Relevant articles illustrating the principal Cooling Effects of Iron Salt Aerosol in the lower atmosphere

GGR: Atmospheric Removal of Greenhouse Gases under the Marine Boundary Layer

Iron oxides, iron oxy-hydroxides, iron chloride, iron organic complexes, and other iron derivatives, in contact with sodium chloride and some acidity generate chlorine atoms in sunlight.

Wittmer Julian D., PhD thesis https://core.ac.uk/download/pdf/44736554.pdf. Bayreuth University, Germany 2015.

1. ### Methane:

Chlorine atoms generated by ISA react 16 times faster with methane than the hydroxyl radical °OH, converting methane to carbon dioxide, cutting its global warming potential from 84 to 1 (on a time-scale of 20 years, or from 28 to 1 on a time scale of 100 years).

Over coastal polluted areas halogen atoms remove methane and ozone.

Atkinson, R., et al. "Evaluated kinetic and photochemical data for atmospheric chemistry: Volume IV–gas phase reactions of organic halogen species." *Atmos Chem & Physics* 8.15 (2008): 4141-4496.

Sommariva, R., & von Glasow, R. (2012). Multiphase halogen chemistry in the tropical Atlantic Ocean. *Environ Sci & Tech*, *46*(19), 10429-10437.

2. ### Ozone:

Chlorine atoms generated by ISA, as well as bromine or iodine atoms generated in a similar way, convert low level surface ozone to non-warming oxygen, with no effect on the high-level stratospheric ozone layer.

Wittmer, J., Bleicher, S., & Zetzsch, C. (2014). Iron (III)-induced activation of chloride and bromide from modeled salt pans. *The J. of Physical Chem A*, 119(19), 4373-4385.

Thompson, C.R., et al. (2015) "Interactions of bromine, chlorine, and iodine photochemistry during ozone depletions in Barrow, Alaska." *Atmos Chem & Physics* 15.16 (2015): 9651-9679.

3. ### Halomethanes:

Chloromethane $ClCH_3$ and other halomethanes such as $BrCH_3$ are natural products which destroy the stratospheric ozone layer. Chlorine atoms react 13 times faster with $ClCH_3$ than the hydroxyl radical °OH.

Bahlmann, Enno, et al. "Evidence for a major missing source in the global chloromethane budget from stable carbon isotopes." *Atmos Chem & Physics* 19.3 (2019): 1703-1719.

Harper, D. B., & Hamilton, J. T. (2003). The global cycles of the naturally-occurring monohalomethanes. In *Natural production of organohalogen compounds* (pp. 17-41). Springer, Berlin, Heidelberg.

4. ### Other climate forcers:

Chlorine radicals destroy volatile organic compounds, some trace gases with high global warming potential and several dangerous pollutants.

Marine fuel additives containing iron organic complexes like ferrocene, iron picrate and others are commercially available. During marine fuel combustion with these iron additives, the emissions of Black Carbon BC are reduced, together with emissions of CO and NOx.

Ryu Y., Lee Y. & Nam J. (2016). Performance and emission characteristics of additives-enhanced heavy fuel oil in large two-stroke marine diesel engine. *Fuel*, *182*, 850-856.

Carbon Dioxide Removal

5. Ocean Plankton Fertilization:

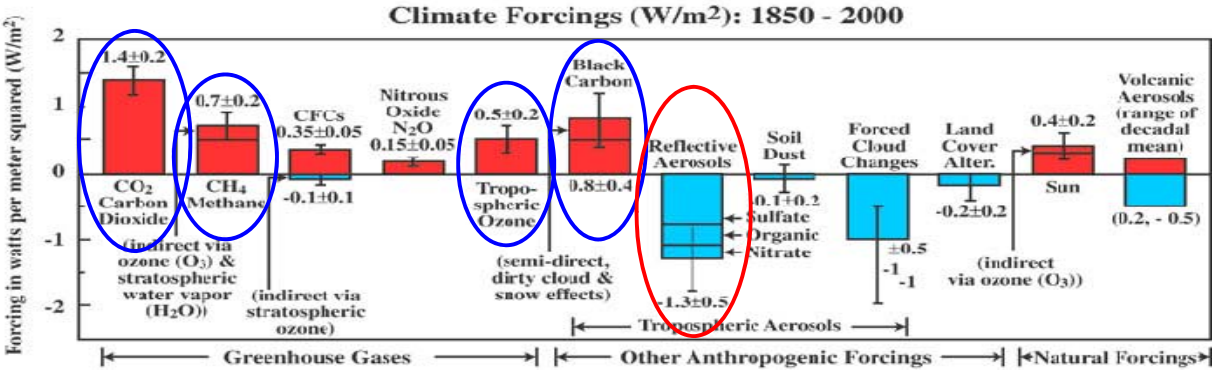
According to the Redfield ratio or stoichiometry, there is nearly a consistent atomic ratio of 106:16:1:0.001 for carbon, nitrogen, phosphorus and iron found in marine phytoplankton and throughout the deep oceans. Each atom of iron added to the ocean can theoretically enable photosynthesis of up to 100,000 carbon atoms, increasing biological abundance, biodiversity and carbon storage. Nearly $^1/_3$ of oceanic surfaces are high nutrient low chlorophyll areas HNLC, iron deficient. Some scientific ocean iron fertilization experiments have conducted phytoplankton to deep ocean C storage, but many marine biologists think that more often rapid and massive organic C mineralization to CO_2 occurs.

