

# ***Interactive comment on “Climate engineering by mimicking the natural dust climate control: the Iron Salt Aerosols method” by Franz Dietrich Oeste et al.***

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The contribution under discussion from Oeste and colleagues reviews prospects for allowing, or even controlling, atmospheric chemical processes in order to enhance iron fertilization of the remote ocean. Emphasis is placed upon a routing of specific additives, through the exhaust or effluent from existing energy infrastructure and transportation modes. But the arguments extend high into the atmosphere, deep within the ocean and even penetrate the lithosphere.

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The paper constitutes a veritable treasure trove of information. A huge variety of lower atmospheric and upper marine chemistry is treated in great detail, with complete contemporary referencing. Special attention is given to iron processing, as it may interact with the remainder of the periodic table across multiple geophysical fluid environments. General aerosol/cloud processing, gas phase photochemistry, surface ocean organosulfur controls and marine biogenic precursor emissions all enter the logic, along with much more. As a bonus, the text delves into long time-scale crustal geochemical cycling. Special attention is given to cross-talk among environmental phase states involving iron oxy-hydroxides, soot and finally aqueous-gas halogen chemistry. Continental shelf clathrates and their destabilization also appear in due course.

Clearly this work is exceptionally broad in its chemical (engineering) scope. It raises fascinating issues regarding the complexities which must be confronted as humankind considers manipulating global geochemical cycles which may be available and accessible. Inevitably, we as a species are likely to test many such concepts and implement some subset of them. Oeste et al. offer the most complete discussion of such topics that I have ever encountered. And I make this statement after a full career involving a substantial amount of geoengineering research. Breadth is in fact the primary virtue of the paper, and not one to be dismissed lightly.

Due in large part to its (breathtaking) scope, the Oeste paper is exceptionally difficult to ingest. Problems will be compounded for certain readers by a consistent use of highly nonstandard scientific English, with a strongly European tone. But the writing style is only a very minor problem. I had no trouble translating into more traditional and expected wording-sentence structure internally, as I was moving through the various sections. In fact I found myself COMPELLED to do so, as I was drawn by my own chemical curiosity into the guts of the material. My reward: An abundance of new and exciting concepts, all exceptionally well referenced.

About halfway through the paper, I was somewhat surprised to find that I had hit my own personal scientific limits as a reviewer. I like to boast of strong interdisciplinary

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training, and consider myself relatively well-versed in most aspects of global scale environmental chemistry. During my career there has been serious involvement in the coupled and highly interactive processes of upper ocean and lower atmosphere, with further experience on either side of this regime –spanning downward into waters of the thermocline and Arctic Ocean shelf-Atlantic Layer plus up through the stratosphere. Still, the research described by Oeste and company pushed well beyond my expertise into several new and remote corners of the Earth System. The work is encyclopedic.

In fact it is truly outstanding in terms of its global physical-chemical scope. I found myself smiling and shaking my head in amazement as new themes kept entering... and entering and entering.

I was not able to identify ANY scientific errors anywhere in the paper. This is usually a very good sign. I noted only well-formulated, testable ideas as I moved through the text. My feeling is that the span of the authors' thinking will make it difficult for your journal to secure a single, all-encompassing review. Hence my recommendation is the following: Let us err on the side of free and open dissemination of scientific information. Publish the paper exactly as it stands. The work should prove to be a valuable source of information for not only the geoengineering community but for Earth System scientists and modelers in a general sense. My judgment is this –get the paper out there since it will be extremely useful to diverse research communities.

I have only one real criticism of Oeste et al. and though major, it is also very much worth exploring even as I suggest that publication is your best strategy. The concern is so critical that I will take an opportunity to devote several paragraphs to it here. Furthermore the points are mainly philosophical, and they are applicable to many generic geoengineering concepts now reverberating through the contemporary market place. Oeste and company offer a perfect springboard for the debate I would hope to engage.

It is of course fascinating to consider whether jet fuel combustion products, power plant plumes or a population of ship tracks might be augmented-spiked-manipulated-

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engineered to add to the tendency of iron cycling to counter the greenhouse effect. But the notion really boils down to combatting one form of large scale pollution with another. Is this perhaps where humanity should draw a geoengineering “line in the sand”?

There are many analogous cases citable from the literature, including papers on which I have been an author. At one point in the early nineties, I participated in evaluation of a scheme to mitigate the ozone hole by engineering the injection of light hydrocarbons -into the total volume of the stratosphere over Antarctica. The immediate inspiration was to convert chlorine radicals (the bare, reactive atoms) into the stored and thus safer form hydrochloric acid (vapor). But simple photochemical modeling performed relatively quickly by our group demonstrated that all was not as it seemed. First impressions had been very deceptive for us. We quickly learned that our elegant little idea would backfire badly. A combination of gas phase and heterogeneous (cloud-ice surface) chemical processes would in fact lead to EXTRA activation of chlorine into the atomic form –a shift TOWARD increased ozone depletion power.

This theme will likely be repeated many times during the era of global change, as increasingly well-educated and well-armed systems technologists explore a myriad of potential and imaginable mitigation concepts. But even a moderate amount of knowledge can be a dangerous thing. We must naturally expect the unexpected, from a singularly complex system which also happens to be our home. It is clear in the foreseeable future that our ability to conceive new and exciting geochemical cycles far outstrips our ability to understand them, whether in the mind’s eye or computationally.

