matters arising

Non-biogenic fixed nitrogen in Antarctic surface waters

PARKER *ET AL.*[1] have reported measurements of the fixed nitrogen content of Antarctic ice core samples, and calculate an annual input to the Antarctic ice sheet of 27×10^6 kg(N). Following Wilson and House[2], Parker *et al.*[1] suggest auroral activity as one possible source of this fixed nitrogen.

Auroral activity may produce $\sim 4 \times 10^9$ kg (N) per yr during sunspot maximum (I assume 100 h of IBC Class II aurora per yr, extending over both polar caps, of total area 7×10^7 km^2 (ref. 3), a production of one ion pair per 35 eV energy input, and 1.3 NO molecules produced per ion pair[4]). This auroral nitrogen fixation occurs in the 70–90 km altitude range, and I do not consider it likely that a large fraction of the nitrogen fixed here will reach the surface because the photochemical lifetime of NO above 40–50 km is significantly shorter than the mean transport time down to this altitude (several days compared with a few weeks). At altitudes below 40 km or so NO has a very long photochemical lifetime, of the order of years, comparable to the mean transport time for an inert tracer to move from these altitudes down to sea level. This long transport time implies a uniform worldwide distribution, and the Antarctic represents approximately 3% of the total surface area of the Earth, so that in the absence of photochemical destruction the auroral source would deposit $\sim 8 \times 10^8$ kg(N) per yr on Antarctica. I estimate (but cannot prove without a detailed calculation) that photochemical destruction may reduce this by perhaps two orders of magnitude on account of the ratio of photochemical to transport times in the lower mesosphere.

However, galactic cosmic ray ionisation produces $\sim 2 \times 10^7$ kg(N) per yr in NO molecules over each polar cap, principally at altitudes between 10 and 20 km. Formation of nitric acid and subsequent precipitation scavenging provides a mechanism for bringing this fixed nitrogen to the ground. Admittedly, the polar caps in this context extend well beyond the Antarctic continent[3], but the atmospheric circulation associated with the meteorological polar cell will bring much of this material down to the ground near Antarctica. Galactic cosmic ray ionisation has a maximum at sunspot minimum, so that 11-yr modulation of variation by a factor of two would be expected.

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2. Wilson, A. T. & House, D. A. *Nature* **205**, 793 (1965).
3. Reid, G. C. *Fundamentals of Cosmic Physics* **1**, 167 (1974).
4. Heaps, M. G. *Planet Space Sci.* (in the press).

PARKER *ET AL.* recently claimed that inorganic nitrogen-laden ice originating on the Antarctic continent might provide a major contribution to the nitrogen budget for the epipelagic zone of the Southern Ocean located south of the Antarctic convergence[1]. They calculated annual inputs via continental ice for NO_3-N and NH_4-N of 2.73×10^4 tonnes and 1.88×10^4 tonnes, respectively. Assuming an average concentration for surface NO_3-N of 2.7 μg l^{-1} and an upper mixed layer volume of 50 m $\times 14 \times 10^6$ km$^2 = 7 \times 10^{17}$ l, they estimated the total NO_3-N in the upper mixed layer at 19×10^5 tonnes, and concluded that 7% of this total is injected annually by the melting of Antarctic continental ice.

This estimated input of non-biogenic fixed NO_3-N, 2.73×10^4 tonnes $\div 19 \times 10^5$ tonnes, is mathematically equivalent to about 1% of the estimated total NO_3-N in the upper mixed reservoir, however, rather than 7% as reported by Parker *et al.*[1]. While it might be argued that an input of non-biogenic fixed NO_3-N which is 1% of the epipelagic reservoir standing total should not be dismissed from budget calculations, I suggest that the total NO_3-N in the reservoir has been underestimated in the calculation of Parker *et al.*, and that the input of NO_3-N from continental ice is more nearly equivalent to about 0.02% of the upper mixed layer total and can be ignored.

The estimate made by Parker *et al.* of 2.7 μg l^{-1} (range 0.02–21.4 μg l^{-1}) for mean NO_3-N concentration of Antarctic circumpolar surface water was derived from summary data tabulated as part of the Antarctic Map Folio series[2]. A comparison with the source nutrient data for this series[3,4] and with a second tabulation of the same data[5], however, demonstrates that the units of nutrient concentration were incorrectly given in the Folio series as μg l^{-1} when they, in fact, represent μg-atm l^{-1} concentrations. Assuming a mean surface NO_3-N concentration of 12 μg-atm l^{-1} (168 μg NO_3-N l^{-1}) then, the amount of NO_3-N in the epipelagic Antarctic region can be recalculated at 7×10^{17} l $\times 168$ μg l$^{-1} \div 10^{12}$ μg tonne$^{-1} = 1.18 \times 10^8$ tonnes. The estimated annual input of NO_3-N from

continental ice[1] is thus 0.02%, or a minor component of the estimated reservoir standing total.

Parker *et al.* did not undertake a similar calculation for the relative contribution of non-biogenic fixed NH_4-N derived from continental ice, as little information on epipelagic NH_4-N levels in the Southern Ocean is available in the literature[1]. Recently, I measured water column NH_4-N concentrations at 16 oceanographic stations in the Ross Sea and south of the Antarctic convergence. NH_4-N was assayed by a modified Solorzano phenol-hypochlorite method[6] aboard USCGC Glacier during December 1977–January 1978. Water samples taken in 5-l Niskin bottles were filtered through 0.45 μm GF/A filters, fixed with phenol alcohol, refrigerated, and analysed within 24–48 h of collection, using a 10-cm path length in a Bausch & Lomb model 710 spectrophotometer. Surface NH_4-N concentrations in ice-free areas averaged 0.1 μg-atm l^{-1} (range <0.1–0.3), with higher concentrations of NH_4-N in subsurface maxima[7]. Subsurface NH_4-N maxima generally occurred deeper than 50 m, and I here assume that 0.1 μg-atm l^{-1} is representative of NH_4-N concentrations in the upper mixed layer. Using Parker *et al.*'s estimate of 7×10^{17} l for volume of the upper mixed layer[1], I calculate a reservoir total for NH_4-N of 7×10^{16} μg-atm, or 1.2×10^6 tonnes. Thus, the estimated annual input of non-biogenic fixed NH^4-N from continental ice[1] is mathematically equivalent to about 2% of my estimated reservoir total.

While the input of NH_4-N derived from continental ice, as a percentage of its reservoir total, is proportionally larger than the input of NO_3-N derived from continental ice as a percentage of its reservoir total, the former is apparently much less than the biogenic input of NH_4-N. For example, a conservative estimate is that 500 million tonnes of krill (*Euphausia superba*) are produced annually in the Southern Ocean[8,9]. Ammonia is the primary nitrogenous waste of planktonic crustacea[10–14], and shipboard measurements of NH_4-N excretion by individual Antarctic euphausiids[7] suggest that this amount of krill alone might excrete approximately 1.1×10^{16} μg-atm NH_4-N d^{-1}.

Daily NH_4-N excretion by krill, then, may represent about 8 times the annual non-biogenic input of NH_4-N from continental ice[1], or about 16% of my estimated epipelagic reservoir NH_4-N total. If one assumes that krill, which live primarily in epipelagic Antarctic waters as adults[8,9,15], excrete their NH_4-N wastes exclusively there, it follows that NH_4-N in