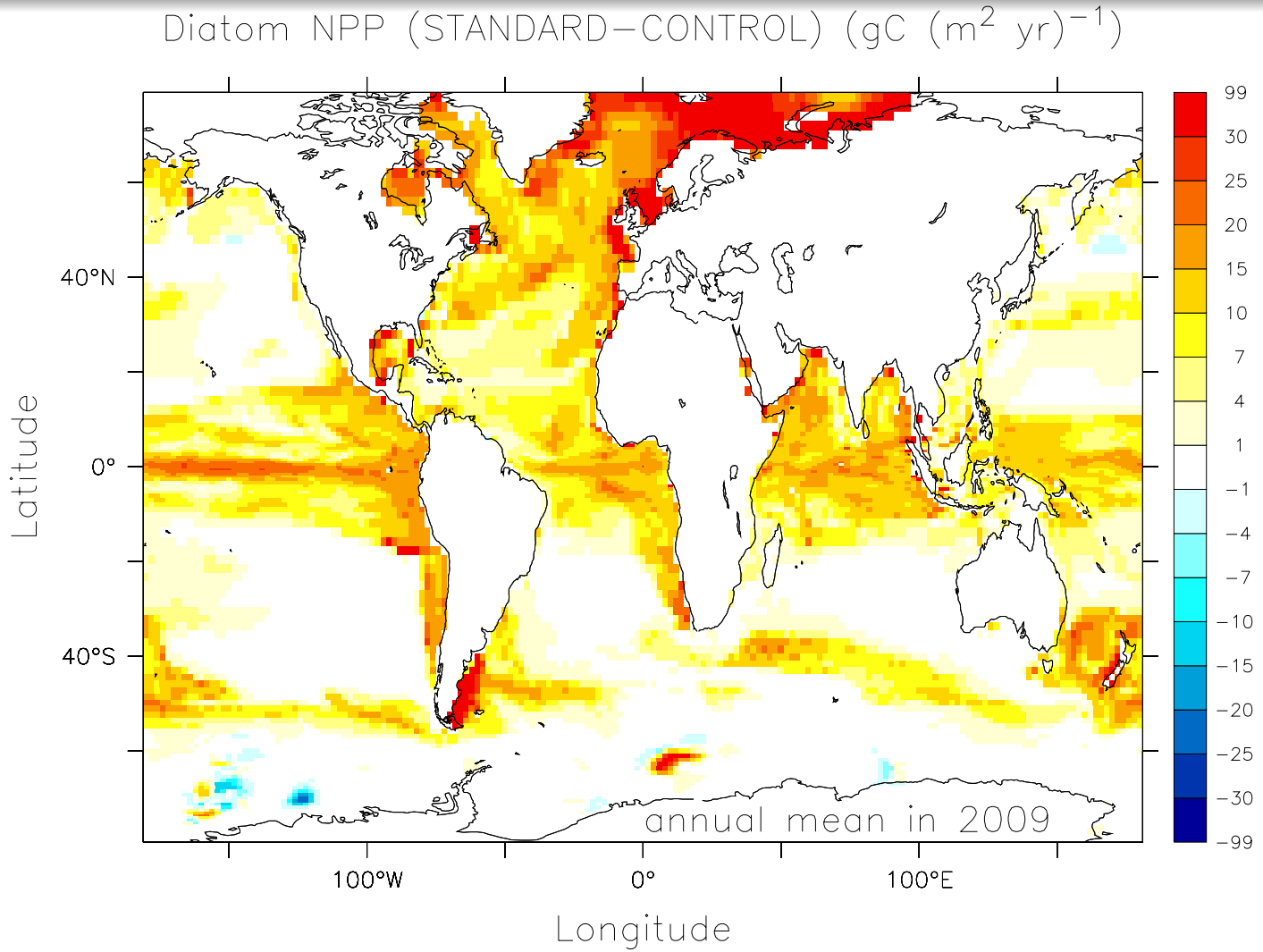
(3) Chemistry: CO_2 removal dominated by alkalinization with add-on by silicate fertilization.



Silicic acid input (ocean fertilization) increases CO_2 removal by 8%.

(Köhler et al., 2013)

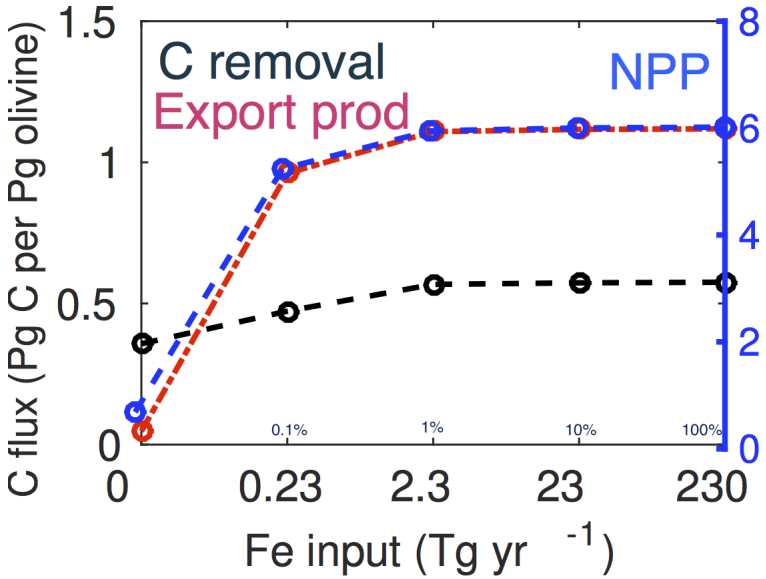
(4) Marine Biology: Enhanced olivine dissolution is also ocean fertilization, leading to species shifts.

