Nitrous oxide and methane in the Atlantic Ocean between 50°N and 52°S: latitudinal distribution and sea-to-air fluxes.

Forster, G., Upstill-Goddard, R.C. and Uher, G.
Ocean Research Group, School of Marine Science and Technology, University of Newcastle upon Tyne, NE1 7RU, U.K.

1. Brief Introduction and Rationale

Nitrous oxide (N$_2$O) and methane (CH$_4$) both strongly influence Earth’s climate and atmospheric chemistry. They have relatively long atmospheric lifetimes and are infrared-active; together they account for ~20% of enhanced greenhouse forcing (IPCC, 2001). N$_2$O participates in atmospheric C$_2$H$_4$ regulation via NO$_x$ generation (Nesbitt and Holland, 1997) and CH$_4$ is involved in the formation of stratospheric water and photochemical reactions that regulate tropospheric OH and O$_3$ (Crutzen, 1991). The atmospheric inventories of N$_2$O and CH$_4$ are currently increasing, but at variable rates that are not well understood (Dlugokencky et al., 1998; Dlugokencky et al., 2001; Khalil and Rasmussen, 1992; Prinn et al., 1990) hence their global-source sink functions are the subject of intense scrutiny (IPCC, 2001).

The marine sources of N$_2$O and CH$_4$ are not well constrained. For CH$_4$ one estimate sets this to 0.4 Tg CH$_4$ yr$^{-1}$ (Bates et al., 1996) although most recent syntheses converge at around 11-18 Tg CH$_4$ yr$^{-1}$, about 2-3% of the global total (Bange et al., 1994; Lei et al., 1996). For N$_2$O the uncertainty is no better; recent estimates are 6.28 Tg N$_2$O yr$^{-1}$ (range 1.99–10.88 Tg N$_2$O yr$^{-1}$) (Nesbitt et al., 1995) and 4.71 Tg N$_2$O yr$^{-1}$ (range 1.57–7.85 Tg N$_2$O yr$^{-1}$) (Kroeze et al., 1989; Mosler et al., 1998) against a global source total ~25.8 Tg N$_2$O yr$^{-1}$ (IPCC, 2001). The Atlantic Meridional Transect Programme (AMTP), which uses the annual transit of RRS James Clark Ross (Figure 2) between the UK and Antarctica in September-October and the return leg (Antarctica-UK) in April-May, offered a unique opportunity to investigate the distributions of N$_2$O and CH$_4$ in a range of Atlantic Waters including temperate shelf seas, upwelling regions, and oligotrophic mid ocean gyres (Hooker et al., 2000; Robinson et al., 2006). Here we report the distributions of N$_2$O and CH$_4$ in 49 vertical profiles covering the upper ~30 m of the water column along two ~13,500 km transects between ~50°N and ~52°S (AMTP cruises 12 and 13, Figure 1). Importantly our measurements include novel data from the SAG, which has been sparsely sampled for N$_2$O or CH$_4$. These data provide a basis for deriving gyre scale sea-to-air fluxes of N$_2$O and CH$_4$ and hence for re-evaluating the contribution from the Atlantic Ocean to the atmospheric budgets of these climatically important gases.

2. Methods

Seawater samples were collected using a 24×20 litre CTD rosette system (SEABIRD) and dissolved N$_2$O and CH$_4$ were respectively analysed with Flame Ionization Detection (FID) and Electron Capture Detection (ECD) determined using single-phase equilibration gas chromatography (Upstill-Goddard et al., 1996).

3.1. Observed distributions

Vertical N$_2$O profiles were amenable to analysis on the basis of common features coincident with Longhurst provinces (Figure 3), indicative of a link between N$_2$O and proxies of ecosystem function. In contrast CH$_4$ showed no such apparent link (Figure 4). The most striking feature of the latitudinal depth distributions was a well defined “plume” of exceptionally high N$_2$O concentrations coincident with very low levels of CH$_4$, located between 20°S and 20°N (Figure 5); this feature reflects the upwelling of deep waters containing N$_2$O derived from nitrification, as identified by an analysis of N$_2$O, AOU and NO$_3$ (Figures 6 and 7), and depleted in CH$_4$ by bacterial oxidation.

