Global N Cycle: Fluxes and N_2O Mixing Ratios Originating from Human Activity

Summary:

Nitrogen is a major nutrient in terrestrial ecosystems and an important catalyst in tropospheric photochemistry. Over the last century human activities have dramatically increased inputs of reactive nitrogen (N_r, the combination of oxidized, reduced and organically bound nitrogen) to the Earth system (**Figure 1**). Nitrogen cycle perturbations have compromised air quality and human health, acidified ecosystems, and degraded and eutrophied lakes and coastal estuaries [*Vitousek et al*., 1997*a,* 1997*b*; *Rabalais*, 2002; *Howarth et al*., 2003; *Townsend et al*., 2003; *Galloway et al*., 2004].

To begin to quantify the changes to the global N cycle, we have assembled key flux data and N_2O mixing ratios from various sources. The data assembled from different sources include fertilizer production from 1920-2004; manure production from 1860-2004; crop N fixation estimated for three time points, 1860, 1900, 1995; tropospheric N_2O mixing ratios from ice core and firn measurements, and tropospheric concentrations to cover the time period from 1756-2004. The changing N_2O concentrations provide an independent index of anthropogenic changes to the global N cycle, in much the same way that changing carbon dioxide concentrations provide an important constraint on the global carbon cycle. The changes to the global N cycle are driven by industrialization, as indicated by fossil fuel NO_x emission, and by the intensification of agriculture, as indicted by fertilizer and manure production and crop N_2 fixation.

The data set and the science it reflects are by nature interdisciplinary. Making the data set available through the ORNL DAAC is an attempt to make the data set available to the considerable interdisciplinary community studying the N cycle.

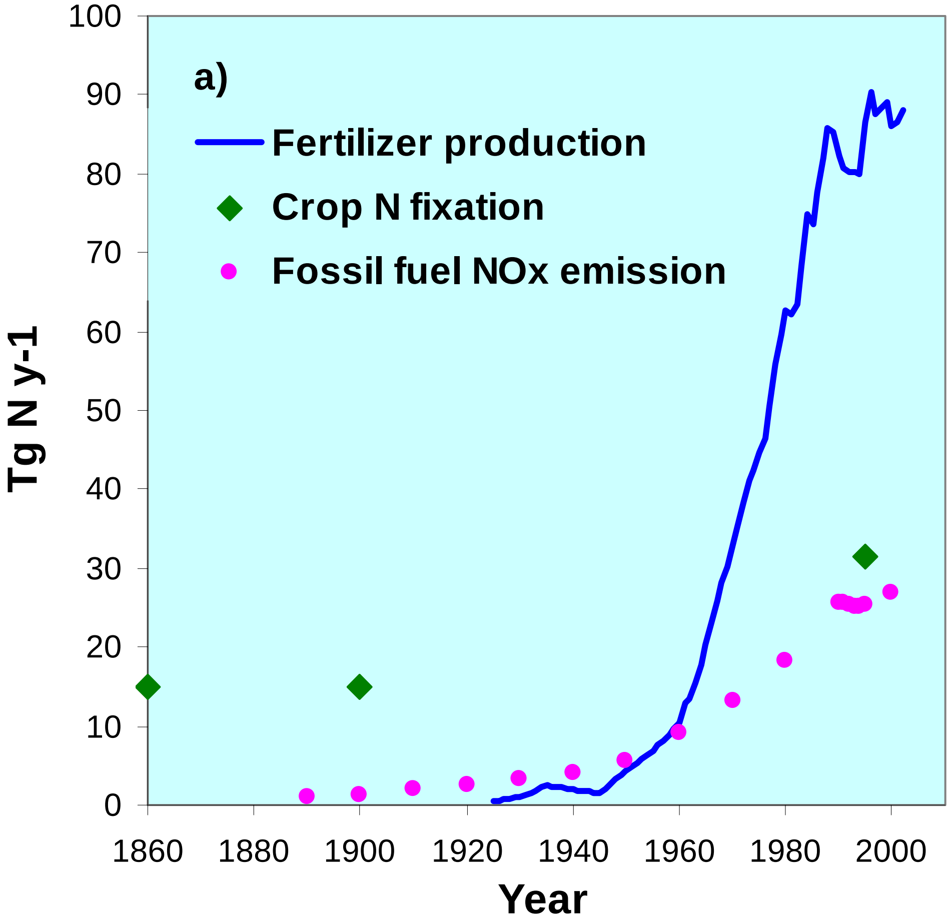

Figure 1. Changes in global fluxes of reactive or biologically available N.