Earth System Models and the ever-so-human teams that build them are currently saturated, even by exercises as simple as inter-comparison of CO<sub>2</sub> drawdown toward the deep sea or into soils. Ecodynamics lead in a well established manner to carbon storage disconnected from the atmosphere, and global warming may indeed alter the biological capability to provide such reservoirs. But carbon dioxide is only one especially long-lived greenhouse gas among many, whether anthropo- or bio-genic. And feed-

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back loops abound which are highly nonstandard, extending far beyond atmospheric accumulation of infrared absorbers to . . .

–Marine and terrestrial biological aerosol sourcing, their relation to cloud condensation nucleus numbers, the attendant influence on short and long wave cloud forcing, ice nucleation with exquisite sensitivity in polar cloud reflection, biogeochemical influences within the sea ice system including pigment layers and exopolymer pore blockage, continental shelf response to riverine chemical change, coastal plumes and aerosol release. . . the list is longer in fact than the Oeste et al. paper itself.

The entire periodic table, Beilstein database and the Linnaean biological hierarchy should be enfolded into this book of unknowns. Multiple oxidation states and phases are intimately involved in making the requisite environmental chemical connections. Bacteria dominate the organic chemistry of the entire exterior of our planet, yet their processing of macromolecules is only crudely represented in current systems models. Surfactant chemistry and especially that of the biopolymers is especially understudied, while interfaces act as a set of critical filters at all major points of communication among bulk phases. In some cases, new geochemical cycles which must be considered as potential feedbacks lead to strong regional effects and the redirection of classic meteorological teleconnections –while cancelling themselves or each other to a large degree at the planetary scale!

These effects are invisible in all modern modeling approaches, reduced or detailed. The influences pass far beyond mere global warming. Critical human dimension issues of the global hydrological system are at stake, including precipitation rates and distributions, drought, flood, landslides, the recharging of aquifers and all manner of severe storms.

I will not even touch upon the implications for biodiversity and ecosystem (food web) structure.

Since the present-day Earth System Modeling culture is so resource limited that it can

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barely push itself beyond traditional CO<sub>2</sub>, complex chemical and biological engineering concepts pose certain inevitable and inalienable risks. But nonetheless, these should (must) be vigorously and repeatedly revisited. Identifying the challenges and attendant problems forces us all to think in new and creative ways about the vast network of biogeochemical controls now being uncovered, across the planetary climate state. Newer and more exotic feedback loops will continue coming to the fore –but history teaches us that this is entirely to be expected. The ozone war had its hole and then a wholly unfamiliar heterogeneous chemistry, driven by multi-element crystalline phases. Southern Ocean iron may prove to be nitrate-appropriating at a vast and tele-connective scale. Biogenic aerosol particles pass information to marine cloud systems in ways which are potentially Gaian and self reinforcing for primitive organisms. Or there may be positive gain on a net basis. Arctic sea ice loss may yet prove to be accelerated by biological influences on coloration, absorption, organic restructuring and pack-internal radiation transfer.

Under these circumstances, my assessment is that the rich exposition of environmental iron chemistry offered to us by Oeste et al. should simply be published as is. It is dense and difficult to read but describes an even more difficult planetary milieu. The paper constitutes a literary metaphor for the only known biosphere. And this gives one appropriate pause. As you can see, the authors already have me thinking in ways I never have before –and I have been working on this sort of material continually over a very long career. But at the same time, I wish to add a note of caution. Earth System Models of the contemporary era are woefully inadequate to the task of truly evaluating such idea suites. And so of course my reader must now be smiling and remarking –like everyone else this guy Elliott has an agenda.

As a community, why don't we bounce off this sort of effort to improve the process treatments in our environmental system codes? This would occur precisely so that we can think more deeply about the biogeochemical details. The devil is in them, I have no doubt. Both our comprehension and management of the planet will benefit from

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contemplation of Oeste et al. and the like. A cascade of investments in laboratory and field work will also be required, but this is a very natural outcome. . . and is anyone out there complaining?

In the interest of generating a timely response for this journal, I will submit my review at the present stage. But I hope to return soon with further comments, cast as a set of tables quantifying the main concepts invoked. I believe it can be shown rigorously that Earth System simulations of the present day can only be improved through disciplined, prioritized introduction of...

-More complete sets of the chemical elements, additional interfaces, minor phases and their transitions, biopolymers, the organisms which synthesize them, surfactants, modes of catalysis and much more. As indeed the authors in question here strongly imply. It's about the chemistry. I further believe that geoengineering propositions could be usefully categorized by their geocycling complexity, in terms much like the ones I have outlined. Plus a metric of "containment" could be incorporated. . . which would encapsulate the notion of pollutant versus pollutant.

I'll try hard to return to these issues in the near future, by submitting further and more persuasively annotated commentary. But for the moment, I recommend that this very speculative and complete review from the Oeste team be added to the ever-expanding geoengineering literary fray. I have with me a thorough listing of edits to the European English along with a few typo identifications, but I will only send such trivia if requested to do so.

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