Biogeochemical signatures of nitrogen fixation in the eastern North Atlantic

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[1] Stable nitrogen isotopic determination of particulate organic matter over the eastern North Atlantic in spring 2000 reveal a region of low natural abundance of 15N relative to 14N between 26°N and 32°N along 20°W. This light isotopic signal, together with phytopigment data and persistently elevated nitrate to phosphate ratios in the upper thermocline, suggest that nitrogen fixation provides a local dominant supply of nitrogen to phytoplankton over part of the eastern North Atlantic. These independent biogeochemical proxies are coincident with a region of enhanced atmospheric dust deposition, as suggested by an atmospheric transport model. Hence, the atmospheric dust events may spatially and temporally constrain the distribution of N2 fixers.

INDEX TERMS: 4805 Oceanography: Biological and Chemical: Biogeochemical cycles (1615); 4845 Oceanography: Biological and Chemical: Nutrients and nutrient cycling; 4870 Oceanography: Biological and Chemical: Stable isotopes; 0315 Atmospheric Composition and Structure: Biosphere/atmosphere interactions.


1. Introduction

[2] Biological fixation of nitrogen (N2) in oligotrophic subtropical gyres is important in supplying nitrogen to surface phytoplankton communities in an otherwise nitrogen-starved environment. The global distribution and significance of N2 fixation have been inferred from direct observations of N2 fixing cyanobacteria (the most well studied being Trichodesmium spp.) [Capone et al., 1998; Orcutt et al., 2001], and indirectly, from nutrient inventories [Gruber and Sarmiento, 1997] and SeaWiFS remote sensing observations [Subramaniam et al., 2002]. In addition, the distribution and fluxes of iron [Berman-Frank et al., 2001] and phosphorus [Wu et al., 2000] have been used as a proxy to predict the potential and geographic differences of N2 fixation in the Atlantic and Pacific.

[3] The eastern North Atlantic is potentially an important region of N2 fixation given the enhanced inputs of atmospheric dust from the Sahara. In this study, we examine independent biogeochemical proxies and chemotaxonomic biomarkers for N2 fixation along a meridional transect passing through the eastern North Atlantic. In addition, we compare our ocean observations with independent predictions of dust transport from an atmospheric model.

[4] The stable nitrogen isotopic composition (ratio of 15N to 14N, expressed as δ15N) [Mariotti et al., 1981] of phytoplankton reflects the isotopic composition of the nitrogen (N) source and biological isotopic fractionation during the uptake and assimilation of the N source. The ratio of δ15N of atmospheric N2 (0 %) is lower than nitrate from the deep ocean (5 %) [Liu and Kaplan, 1989]. Thus, primary production fuelled by N derived from N2 fixation will be depleted in 15N relative to 14N. Inputs of N to the surface ocean through N2 fixation are accompanied by inputs of phosphorus (P). Elevated N to P, both in the dissolved inorganic and organic pools, may therefore be indicative of N2 fixation [Gruber and Sarmiento, 1997].

2. Methodology

[5] Suspended particulate matter (SPM) and filtered seawater samples were collected along an Atlantic Meridional Transect (AMT10) between 35°S, 49°W and 48°N, 20°W (Figure 1) in April and May 2000.

[6] SPM was filtered (200–1000 L) from the underway seawater supply (7 m) onto pre-combusted (450°C for over 4 hours) 150 mm Whatman GF/F filters using a Sartorius GmBH large volume filtration unit. Filtered (250 mL) seawater and SPM (pre-combusted 47 mm GF/F filters) were collected from 7 to 10 depths using Niskin bottles (10 L). All samples were stored at −20°C prior to analysis.

[7] Underway chlorophyll a (mg m−3) [Welschmeyer, 1994] and phytoplankton pigment distributions (expressed as percentage of total pigments) [Barlow et al., 1997] were determined, and chemotaxonomic marker pigments were grouped to assess the relative contribution of three functional classes of phytoplankton [Gibb et al., 2000].

