This often requires a less traditional and more multidisciplinary approach to understanding and interpreting observed changes. Models in particular have a very important role to play: as integrators of our scientific knowledge, they allow the relationships between physical and chemical changes to be identified and explored both in the past and future, and aid in the interpretation of observations.

Resplandy and co-authors[2] have provided an important baseline for understanding and attributing changes in land and ocean sinks in response to increasing atmospheric CO_2 concentrations. Their results demonstrate the importance of the pre-industrial carbon cycle in setting the distribution of carbon sinks in the present day, and the power of exploiting the relationship between ocean heat and carbon transport driven by large-scale circulation (Fig. 1). ❐

Andrew Lenton[1,2,3]

[1]*CSIRO Oceans and Atmosphere, Hobart, Australia.* [2]*Centre for Southern Hemisphere Oceans Research, Hobart, Australia.* [3]*Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Australia.*
e-mail: Andrew.Lenton@csiro.au

Published online: 11 June 2018
https://doi.org/10.1038/s41561-018-0165-x

References

1. Sarmiento, J. L. & Sundquist, E. T. *Nature* **356**, 598–593 (1992).
2. Resplandy, L. et al. *Nat. Geosci.* https://doi.org/10.1038/s41561-018-0151-3 (2018).
3. Le Quéré, C. et al. *Earth Syst. Sci. Data* **10**, 405–448 (2018).
4. Tans, P. P. et al. *Science* **247**, 1431–1438 (1990).
5. Raymond, P. A. & Cole, J. J. *Science* **301**, 88–91 (2003).
6. Regnier, P. *Nat. Geosci.* **6**, 597–607 (2013).
7. Lenton, A. et al. *Biogeosciences* **10**, 4037–4054 (2013).

ANNIVERSARY RETROSPECTIVE

Iron from ice

Melting icebergs are an inspiring reminder of nature's immense beauty, yet also a poignant symbol of the effects of anthropogenic climate change. Icebergs in the Southern Ocean transfer iron, an essential micronutrient for all life, from glaciers to the open ocean, where it is in short supply. This iceberg iron supply can result in phytoplankton blooms visibly associated with iceberg tracks, and it is thought that icebergs can be a particularly effective iron source as they deliver iron to the open ocean. Yet quantifying the size of the iceberg fertilization effect, and what it means for marine biogeochemical cycles and ocean productivity, is a formidable research challenge.

Credit: Mie Hylstofte Sichlau Winding

Iron rapidly becomes associated with sinking particles in the ocean, rendering it unavailable to support life at the surface. It may therefore matter exactly when and where iron is delivered to a marine ecosystem. Thus, the fertilizing potential of iron may differ between sources comparing, for example, atmospheric dust with icebergs and with the shape, size and mineral state of the iron. To quantify how efficient different iron sources are for phytoplankton, Boyd et al. (*J. Geophys. Res. Ocean.* **117**, C06009; 2012) conducted an elegant study that compared the utilization of different iron sources by phytoplankton in the Southern Ocean. Surprisingly, of all the studied sources, the supply to utilization ratio for icebergs was one of the lowest. One critical problem in determining the supply to utilization ratio is simply quantifying the supply term; that is, how much iron is contained in ice? We know that icebergs themselves are highly heterogeneous, with most iron concentrated in dirty smears and particle-rich layers that are visibly blackened. In my own work, I decided to investigate the variability of iron contained within icebergs from the same source. Working in a single catchment in Svalbard, we found that iron concentrations in icebergs varied over three orders of magnitude (M. J. Hopwood et al. *Geochem. Perspect. Lett.* **3**, 200–209; 2017). Determining a mean iceberg iron content by direct measurements is thereby impractical without huge datasets, which are logistically difficult to collect when your targets are immense blocks of ice that roll in frigid waters without warning, or care, for what rolls with them. Yet there are alternatives to measuring iron itself, as any tracer of terrestrial or sediment input around icebergs would serve to approximate the oceanic iron input from icebergs.

With increasing discharge around Greenland and Antarctica, there is an obvious need to assess how marine ecosystems will respond to changing iceberg input and distribution. Better constraints on iron delivery by icebergs and the biological activity supported by this iron, as pioneered by Boyd et al., will help us to understand the ecosystem impacts of icebergs. ❐

Mark Hopwood
GEOMAR, Kiel, Germany.
A winner of the Geostory competition.
e-mail: mhopwood@geomar.de

Published online: 2 July 2018
https://doi.org/10.1038/s41561-018-0167-8