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Comment on “The Southern Ocean Biological Response to Aeolian Iron Deposition”

Philip W. Boyd* and Douglas Mackie

Cassar *et al.* (Reports, 24 August 2007, p. 1067) proposed that aerosol-iron input enhances Southern Ocean export production. Their conclusion critically depends upon aerosol-iron modeling simulations not validated with iron-deposition data and dust dissolution rates based on Northern Hemisphere atmospheric chemical conditions (low pH). This diminishes the relevance of their findings and demonstrates that applying such models to this region is premature.

Cassar *et al.* (1) reported that airborne delivery of iron associated with dust particles increases both primary and export production in Southern Ocean waters, with implications for alteration of atmospheric carbon dioxide concentrations, and hence global climate in both the geological past and the future. The authors used two distinctly different data sources to arrive at this conclusion: a large number of very accurate productivity observations in Southern Ocean waters based on either oxygen/argon samples or the oxygen triple isotope anomaly (whose limitations are identified and scrutinized), and model simulations of aerosol iron deposition (2). Although the productivity data set represents an important advance and valuable resource, we contend that it is mismatched with the aerosol-iron simulations (1, 2).

The Fan *et al.* model (2) should not be applied to the Southern Ocean for two important reasons. First, the aerosol solubility is based on atmospheric sulfur chemistry (1, 2), but the model parameterization [from (3)] is not described, and unrealistically low pH values (<2) are used to set aerosol dissolution. Such low aerosol pH values are only observed for dust plumes in Northern Hemisphere regions with high levels of atmospheric pollutants (4). Second, the published model predictions of global total input of both dust and soluble iron (2) were not validated with observations but only related to previous global model simulations (5).

In the Cassar *et al.* study (1), the model output was compared, without statistical analysis, with published aerosol iron dissolution estimates, mainly from the Northern Hemisphere (with only one aerosol sample from south of 45°S). Atmospheric sulfur concentrations, which affect dust dissolution (4), are much higher in the Northern Hemisphere compared with the rela-

tively pristine atmosphere above the Southern Ocean (3). In the supplementary information for (1), Cassar *et al.* compared predicted dust atmospheric concentrations with observations at three island sites ranging from Tasmania toward the pole, but acknowledged the absence of measurements of aerosol-iron supply to the Southern Ocean.

The conversion of dust deposition fluxes to those of oceanic iron supply currently represents a major challenge for ocean biogeochemists (6). Data are rare on dust deposition into Southern Ocean waters (7), and recent attempts to sample dust in this region revealed major technical issues such as high winds and seas (sea spray) and the need for longer sampling times to overcome the low aerosol deposition rates. Thus, Cassar *et al.*'s discussion of aeolian-iron deposition to these waters is based on data derived from an unvalidated model, which assumes low aerosol pH conditions for the Southern Hemisphere, and thus has poorly constrained links between the atmospheric sulfur (3) and iron dissolution (2) models.

Even if the described model (1, 2) was applicable to Southern Ocean waters, other important information from the emerging field of iron biogeochemistry was not considered by Cassar *et al.* (1), which raises questions about the validity of their conclusions. One of their central arguments for the importance of aerosol-iron deposition is the observed south-to-north increase in productivity. Cassar *et al.* argue that this cannot be driven by upwelled iron, which they suggest would be rapidly removed by scavenging and export. However, their argument ignores well-established trends from both lab culture (8) and field studies that phytoplankton take up high amounts of iron when it is readily available. This high iron uptake [termed “luxury uptake” (8)] ensures that cells remain iron-replete for several divisions and that high productivity can be maintained as phytoplankton are transported northward in this region. Such luxury iron uptake is likely responsible for the exceptional longevity of a polar mesoscale iron-enrichment (9) and may explain the presence of 2000-km-

long high chlorophyll plumes downstream of Southern Ocean islands such as South Georgia (10). These examples illustrate how biological responses to iron supply can complicate the identification of the relative importance of different iron supply mechanisms in these waters.

Problems in attributing the geographical influence of different iron supply mechanisms are further illustrated by Cassar *et al.*'s statement that high productivity is driven solely by dust supply downstream from Patagonia, Australia, New Zealand, and South Africa. The waters off New Zealand are characterized by the subtropical front [higher dissolved iron concentrations than subantarctic waters (7)], shallow shelf regions, and eddy activity, whose interactions, in addition to dust supply, play a key role in setting local productivity. Similar oceanic characteristics are evident east of Patagonia. Furthermore, there is little evidence, from an event-based analysis, of the biological impact of episodic dust storms in the waters south of both Australia and New Zealand (7).

Other recent findings from iron biogeochemistry negate the assumptions of Cassar *et al.*, including those centered on figure 3 in (1). For example, particulate iron has a deeper remineralization length scale than particulate organic carbon or nitrogen in the upper ocean (11, 12). Also, there is both direct (13) and indirect evidence (11) that oceanic microbes can access particulate iron, which suggests that aerosol solubility is only one component of particulate iron dissolution. Multiple time scales for surface mixed-layer iron dissolution have been proposed (12), from hours (physico-chemical mechanisms) to weeks (microbial/photochemical mechanisms). Such longer dissolution time scales, in conjunction with upper ocean physical transports, will also confound the attribution of the geographical extent of different iron supply mechanisms.

Although there is no doubt that dust supply plays an important role in oceanic iron supply (6, 12), the challenge is to determine the relative roles of both atmospheric and oceanic iron supply in the present, the geological past, and the future (14). Currently, there are insufficient data on atmospheric and oceanic iron supply, iron inventories, and the biogeochemical fate of iron. The Southern Ocean study of Cassar *et al.* (1) highlights many of these gaps in this region. A marked increase in data coverage on the above iron biogeochemical properties will be provided by new programs like GEOTRACES (15), with the subsequent development of more powerful iron biogeochemical models, parameterized and validated specifically for the Southern Ocean.

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