Bio-availability of Iron Inputs to the Ocean Driven by Aerosol Chemistry in Dust

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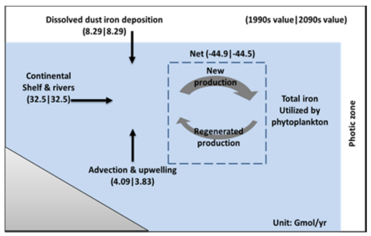
Introduction

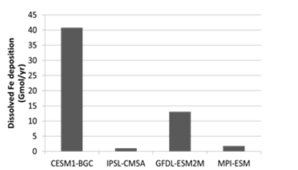
Iron (Fe) is responsible for limiting marine phytoplankton productivity and primary production in high-nutrient low-chlorophyll areas of the ocean. The principle source of bio-available Fe to the open ocean is mineral dust transported from the atmosphere. Therefore, future ocean biogeochemistry strongly depends on changes in dust emissions and aerosol chemistry in dust that determines solubility thus bio-availability of dust Fe to phytoplankton under future climate states. In the CMIP5 Earth System models, information about Fe dissolution along the pathway from dust source regions to the oceans remains incomplete. There is large variability in the predicted atmospheric deposition of Fe among models (Figure below). Here we present a dust Fe dissolution scheme that can be implemented into the CESM to link the bio-availability of Fe inputs to aerosol chemistry. Sensitivity of soluble Fe deposition to Fe sources, dust mineralogy and emissions are examined.

Globally dissolved Fe budget in CESM1-BGC



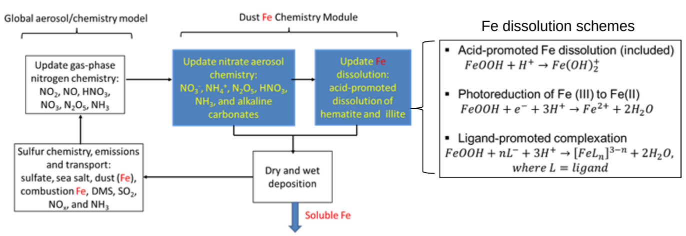
(Misumi et al., 2014)

Dissolved Fe deposition in four CMIP5 ESMs



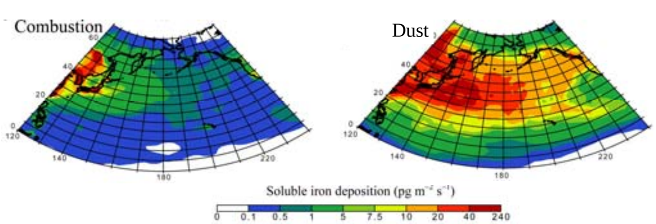
Dissolved Fe deposition = dust + sediment from shelf & rivers (constant between 1850-2005)

Dust Fe chemistry module



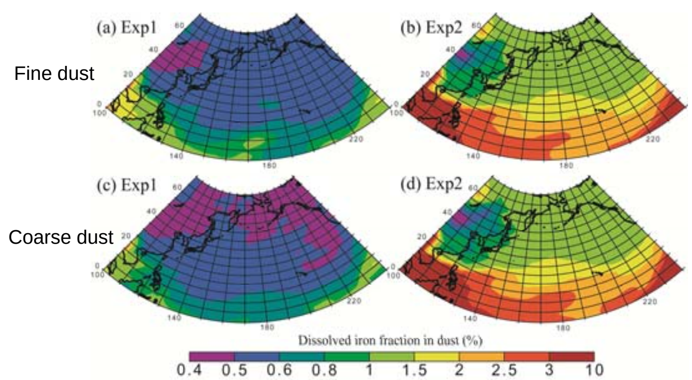
The dust Fe chemistry module has been implemented into the global chemical transport model Umich/IMPACT (Ito and Feng, 2010). Simulations shown below were performed to examine the dependence of predicted soluble Fe deposition on dust and aerosol properties

Dependence on Fe sources



Dust is the dominating source of soluble iron deposition from the atmosphere

Dependence on dust chemical composition



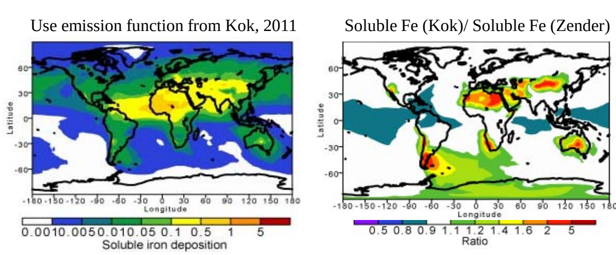
Dissolved Fe fraction in dust (%) calculated in the model surface layer. Exp. 1 (a) and (c) assumes the calcite-rich dust composition (11% $CaCO_3$, 5.5% $MgCO_3$, and 5% Fe_2O_3); Exp. 2: (b) and (d) assumes the aluminosilicate-rich (Al-rich) dust (5% Fe_2O3 without alkaline minerals).

