Did the glacial Atlantic overturning circulation run backwards?

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Recently Pa/Th profiles from the South Atlantic were published [1] that display structures very different from Pa/Th profiles in the North Atlantic. It was argued that these profiles indicate i) deep waters leaving the glacial Southern Ocean had a Pa/Th fingerprint not much different from that of NADW today, due to extensive Pa scavenging; ii) a basin-scale meridional Pa/Th gradient developed in the glacial Atlantic that run opposite to that of today, reflecting a more substantive northward flow of “southern sourced water” (SSW). This concept, in our view, reconciles an apparent conflict between εNd measured on Fe-Mn oxide coatings on planktonic foraminifera at the Bermuda Rise and Pa/Th data at the same location: the first indicating northward flowing SSW at the LGM while the second supposedly reflecting southward flowing “northern source water” (NSW) [2].

We borrow the provocative title from the conveners because it reflects the debate over how far we can take the proxy records. The interplay between NSW and SSW is reflected by a suite of proxy data e.g., stable carbon isotopes ($\delta^{13}C$), Pa/Th and nutrient-based trace element ratios (Cd/Ca). Pa/Th profiles are scarce and meridional gradients must be mapped using Pa/Th from a range of different water depths while gas-exchange normalized $\delta^{13}C_{as}$ suggests a prominent role of SSW in the glacial AMOC. Taking all evidence at face value suggests the glacial AMOC received a stronger water mass contribution from the southern hemisphere oceans. At the same time several questions arise: does scavenging of Pa in the Southern Ocean outcompete lateral advection and so depleting the water column of Pa? Do radiogenic isotope and nutrient-based proxies uniquely identify water mass end members? How robustly do the proxies reflect the AMOC in the past, including physical near-bottom flow speeds? These questions are not easy to answer but they help refine the direction of future work.

[1] Negre *et al*. (2010) *Nature* **468**, 84-88. [2] Roberts *et al*. (2009) *Science* **327**, 75-78.

Xenon the magnificent

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Xenon is the heaviest noble gas and the heaviest gas likely to be found in a primoridal atmosphere. It would seem to be the least likely gas to escape. Yet there is probably more evidence for massive Xe escape from Earth than for any other element save helium. Nonradiogenic atmospheric Xe is strongly mass fractionated (by about 4% per amu) compared to any of its plausible solar system sources. By contrast, Kr is only mildly fractionated, if at all. Xenon is also relatively underabundant with respect to Kr.

Radiogenic Xe also suggests escape. Radiogenic ^{129}Xe (from ^{129}I decay, half-life 15.7 Myr) is present in the atmospheres of Earth and Mars but at less than 1% the qunatity expected given the primoridal abundance of ^{129}I, Radiogenic Xe from spontaneous fission of ^{244}Pu (half-life 82 Myr) is also notably underabundant. The upper limit on fissogenic ^{136}Xe in air is about 1 part in 6 of Earth's cosmic complement from ^{244}Pu. This is an upper limit because it depends on U-Xe (rather than solar Xe) being the primordial Xe of Earth. U-Xe makes modeling Earth’s Xe much easier, but it has not otherwise been seen in the solar system.

For Xe escape to explain the dearth of fission Xe in air, escape must have taken place late enough in Earth’s story that ^{244}Pu was extinct. The mechanism would have affected Xe but not Kr or Ar. One possibility is that Xe escaped as an ion, probably in polar winds of hydrogen and hydrogen ions channelled by planetary magnetic fields. This can occur because Xe, alone among the noble gases, is more easily ionized than hydrogen. Thus Xe will tend to be present oin the H-H+ wind as Xe+, whilst the other noble gases would be neutral. Because of the Coulomb force, at 2000 K and 1% H ionization, diffusivity of Xe^+ is 3 orders of magnitude lower than that of neutral Xe or Kr. The Xe^+ ions are therefore dragged to space by the protons. Under these circumstances fractionating hydrodynamic escape can apply uniquely to xenon among the noble gases over a wide range of hydrogen escape fluxes.