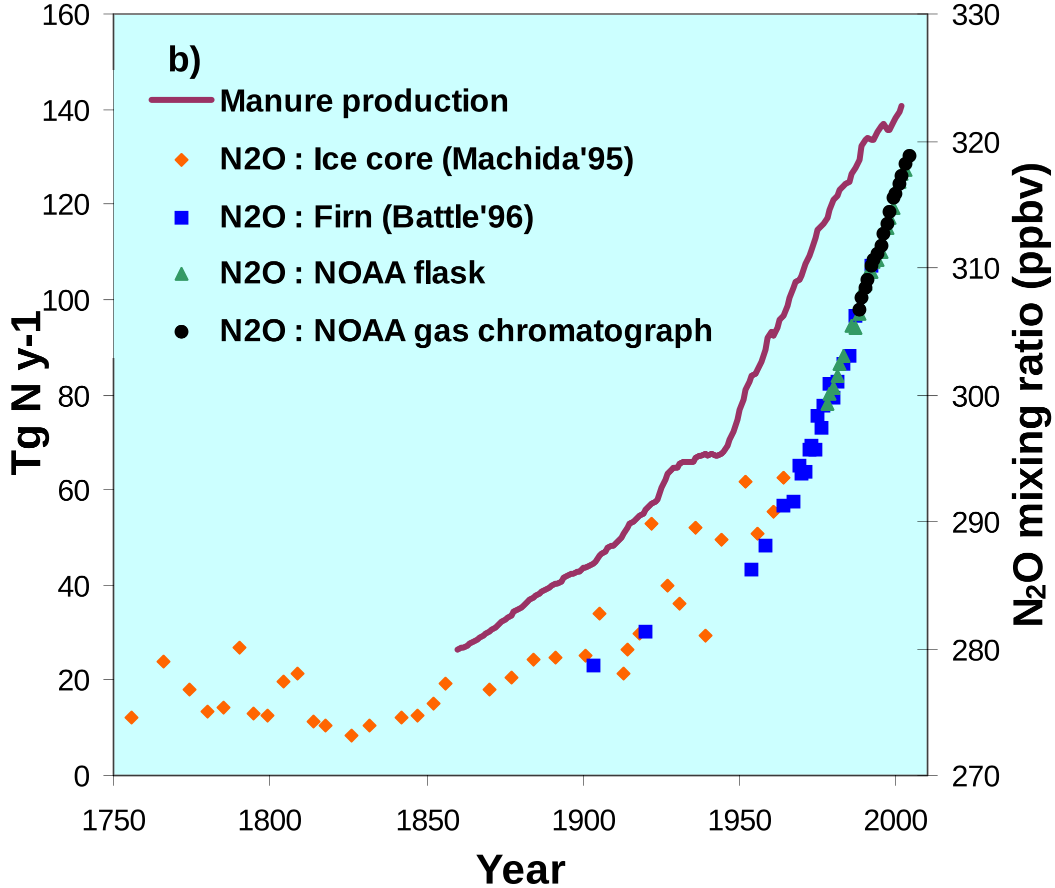

Figure 2. The simultaneous increase in atmospheric N_2O concentrations, and increased manure production as a result of reactive N generation in Figure 1.

Data Citation:

Cite this data set as follows:

E. A. Holland, J. Lee-Taylor, C. Nevison, and J. Sulzman. 2005. Global N Cycle: Fluxes and N_2O Mixing Ratios Originating from Human Activity. Data set. Available on-line [http://www.daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.

Table of Contents:

1. Data Set Overview:

Project: Climate

Investigators:

Dr. Elisabeth A. Holland (eholland@acd.ucar.edu)

Dr. Julia Lee-Taylor, (julial@ucar.edu)

Dr. Cynthia Nevison, (nevison@ucar.edu)

James Sulzman, (sulzman@casco.net)

2. Data Characteristics:

Data Descriptions

Fossil fuel NO_x Emissions 1890-1980

Anthropogenic emissions data for NO_x spanning the period 1890-1980 are from version 1.3 of the Emission Database for Global Atmospheric Research (EDGAR 1.3). EDGAR emissions are cestimated per country and economic sector using an emission factor approach. Calculations of the emissions with 10-year intervals are based on historical activity statistics and selected emission factors that account for changes in economical and technological developments through time.