Observed and Modeled Iron Fractional Solubility (%)

Location	GOSAN (33°N, 126°E)		Cruise (24°N-28°N, 170°E-155°W)		Cruise (5°S-35°N, 60°W-20°W)	
Particle size	Bulk	Bulk	Fine	Coarse	Fine	Coarse
# of data points	27	23[b]	18	18		
Observations[a]	2.6±3.3	1.4±1.2	1.7±0.8	0.6±0.2	2.2±7.1	0.3±0.7
Experiment 1	1.2±0.5	1.1±0.5	0.7±0.1	0.52±0.02		0.5
Experiment 2	1.7±0.7	1.6±0.7	2.0±0.2	1.8±0.2	1.2	

[a]References: Chen and Siefert, 2003; Duvall et al., 2008; Hand et al., 2004
[b]Four distinct high values of the water-soluble fraction of iron in total particles were excluded

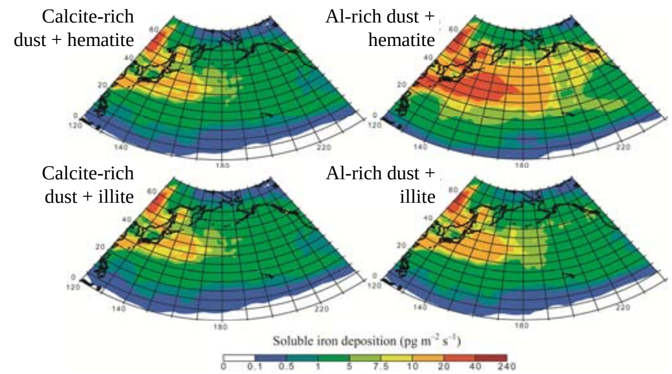
Dependence on dust source function



The impact of dust size distribution in several source functions is examined for soluble Fe deposition (Ito et al., 2012). Large differences between Kok (2011) and Zender et al. (2003) are found in regions where the concentration of acidic gases is not sufficient to promote Fe dissolution, such as the South Atlantic downwind of the Patagonian desert.

References: Gao et al., (2013), JGR, 118, 1-15; Ito and Feng (2010), ACP, 10, 9237-9250; Ito et al. (2012), GRL, 39, L05807; Kok (2011), PNAS, 108(3), 1016-1021; Misumi et al. (2014), Biogeosciences, 11, 33-55; Zender et al. (2003), JGR, 108, 4416.

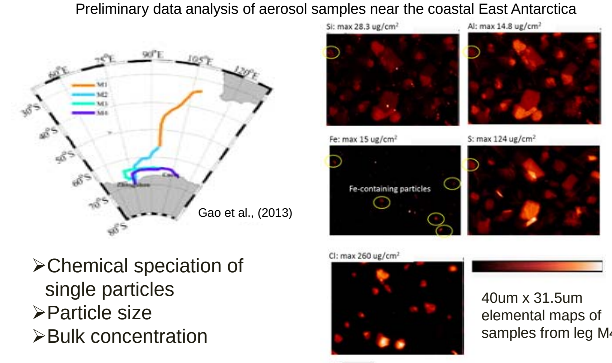
Dependence on dust Fe mineralogy



Illite is assumed to the insoluble Fe form in fine dust (1.8%) For calcite-rich dust, the faster dissolution rate of illite is compensated by the lower Fe fraction in dust. But without the buffering effect of alkaline minerals, the assumption of illite leads to much lower soluble Fe deposition..

Synchrotron-based X-ray spectroscopy of dust mineralogy

Preliminary data analysis of aerosol samples near the coastal East Antarctica



- Chemical speciation of single particles
- Particle size
- Bulk concentration

Conclusions and future work

- We demonstrate a modeling framework that can test our understanding of the temporal and spatial variation in atmospheric Fe input to the ocean, driven by human-induced pollution perturbations overlaid with climate- and land-use-driven dust emission changes. We have shown that the supply of bio-available Fe varies considerably from near-source regions to open sea, depending on chemical speciation of Fe and alkaline dust minerals, and dust source functions.
- Next step is to implement Fe dissolution schemes in the CAM model that distinguish different dust mineralogy, and couple it with the ocean biogeochemistry model to examine the impact of Fe deposition on marine biogenic emissions under future climate states. Organic acids, or cloud processing of dust may also need to be considered.