

New estimates of global emissions of N₂O from rivers and estuaries

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Abstract

We present new estimates of emissions of nitrous oxide (N₂O) from rivers and estuaries, using the NEWS-DIN model. NEWS-DIN is a model of the global transport of dissolved inorganic nitrogen (DIN) by rivers to coastal waters (Dumont et al. forthcoming). It calculates DIN export rates as a function of watershed characteristics, including human influences. We used the calculated DIN export rates by river to estimate emissions of N₂O from aquatic systems. Our new estimates for N₂O emissions from rivers and estuaries are 1.26 and 0.25 Tg N/year, respectively, totaling to 1.5 Tg N/y. These estimates are somewhat higher than earlier estimates. Next we investigated the consequences of our new estimates for the global N₂O budget. We did this by running an atmospheric box model and comparing the results to observed values from different monitoring networks. The results indicate that the global budget using the new NEWS-DIN estimates for aquatic N₂O emissions is in good agreement with observed concentrations.

Keywords: *Nitrous oxide, emissions, rivers, estuaries, aquatic systems, model*

1. Introduction

Nitrous oxide (N₂O) is an important greenhouse gas. Most of the N₂O in the atmosphere is of biological origin, being produced by bacteria in soils and surface waters. Emissions of N₂O from rivers, estuaries and continental shelves are increased as a result of human activities on land resulting in enhanced nitrogen availability in aquatic systems. These human activities include agricultural activities such as fertilizer use, as well as industrial activities resulting in nitrogen losses to the environment.

Earlier studies indicate that aquatic sources of N₂O may account for at least one-fifth of the current global anthropogenic N₂O emissions. This estimate was based on modeling studies, focusing on the global distribution of nitrogen (N) inputs in freshwater and coastal marine systems (Seitzinger and Kroeze 1998). Recently, an updated version of this model was made available (Dumont et al. forthcoming). This new model, referred to as the NEWS-DIN model, calculates the export of dissolved inorganic nitrogen (DIN) to coastal waters by world rivers,

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while taking into account different human activities on the land, as well as biological N₂ fixation and different methods of nitrogen retention in river basins, including the effect of dams.

We used the NEWS-DIN model to present new estimates of global emissions of N₂O from rivers and estuaries. We present total global emissions, as well as regional shares.

2. Description of the NEWS-DIN model

NEWS-DIN is a model of the global transport of dissolved inorganic nitrogen (DIN) by rivers to coastal waters (Dumont et al. forthcoming). It calculates DIN export rates as a function of river basin characteristics, including human influences. DIN export rates are calculated for 453 watersheds. The NEWS-DIN model can be summarized as:

$$DIN = (1 - L_{den}) \cdot (1 - Q_{rem}) \cdot (1 - D) \cdot [DIN_{sew} + (EF_{ws} \cdot TN_{diff})] \quad (1)$$

where DIN is modeled DIN yield per river basin (kg N/km²/y), DIN_{sew} is DIN from sewage point sources (kg N/km²/y), and TN_{diff} is total nitrogen from inorganic fertilizer, animal manure, biological fixation and NO_x deposition, that is not removed by harvesting or grazing (kg N/km²/y). EF_{ws} is the fraction (0–1) of TN_{diff} reaching the surface water as DIN. L , Q and D are fractions (0–1) of DIN retention by denitrification during transport throughout entire river networks, by anthropogenic removal of river water, and by retention processes in reservoirs, respectively. L_{den} is modeled as a function of basin area, Q_{rem} as a function of irrigation and artificial river water removal, and D as a function of reservoir discharge, depth, and residence time. DIN_{sew} is based on estimates of sewage treatment efficiency, sewage connectivity, and human N-excretion. EF_{ws} is a calibrated function of runoff.

To estimate total DIN export per basin (kg N/basin/y), DIN yield was multiplied by basin area. Inputs to the NEWS-DIN model are averages over river basins delineated from a gridded global river network (Vörösmarty et al. 2000a, 2000b). These inputs refer to the period 1990–1997.