Behrenfeld, Michael J., et al. "Confirmation of iron limitation of phytoplankton photosynthesis in the equatorial Pacific Ocean." *Nature* 383.6600 (1996): 508.
Smetacek, Victor, et al. "Deep carbon export from a Southern Ocean iron-fertilized diatom bloom." *Nature* 487.7407 (2012): 313.

6. Land Plants:

On continents, plant chlorosis or iron deficiency is a common disorder affecting plants (crops, orchards, forests) in many areas of the world, and has economic significance, because crop quality and yields can be severely compromised.

Fernández, V., & Ebert, G. (2005). Foliar iron fertilization: a critical review. *Journal of plant nutrition*, *28*(12), 2113-2124.
Rizzolo, J.A., et al. "Soluble iron nutrients in Saharan dust over the central Amazon rainforest." *Atmos. Chem. Phy* 17.4 (2017): 2673-2687.



Iron salt aerosol acts on several GHGs and climate forcers.

Image from IPCC 3rd Assessment Report 2001

Sunlight Reflection

7. Cloud Albedo (direct effect):

Iron-based particles act as cloud condensation nuclei that increase cloud growth, whiteness and duration.

8. Cloud Albedo (indirect effect) by plankton emitted gases:

Dimethyl sulphide and Dimethyl sulfonio propionate are cloud-producing natural gases which are released by phytoplankton blooms produced by ISA.

Grandey B.S.,Wang, C. (2015). Enhanced marine sulphur emissions offset global warming and impact rainfall. *Scientific reports*, *5*, 13055.
Wingenter, Oliver W. "New Directions: Enhancing the natural sulfur cycle to slow global warming." *Atmos. Environ.* 41 (2007): 7373-7375.

9. **Ocean albedo by Algae:**

By enhancing growth and blooms of calcium carbonate light-colored coccoliths and of diatoms with silica skeletons, ISA makes the ocean more reflective.

There are many other effects of Iron Salt Aerosol ISA.

Oeste, Franz Dietrich, et al. "Climate engineering by mimicking natural dust climate control: the iron salt aerosol method." *Earth System Dynamics* 8.1 (2017): 1-54.
de Richter R. et al., Iron Salt Aerosol a natural method to remove methane & other greenhouse gases. IMechE Conference 11th September 2019, New tools for Climate Repair: an introduction for Engineers.

Iron Salt Aerosols are natural, and already occurring, both by natural processes and by human made (anthropogenic) ones.

10. **Natural ISA:**

In volcanic plumes CH_4, O_3, and VOCs depletions occur. When the volcanic ash falls into the ocean, phytoplankton booms occur.

Gliss, Jonas, et al. "OClO and BrO observations in the volcanic plume of Mt. Etna–implications on the chemistry of chlorine and bromine species in volcanic plumes." *Atmospheric Chemistry and Physics* 15.10 (2015): 5659-5681.
Baker, A. K., et al. (2011). Investigation of chlorine radical chemistry in the Eyjafjallajökull volcanic plume using observed depletions in non-methane hydrocarbons. *Geophysical Research Letters*, *38*(13).
Surl, L., et al., (2015). Quantification of the depletion of ozone in the plume of Mount Etna. *Atmospheric Chem & Phys 15*(5), 2613-2628.
Achterberg, Eric P., et al. "Natural iron fertilization by the Eyjafjallajökull volcanic eruption." *Geophysical Research Letters* 40.5 (2013): 921-926.
Langmann, Bärbel, et al. "Volcanic ash as fertiliser for the surface ocean." *Atmospheric Chemistry and Physics* 10.8 (2010): 3891-3899.
Hamme, Roberta C., et al. "Volcanic ash fuels anomalous plankton bloom in subarctic northeast Pacific." *Geophysical Research Letters* 37.19 (2010).

11. **Human made anthropogenic ISA is already occurring:**

There is extensive scientific evidence that large-scale, open-field ISA emissions are already occurring, mainly from the steel industry, the fossil fuel power plants and from other combustion processes such as marine container ships.

Li, W., et al. (2017). Air pollution–aerosol interactions produce more bioavailable iron for ocean ecosystems. *Science advances*, *3*(3), e1601749.
Lin, Y.C., et al. (2015). Atmospheric iron deposition in the north-western Pacific Ocean and its adjacent marginal seas: the importance of coal burning. *Global Biogeochemical Cycles*, *29*(2), 138-159.
Ito A. et al. (2013). Global modeling study of potentially bioavailable iron input from shipboard aerosol sources to the ocean. *Global Biogeochem Cycles*, *27*(1),1-10.
Sedwick, P. N., et al. (2007). Impact of anthropogenic combustion emissions on the fractional solubility of aerosol iron: Evidence from the Sargasso Sea. *Geochemistry, Geophysics, Geosystems*, *8*(10).
Wang, R. et al. (2015). Sources, transport and deposition of iron in the global atmosphere. *Atmospheric Chemistry and Physics*, *15*(11), 6247-6270.
Luo, C. et al. (2008). Combustion iron distribution and deposition. *Global Biogeochemical Cycles*, *22*(1).

12. **Iron dust decreased atmospheric CO_2 during glacials:**

Yamamoto, Akitomo, et al. "Glacial CO2 decrease and deep-water deoxygenation by iron fertilization from glaciogenic dust." *Climate of the Past* 15.3 (2019): 981-996.
Muglia, Juan, et al. "Weak overturning circulation and high Southern Ocean nutrient utilization maximized glacial ocean carbon." *Earth & Planetary Sci. Let* 496 (2018): 47-56.
Shoenfelt, Elizabeth M., et al. "Highly bioavailable dust-borne iron delivered to the Southern Ocean during glacial periods." *PNAS* 115.44 (2018): 11180-11185.