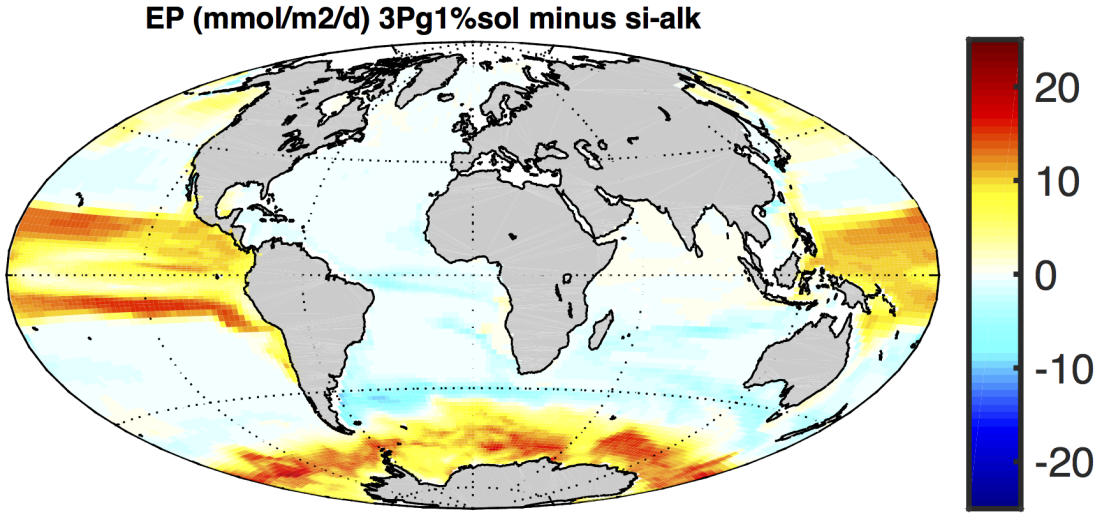


Silicic acid input from olivine dissolution ⇒ species shift

Diatom NPP: + 14%; organic C export: + 1% (Köhler et al., 2013)

(5) Iron: Iron fertilization (+50% CO_2 removal) is possible but less feasible.





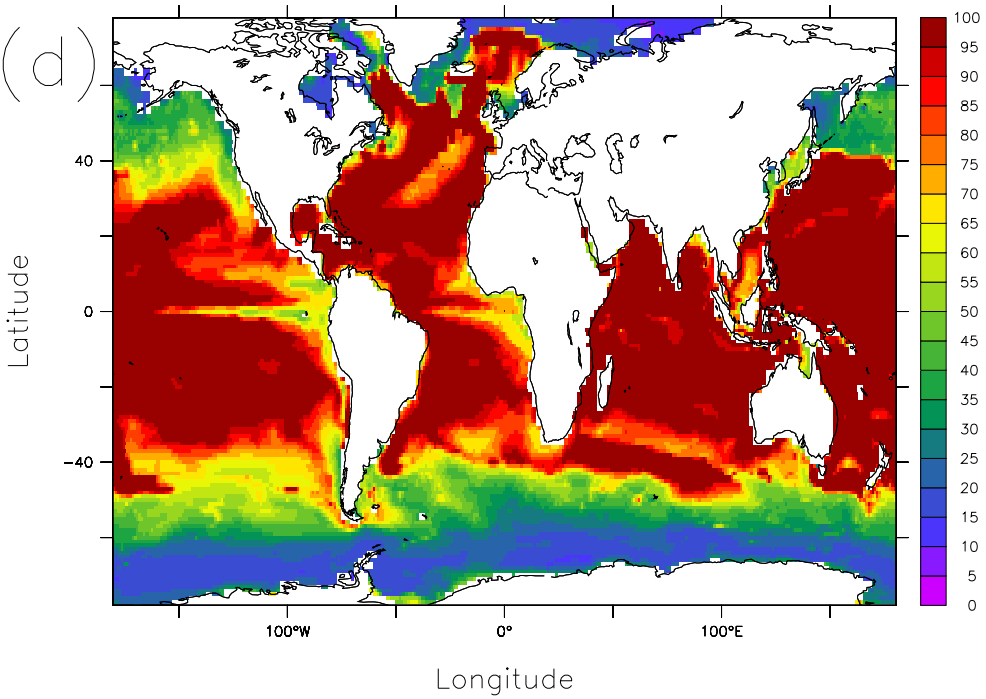
Already a dissolution and biological availability of 1% of the iron contained in olivine leads to iron saturation.
Iron fertilization is restricted to HNLC areas,
mainly in Eq Pac (model-dependent) and the Southern Ocean.