[8] Particulate organic nitrogen (PON) concentrations were determined using a Carlo Elba elemental analyser (CE-EA) (precision <8 %, number of samples, n = 47). The δ15N PON, defined by ([15N: 14N sample/15N: 14N standard] − 1) × 1000, where the standard is N2 gas, was determined using an on-line Finnigan Delta CE EA-IRMS, (precision better than 0.3%, n = 51). A potential isotopic enrichment by inclusion of zooplankton during sampling was deemed negligible, since no relationship (R2 = 0.12, n = 35) between the ratio of PON to chlorophyll a and δ15N PON
was observed [Waser et al., 2000]. Thus, the isotopic composition of phytoplankton was assumed from δ15N of PON.

[8] Nitrate (nitrate plus nitrite, nitrate herein) and phosphate concentrations in seawater collected during AMT 10 were determined using a Skalar Sanplus segmented flow autoanalyzer [Sanders and Jickells, 2000]. Precision was better than 10% (n = 143). Nutrients from all other AMT cruises were analysed according to Woodward and Rees [2001].

3. Observational in the North Atlantic
3.1. Phytoplankton Species and Nutrients
[10] Along the 20°W transect from 20°N to 32°N, there were low concentrations of nutrients (nitrate < 0.07 µM) and phytoplankton biomass (chlorophyll a < 0.2 mg m−3, PON 0.1 to 0.4 µM) (Figure 2a). In these oligotrophic surface waters, chemotaxonomic data (at 26°N and 30°N) revealed a dominance of prokaryotic picoplankton (cyanobacteria and prochlorophytes), (> 22%; Figure 2b, solid line).

[11] Along the northern flanks of the subtropical gyre (north of 40°N), elevated nitrate concentrations (> 5 µM; Figure 2a, black circle) and phytoplankton biomass (chlorophyll a < 0.4 to 0.9 mg m−3, PON 0.9 to 1.6 µM; Figures 1 and 2a), was probably due to convection and lateral wind-driven transfer of nutrients [Williams and Follows, 1998]. Chemotaxonomic data revealed a dominance of eukaryotic nanoflagellates (prymnesiophytes, chrysophytes and chlorophytes) (> 21%; Figure 2b, dashed line), with a contribution from large eukaryotes (diatoms and dinoflagellates; ~10%; Figure 2b, dotted line).

3.2. Stable Nitrogen Isotopes
[12] Isotopically light phytoplankton were observed at 26°–32°N, (1.23 to 2.58 %o, n = 9), and at 40°–48°N, (1.3 to −3.0 %o, n = 13) (Figure 2c). The lightest isotopic signal at 40°–48°N (mean ± standard deviation, −0.72 ± 0.52 %o) coincided with the spring bloom and reflected net isotopic fractionation by phytoplankton during uptake and assimila-
tion of nitrate at high ambient concentrations (Figure 2a, 2c) [Mariotti et al., 1981]. However, isotopically light phytoplankton were also observed in the eastern flank of the subtropical gyre at 26°–32°N (2.25 ± 0.36‰) where net isotopic fractionation is not expected [Altabet and McCarthy, 1985] (Figure 2a, 2c). Hence, these light signals suggest that the phytoplankton were utilising a light isotopic source of N, possibly provided by N2 fixation [Mahaffey et al., 1999]. Although it is not possible to directly identify which light isotopic N source is responsible for the observed isotopically light PON, we speculate that the N was supplied by N2 fixation due to the dominance of phytopigments indicative of cyanobacteria in this region.

Here, we assume negligible isotopic fractionation and that there is a light (0‰) and a heavy (5‰) source of N, possibly representing N2 fixation and a supply of deep nitrate, respectively [Liu and Kaplan, 1989]. Using this simple two-member mixing model, we estimate that the light isotopic source provides between 48% to 75% of the N demand of phytoplankton (63%) over this region.