There are several differences between the NEWS-DIN model that we used, and the original model used by Seitzinger and Kroeze (1998). For instance, NEWS-DIN includes several input variables that were not considered by Seitzinger and Kroeze (1998), such as nitrogen (N) inputs to watersheds from manure, and biological N₂ fixation. In addition, NEWS-DIN accounts for retention and loss terms in more detail than Seitzinger and Kroeze (1998) did: NEWS-DIN distinguishes between N retention in river networks, N retention in dammed reservoirs, N loss via consumptive water use, and N loss via harvesting and grazing. NEWS-DIN also includes a more sophisticated treatment of sewage point sources than Seitzinger and Kroeze (1998), by incorporating estimates of sewage treatment, sewage connectivity, and variable N-excretion. The spatial resolution of input data and basin delineations was increased from 1 × 1° to 0.5 × 0.5° grids in NEWS-DIN. Moreover, NEWS-DIN has been calibrated and validated using an enhanced dataset; NEWS-DIN has been calibrated exclusively for one specific period of time: 1990–1997, rather than to data spanning three decades of measurements. This restriction gives a better temporal match between input data and DIN export data used in the calibration. Finally, in the calibration of NEWS-DIN, more river basins (61 basins) were used than in the formulation of the model used by Seitzinger and Kroeze (1998) (35 basins).

The NEWS-DIN model is developed as part of an international activity, focusing on the global modeling of Nutrient Export from Watersheds to Seas (Global NEWS group, see <http://marine.rutgers.edu/globalnews/index.htm>). Global NEWS is an international, interdisciplinary scientific taskforce, focused on understanding the relationship between human activity and

coastal nutrient enrichment. Global NEWS was formed in spring 2002 as a workgroup of UNESCO's Intergovernmental Oceanographic Commission (IOC) (with co-sponsorship by UNEP, US-NSF, and US-NOAA). The primary aim of Global NEWS is to construct and apply the next generation of spatially explicit, global nutrient export models.

3. New estimates for DIN export by rivers, and associated N_2O emissions

Using the NEWS-DIN model, Dumont et al. (forthcoming) calculated DIN export rates by world rivers to coastal waters. According to these calculations, worldwide, DIN export by rivers amounts to 25 Tg N/y. We used the calculated DIN export rates by river to estimate emissions of N_2O from rivers and estuaries. To this end, we adopted the method as described by Seitzinger and Kroeze (1998). In short, this approach includes emissions of N_2O from rivers and estuaries as a result of nitrification and denitrification. It is assumed that during river transport, 50% of the DIN is lost through denitrification and that all DIN is nitrified once. For estuaries it is assumed that 50% of the DIN inputs are denitrified and that nitrification rates exceed denitrification rates by 20% (see Seitzinger & Kroeze for the basis of these assumptions). In addition, Seitzinger and Kroeze (1998) assumed that 0.3% of the nitrified and denitrified N is lost as N_2O , or 3% when the average watershed N loading are relatively high (> 10 kg N/ha/y). When analyzing the results from Seitzinger and Kroeze (1998), we conclude that emissions from rivers amount to 5% of the DIN export by rivers, and emissions from estuaries 1%. Using these percentages, our new estimates for N_2O emissions from rivers and estuaries, are 1.26 and 0.25 Tg N/y, respectively, totaling to 1.5 Tg N/y (compared with 1.27 Tg N/y as estimated by Seitzinger and Kroeze [1998]).