Data Source

http://www.rivm.nl/edgar

Temporal Characteristics

Temporal Coverage

1890-1980

Temporal Resolution

10-year intervals

Fossil fuel NO_x Emissions 1990-1995

According to the EDGAR website documentation for EDGAR Version 3.2 (http://www.rivm.nl/edgar/documentation/differences/)

"As a result of the validation of EDGAR 2.0 with other global and regional emission inventories it was decided that several items should be modified for the reference year 1990. Compared to Version 2.0 the following amendments have been made for 1990:"

"Global default emission factors for NO_x, CO, and NMVOC [non-methane volatile organic compound] for the following non-road transport activities are updated: Rail transport, Inland water, Other land - non-road and Non-specified transport. Emission factors are entered for coal, diesel oil and gasoline when applicable.

Global default emission factors for NO_x and SO_2 for sea ships have been updated; in particular the emission factor for NO_x has increased significantly."

This accounts for the jump in the dataset between 1980 and 1990.

Data Source

http://www.rivm.nl/edgar

Temporal Characteristics

Temporal Coverage

1990-1995

Temporal Resolution

1-year intervals

Fossil fuel NO_x Emissions 2000

Scaled from fossil fuel CO_2 (Marland et al 2003), using 1990-1995 EDGARV3.2 NO_x as scale basis. Marland et al (2003) estimates of fossil fuel CO_2 emissions were summed over categories {Gas, Liquids, Solids, Flaring} for the year 2000 and multiplied by the mean of the ratios for each year (1990-1995) between EDGAR 3.0 fossil fuel NO_x and fossil fuel CO_2 (defined as above).

Data Source

http://www.rivm.nl/edgar

Temporal Characteristics

Temporal Coverage

2000

Temporal Resolution

Single-year value

Synthetic Fertilizer Nitrogen 1925-1947

Taken from figure 25.3 in Smil (1990)

Data Source

See references.

Temporal Characteristics

Temporal Coverage

1925-1947

Temporal Resolution

1-year intervals

Synthetic Fertilizer Nitrogen 1948-1960

Taken from FAO (Food and Agriculture Organization of the United Nations) yearbooks, and presented in Nevison (1994), Nevison et al. (1996)

Data Source

See references.

Temporal Characteristics

Temporal Coverage

1948-1960

Temporal Resolution

1-year intervals

Synthetic Fertilizer Nitrogen 1961-2002

FAOSTAT data, 2004

Data Source

http://faostat.fao.org (last updated 4 April, 2005).
Under links: Agriculture > Means of Production: Fertilizers > WORLD+, Nitrogenous Fertilizers, Production
Variable name: Fertilizer Nitrogen

Temporal Characteristics

Temporal Coverage

1961-2002

Temporal Resolution

1-year intervals

Manure Nitrogen 1860-1960

Taken from Nevison (1994), Nevison et al. (1996)

Data Source

See references.

Temporal Characteristics

Temporal Coverage

1860-1960

Temporal Resolution

1-year intervals

Manure Nitrogen 1961-2004

FAOSTAT data, 2004

Data Source

http://faostat.fao.org (last updated 20 December, 2004).
Under links: Agriculture > Live Animals

Variable Name: Manure Nitrogen

Temporal Characteristics

Temporal Coverage

1961-2004

Temporal Resolution

1-year intervals

Crop N fixation 1860 and 1995

Taken from table 1 in Galloway et al (2004) [based on Smil (1999; pers. comm.) and Galloway and Cowling (2002)]

Data Source

See references.

Temporal Characteristics

Temporal Coverage

1860 and 1995

Temporal Resolution

2 separate years of data

Crop N fixation 1900

Taken from Galloway and Cowling (2002)

Data Source

See references.

Temporal Characteristics

Temporal Coverage

1900

Temporal Resolution

1 separate year of data

N_2O mixing ratio 1756-1964

Taken from table 1 in Machida et al (1995)

Data Source

See references.