⇒ (up to) 0.55 gC per g olivine (63%alk + 5%Si + 32%Fe)

(Hauck et al., in prep)

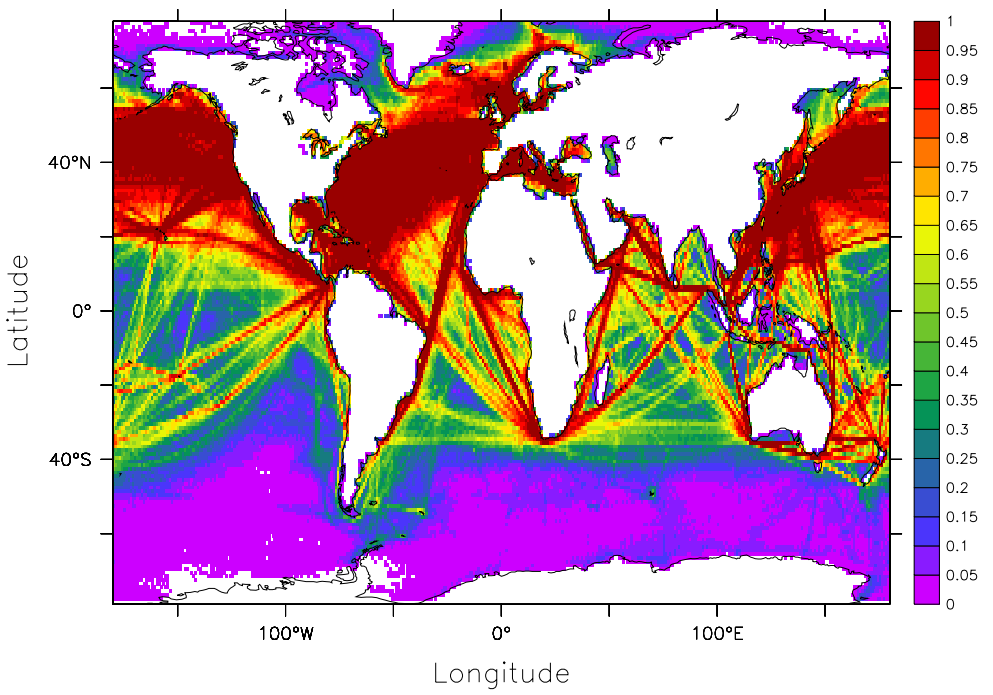
(6) Ships of opportunity: Ballast water of ships has potential to dissolve 0.9 Pg olivine.

dissolution kinetics



dissolution (%) of 1μm particles

ship tracks



based on NOAA data

Southern Ocean:

particle dissolution slow

no ships to go

(Köhler etal., 2013)

- **(1) Potential:** Process changes carbonate system $\Rightarrow$ CO_2 removal potential $\sim$ 20% smaller
- **(2) Dissolution kinetics:** Only particles of 1μm sink slow enough for surface dissolution.
- **(3) Chemistry:** CO_2 removal dominated by alkalinization ($\sim$90%) with add-on by silicate fertilization.
- **(4) Marine Biology:** Enhanced olivine dissolution is also ocean fertilization, leading to species shifts.
- **(5) Iron:** Iron fertilization (+50% CO_2 removal) is possible, but less feasible.
- **(6) Ships of opportunity:** Ballast water of commencial ships has potential to dissolve 0.9 Pg olivine.
- **(7) Limitation:** Local bottleneck might be the saturation concentration of silicic acid H_2SiO_4.
- **(8) pH:** If distributed on land river pH might rise significantly.
- **(9) Time:** CO_2 removal is not permanent.
- **(10) Size of problem:** 3 Pg yr^{-1} of olivine to remove 1-2 Pg C yr^{-1} (coal production: 8 Pg yr^{-1}).

References

Hartmann, J.; West, J.; Renforth, P.; Köhler, P.; De La Rocha, C.; Wolf-Gladrow, D.; Dürr, H. & Scheffran, J. 2013. Enhanced Chemical Weathering as a Geoengineering Strategy to Reduce Atmospheric Carbon Dioxide, a Nutrient Source and to Mitigate Ocean Acidification. *Reviews of Geophysics*, 51, 113 - 149.

Köhler, P.; Abrams, J. F.; Völker, C.; Hauck, J. & Wolf-Gladrow, D. A. 2013. Geoengineering impact of open ocean dissolution of olivine on atmospheric CO_2, surface ocean pH and marine biology. *Environmental Research Letters*, 8, 014009.

Köhler, P.; Hartmann, J. & Wolf-Gladrow, D. A. 2010. Geoengineering potential of artificially enhanced silicate weathering of olivine. *Proceedings of the National Academy of Science*, 107, 20228-20233.

The End

Open questions

- Dissolution kinetics of olivine not yet clear, our theory needs support from experiments.

- Scavenging and ballast effect might effect how much iron is biological available.