Figure 1 and Table I show the calculated emissions of N_2O from rivers and estuaries summarized for different world oceans. The results indicate that most N_2O is emitted from the Atlantic, Indian and Pacific Oceans. This is in line with the relatively large area that is draining into these oceans and the relatively large amounts of DIN exported from these basin

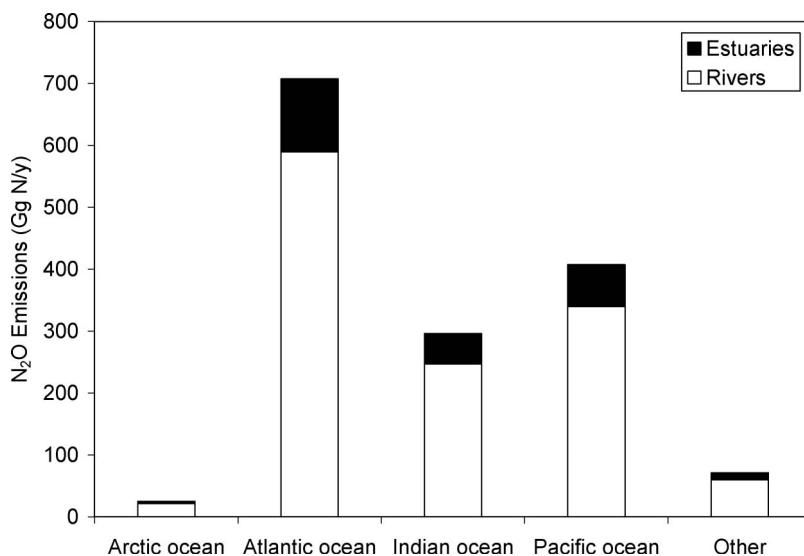


Figure 1. Emissions of N_2O from rivers and estuaries draining into different world oceans for the early nineties (based on NEWS-DIN calculations).

areas (Table I). The riverine and estuarine N_2O emissions from rivers draining into the Arctic and other oceans are relatively small.

We also summarized the results for rivers draining from different continents (Figure 2 and Table II). Clearly, most N_2O is emitted from rivers and estuaries located in Asia and South America (Figure 2). These results are in general agreement with those of Kroeze and Seitzinger (1998), although the relative contribution from rivers in South America is larger in our new estimates. This can be explained by the fact that biological N_2 fixation, which is a relatively important source of DIN export in South America, is not explicitly represented in the model used by Seitzinger and Kroeze (1998), whereas it is accounted for in NEWS-DIN.

4. Implications for the global N_2O budget

Next, we investigated the consequences of our new estimates for the global N_2O budget (Figure 3). We did this by running the atmospheric box model as described by Kroeze et al. (1999) and compared the results with observed values from different monitoring networks. The model is a simple one-box model, calculating atmospheric concentrations mainly as a

Table I. Results for watersheds draining into different oceans (based on NEWS-DIN calculations).

Ocean	Basin area (1,000 km ²)	DIN export (Gg N/y)	N_2O emissions (Gg N/y)		
			Rivers	Estuaries	Total
Arctic Ocean	17,774	421	21	4	25
Atlantic Ocean	45,006	11,794	590	118	708
Indian Ocean	20,822	4,935	247	49	296
Pacific Ocean	19,880	6,791	340	68	407
Other	30,356	1,188	59	12	71
Total	133,838	25,129	1,256	251	1,508

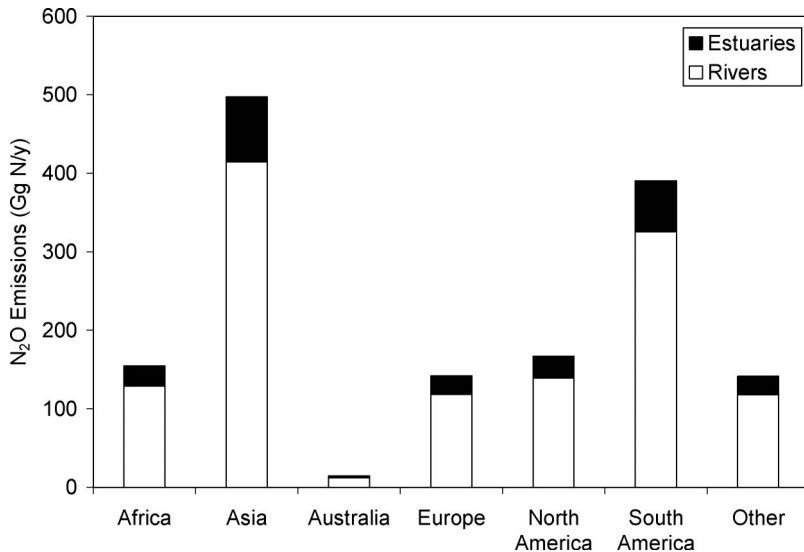


Figure 2. Emissions of N_2O from rivers and estuaries draining from different continents for the early nineties (based on NEWS-DIN calculations).