### 3.3. Excess N Versus P

[14] Over the transect in the eastern North Atlantic, elevated nitrate to phosphate ratios (greater than 16:1) in the thermocline (> 100m black circles; Figure 2d) were observed during AMT 10. This “excess” nitrate signal appears to be a persistent feature over the North Atlantic subtropical region during spring, occurring for three previous AMT’s (Figure 2d). In agreement, Gruber and Sarmento [1997] diagnose elevated nitrate to phosphate ratios in the thermocline (as measured by N*) between 16°N and 44°N along a 20° to 30°W transect from GEOSECS. This appears to be a persistent feature in the eastern North Atlantic subtropical gyre. In the same region, there is also an increase in the DON to DOP ratio from the gyre flanks [Mahaffey et al., manuscript in preparation, 2003]. Consequently, the elevated nitrate to phosphate ratios in the thermocline are probably a result of additional nitrogen supply from N2 fixation, although other processes, such as differential recycling, may also modify the N to P ratio [Karl et al., 2002].

### 3.4. Why is Nitrogen Fixation Locally Enhanced?

[15] The distribution and rate of N2 fixation is limited by iron [Berman-Frank et al., 2001] and phosphorus [Samudra-Wilhelmy et al., 2001]. Atmospheric dust inputs from the Sahara can provide a source of iron [Berman-Frank et al., 2001] and possibly phosphorus [Ridame and Guieu, 2002] to the surface ocean. Our depleted isotopic values observed between 24°–32°N were coincident with a region of anomalously strong injection of Saharan dust observed for a series of atmospheric events from February to mid-April 2000, as independently suggested by an atmospheric transport model (Figure 3a) (N. Mahowald et al., Interannual variability in atmospheric mineral aerosols from a 22-year mineral aerosol simulation and observational data, submitted to Journal of Geophysical Research, 2002) and TOMS images (Figure 3b, 3c). The atmospheric transport model predicts the source, transport and wet and dry deposition of dust using NCEP/NCAR meteorological reanalysis from 1979 to 2000. The model predictions of dust deposition are significantly correlated with the observed aerosol index from TOMS over the AMT 20°W transect, (correlation coefficient 0.6 at a 95% confidence level), as well as with in situ surface observations. The model predicts that the dust deposition from February to mid-April of 2000, was twice the climatological monthly mean between 22° and 35°N. In view of the residence time of dissolved and total iron in the surface ocean (> ~200 and 18 days, respectively) [Jickells, 1999], turnover time of phosphorus (weeks to months) [Benitez-Nelson and Karl, 2002] and the response time of Trichodesmium (days to weeks) [Lenes et al., 2001], it is plausible that the atmospheric dust injection in March 2000 (Figure 3a, b) led to natural iron and phosphorus deposition.
fertilisation, and thus may be responsible for the biogeochemical signals observed between 27 April and 1 May during AMT 10.

However, *Trichodesmium spp.*, a dominant cyanobacterial N₂ fixer, usually shows enhanced abundance in the tropics [Tyrrell et al., 2003], rather than in the subtropical gyre as implied in this study. This apparent inconsistency might be due to utilisation of inorganic nutrients by *Trichodesmium spp.* [Mulholland et al., 2001], the presence of N₂ fixing cyanobacteria other than *Trichodesmium spp.* [Zehr et al., 2000] and the temporal variability in N₂ fixation [Orcutt et al., 2001; Dore et al., 2002].

4. Conclusions

[17] A range of independent biogeochemical proxies when viewed together suggest that N₂ fixation provides a dominant supply (63%) of N over part of the oligotrophic eastern North Atlantic: (i) ¹⁵N depleted phytoplankton between 24°N and 32°N along 20°W; (ii) phytopigments indicative of cyanobacteria and prochlorophytes at 26°N and 30°N, and (iii) persistently elevated nitrate to phosphate ratios in the thermocline between 20°N and 45°N revealed in a series of spring Atlantic Meridional Transsects.

[18] These biogeochemical proxies are coincident with independent atmospheric transport model predictions of enhanced atmospheric dust deposition in spring 2000 around 24°N and 28°N. Hence, the atmospheric dust inputs probably created an ecological niche for N₂ fixers in the eastern Atlantic. The atmospheric dust inputs vary episodically with atmospheric synoptic-scale events, as revealed in sequences of satellite images and model predictions, and thus might drive temporal variability in N₂ fixation.

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