3.2. Sea-to-air emission estimates

Based on contemporary estimates of the global ocean source strengths of atmospheric N$_2$O and CH$_4$, the Atlantic Ocean could account for ~7-16% and 14-37% respectively, of these source totals. Given that the Atlantic Ocean accounts for around 20% of the global ocean surface, on unit area basis it appears that the Atlantic may be a slightly weaker source of atmospheric N$_2$O than other ocean basins but it could make a disproportionately large contribution to marine derived atmospheric CH$_4$, Sea-to-air emissions fluxes for a region equivalent to ~42% of the Atlantic Ocean surface area were in the range of 0.44-0.74 Tg N$_2$O yr$^{-1}$ and 2.46-4.12 Tg CH$_4$ yr$^{-1}$ (Table 1).

References


Table 1. Estimated average sea-to-air flux density and annual fluxes of N$_2$O and CH$_4$ grouped in relation to Longhurst provinces.

<table>
<thead>
<tr>
<th>Province</th>
<th>Surface area (× 10$^5$ km$^2$)</th>
<th>Average flux density (m$^2$ d$^{-1}$)</th>
<th>Annual flux (Tg yr$^{-1}$)</th>
<th>N$_2$O</th>
<th>CH$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSVY</td>
<td>4.1</td>
<td>0.79 – 1.97</td>
<td>3.88 – 8.61</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>SATL</td>
<td>17.6</td>
<td>1.97 – 2.62</td>
<td>3.83 – 5.89</td>
<td>0.25 – 0.41</td>
<td>3.16 – 5.64</td>
</tr>
<tr>
<td>WTRA</td>
<td>5.4</td>
<td>1.17 – 2.13</td>
<td>3.92 – 6.63</td>
<td>0.16 – 0.33</td>
<td>3.96 – 4.33</td>
</tr>
<tr>
<td>NATR</td>
<td>8.3</td>
<td>0.10 – 0.67</td>
<td>0.64 – 1.49</td>
<td>0.02 – 0.34</td>
<td>3.13 – 5.09</td>
</tr>
<tr>
<td>NATAD</td>
<td>4.4</td>
<td>0.72 – 1.05</td>
<td>1.91 – 3.65</td>
<td>0.36 – 0.71</td>
<td>1.21 – 2.26</td>
</tr>
<tr>
<td>CRBY</td>
<td>5.3</td>
<td>0.04 – 0.06</td>
<td>0.46 – 0.90</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>NADH</td>
<td>0.8</td>
<td>n.a.</td>
<td>2.73 – 4.65</td>
<td>2.31 – 4.04</td>
<td>2.04 – 3.05</td>
</tr>
</tbody>
</table>

* Annual flux calculated from samples collected during boreal fall.
* Annual flux calculated from samples collected during austral fall.
* n.s. refers to not sampled.

Acknowledgements

Numerous colleagues assisted us in many ways during AMTP and without them this study would not have been realised. In particular we recognised the starting efforts of the captain and crew of RRS James Clark Ross and the Principal Scientists Tim Jenkins and Carola Robinson on AMTP12 and support given us to by staff at the UK Natural Resource Research (NERRS), in particular UK Oceanographic Research Services (UKORS) and Research Ships Unit (RSU), the British Antarctic Survey (BAS), and all the logistics companies and sea-farers whose assistance we would like to acknowledge. In particular thanks are due to Carol Robinson and Nicky Gut for providing us with the CTD data, and to Malcolm Woodhead for the weather analyses. Figures were produced by Claire Smith and Paul Stoddart with support from the University of Newcastle upon Tyne. We would also like to thank the Atlantic Meridional Transect Consortium (AMTP) for providing access to their data.

Figure 1. AMT12 (white triangles) and AMT13 (white circles) stations sampled in relation to Longhurst provinces. North Atlantic Drift Province (NADP); North Atlantic Subtropical Province (NASP); North Atlantic Tropical Province (NATP); East Equatorial Province (EEP); East Equatorial Convergence Zone (EECZ); Subtropical Atlantic Province (SAP); Subtropical South Atlantic Province (SSAP); Equatorial Central Pacific Province (CEPP).