Table II. Results for watersheds draining from different continents (based on NEWS-DIN calculations).

Continent	Basin area (1,000 km ²)	DIN export (Gg N/y)	N ₂ O emissions (Gg N/y)		
			Rivers	Estuaries	Total
Africa	30,147	2,578	129	26	155
Asia	42,140	8,290	415	83	497
Australia	7,810	244	12	2	15
Europe	9,832	2,370	119	24	142
North America	22,352	2,784	139	28	167
South America	18,020	6,507	325	65	390
Other	3,537	2,356	118	24	141
Total	133,838	25,129	1,256	251	1,508

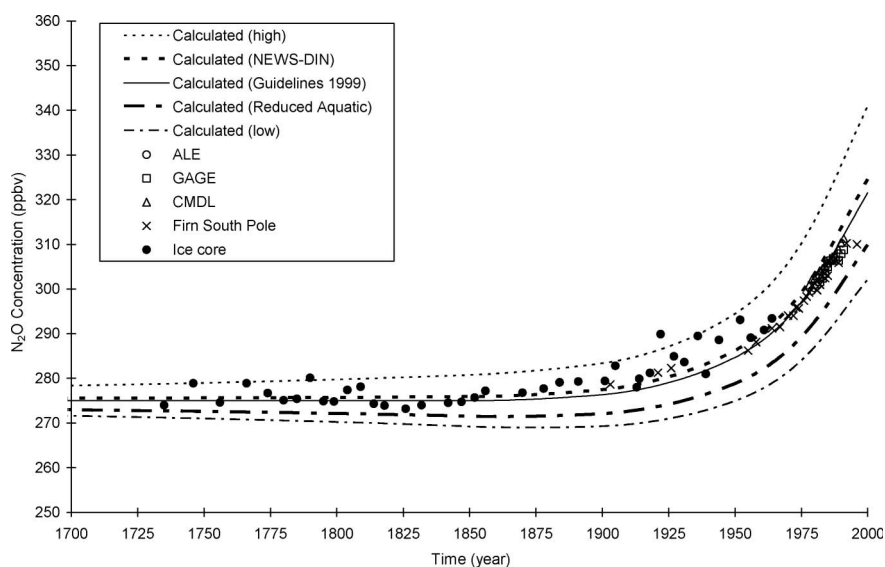


Figure 3. Calculated atmospheric concentrations of N_2O since 1700, and observed concentrations in the Atmospheric Lifetime Experiment (ALE), the Global Atmospheric Gases Experiment (GAGE), the Climate Monitoring and Diagnostics Laboratory (CMDL), and concentrations deduced from the South Pole and ice cores (see Kroeze et al. [1999] for references). The calculated emissions are shown for a *high* and *low* case, reflecting the high and low range of calculated concentrations by Kroeze et al. (1999). The *IPCC Guidelines 1999* case is the base case in Kroeze et al. (1999) and uses the 1999 IPCC Guidelines as a basis for aquatic emissions. The *Reduced Aquatic* case uses a 15% lower estimate for anthropogenic emissions than the 1999 Guidelines, and the *NEWS-DIN* case uses emission estimates for aquatic sources from the present study.

function of emissions and atmospheric lifetime, while taking into account conversions from mass to concentrations. The model calculated trends in atmospheric N_2O on an annual basis starting in the year 1500. Kroeze et al. (1999) used trends in global emissions of N_2O as inputs to the model. These emissions were estimated following the IPCC Guidelines for estimating anthropogenic emissions. The IPCC Guidelines include default methods for estimating emissions of greenhouse gases at the national level (e.g. IPCC, 1997, 2000). Kroeze et al. (1999) concluded that the increase in atmospheric N_2O is largely associated with agricultural activities. Their estimated emissions of N_2O from agriculture include the

formation of N₂O in aquatic systems induced by losses of nitrogen from agricultural systems through leaching and runoff.

Here, we run the atmospheric box model using new estimates of global emissions as input, which include our new estimates for aquatic N₂O emissions as input. We compare the results with those of Kroeze et al. (1999). The calculated atmospheric concentrations are shown in Figure 3 for several cases. First, Figure 3 includes a *high* and *low case*, reflecting the high and low range of calculated concentrations by Kroeze et al. (1999), who, in these cases, varied assumptions on emissions as well as selected model parameters. In addition, we included the base case by Kroeze et al. (1999)—here referred to as the *IPCC Guidelines 1999 case*—because the aquatic emissions in this case are based on the 1999 IPCC Guidelines. The *NEWS-DIN case* uses emission estimates from the present study as shown in Figures 1 and 2 above. Figure 3 shows that the case using the new NEWS-DIN estimates for aquatic N₂O emissions is in good agreement with observed concentrations. We realize that this conclusion is only valid if we assume that all other contributors to the atmospheric increase are well quantified. Furthermore, the case using the new NEWS-DIN estimates for aquatic N₂O emissions is close to the original base case of Kroeze et al. (1999).

Kroeze et al. (1999) concluded that by using the 1999 IPCC Guidelines for estimating anthropogenic emissions, the global N₂O budget can be closed. Currently, the IPCC Guidelines are being revised. Some recent studies call for lower emission factors for aquatic emissions. For instance, Sawamoto et al. (2005) argue that the 1999 IPCC Guidelines considerably overestimate emissions associated with leaching of N from the terrestrial system. To test the sensitivity of the modeled increase in atmospheric N₂O to changes in emission factors, we include a *Reduced Aquatic case* in Figure 3. This case tentatively assumes that the anthropogenic emissions are 15% lower than in the *IPCC Guidelines 1999 case*, in line with Sawamoto et al. (2005). From the results, it may be concluded that both the *IPCC Guidelines 1999 case* and the *Reduced Aquatic case* are within the range of uncertainties indicated in earlier analyses. However, the *Reduced Aquatic case* is considerably lower than the observed values.

When interpreting the results presented in Figure 3, it is important to realize that estimates of N₂O from aquatic systems are uncertain. It is not only that the emission factor is surrounded with uncertainties, but the amount of N leaching from the terrestrial system is also difficult to quantify. One could analyze to what extent N₂O emissions from aquatic sources based on the new NEWS-DIN model are comparable to the estimates based on the IPCC Guidelines. There are at least two differences. First, the IPCC Guidelines only estimate anthropogenic emissions, whereas NEWS-DIN estimates also include natural emissions. Second, the IPCC Guidelines approach distinguishes between emissions from groundwater and surface waters, whereas NEWS-DIN does not. These observations, however, do not affect our conclusions that the increase in atmospheric N₂O can be reasonably well explained by both the *IPCC Guidelines 1999 case* and the *NEWS-DIN case*.

5. Conclusions

In this paper, we present new estimates of emissions of nitrous oxide (N₂O) from rivers and estuaries, using the NEWS-DIN model. Our new estimates are that emissions from rivers amount to 1.26 Tg N/y, and emissions from estuaries 0.25 Tg N/y. Total emissions amount to 1.5 Tg N/y. These estimates are somewhat higher than earlier estimates. Next, we investigated the consequences of our new estimates for the global N₂O budget. We did this by running an atmospheric box model, and compared the results with observed values from different monitoring networks. The results indicate that a global budget using the new NEWS-DIN estimates for aquatic N₂O emissions is in good agreement with observed concentrations.

Lowering estimates of aquatic emissions, as suggested by some other studies, would, without other changes in estimates of other sources of N₂O, imply that we can less well explain the observed increase in atmospheric N₂O.

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