Variable name: N_2O concentration, H15 ice core

Temporal Characteristics

Temporal Coverage

1756-1964

Temporal Resolution

1-year values, variable intervals

N_2O mixing ratio 1954-1992

James Butler, personal communication

Data Source

See references.

Variable name: N2O concentration, South Pole Firn

Temporal Coverage

1954-1992

Temporal Resolution

1 year values, variable intervals

N_2O mixing ratio 1988-1999

Source data is monthly mean data

Data Source

ftp://ftp.cmdl.noaa.gov/hats/n2o/insituGCs/RITS/global/gaven2o.dat (updated 05/18/2005).

Variable name: N_2O concentration, global mean (measured by NOAA-RITS In-Situ Gas Chromatograph)

Temporal Coverage

1988-1999

Temporal Resolution

1 year interval.

N_2O mixing ratio 2000-2004

Source data is monthly mean data

Data Source

ftp://ftp.cmdl.noaa.gov/hats/n2o/insituGCs/CATS/global/insitu_global_N2O (updated 5/18/05)

Variable name: N_2O concentration, global mean (measured by NOAA-CATS In-Situ Gas Chromatograph)

Temporal Coverage

2000-2004

Temporal Resolution

1-year interval

N_2O mixing ratio 1978-2003

Source data is monthly mean data

Data Source

ftp://ftp.cmdl.noaa.gov/hats/n2o/flasks/pre1996/ (updated 3/17/2004) and
ftp://ftp.cmdl.noaa.gov/hats/n2o/flasks/post1996/ (updated 5/21/2004)

Variable name: N_2O concentration, global mean (from NOAA/CMDL flask samples)

Temporal Coverage

1978-2003

Temporal Resolution

1-year interval (missing data for years 1984, 1985, 1996, 2000)

File Format

Space-delimited ASCII file format

Parameter/Variable

Variable	**Column Number**	**Units**	**Format**
Year	1	years	integer
Fossil fuel NO_x emission	2	TgN/yr	Floating point
Synthetic fertilizer nitrogen emission	3	TgN/yr	Floating point
Manure nitrogen emission	4	TgN/yr	Floating point
Crop nitrogen fixation emission	5	TgN/yr	Floating point
N_2O mixing ratio from machida (1995)	6	ppbv	Floating point
N_2O mixing ratio from Battle (1996)	7	ppbv	Floating point

N_2O mixing ratio (in situ gas chromatograph)	8	ppbv	Floating point
N_2O mixing ratio (flask sample)	9	ppbv	Floating point

Missing data is filled with the value of -99.9

Example of data format

```
1999 -99.9  89.2 137.3 -99.9 -99.9 -99.9 315.5 314.8
2000  26.9  86.0 138.4 -99.9 -99.9 -99.9 315.8 -99.9
2001 -99.9  86.6 139.4 -99.9 -99.9 -99.9 316.5 316.7
2002 -99.9  88.2 140.8 -99.9 -99.9 -99.9 317.2 317.5
2003 -99.9 -99.9 141.7 -99.9 -99.9 -99.9 318.1 317.7
2004 -99.9 -99.9 142.5 -99.9 -99.9 -99.9 318.8 -99.9
```

3. Data Methods:

Fossil fuel NO_x Emissions 1890-1990

Units are given as Tg N yr^{-1} as found in the original data source.

Fossil fuel NO_x Emissions 1990-1995

Units were converted from Tg NO_x yr^{-1} as found in the original data source to Tg N yr^{-1} as found in this data set (multiplied by 0.305).

We summed EDGAR categories: {F10-INDUSTRIAL SECTOR, F20-POWER GENERATION. F30-OTS(ALL). F40-RCOSECTOR(RES+COM+OTH), F51-ROAD TRANSP.(INCL.EVA), TRANS.LAND NON-ROAD, F57-AIR (ALL), F58-INTERN.SHIPPING, F80-OIL PROD/(TRANSM)/HANDL}

Fossil fuel NO_x Emissions 2000

Scaled from fossil fuel CO_2 (Marland et al 2003), using 1990-1995 EDGAR NO_x as scale basis. Marland et al (2003) fossil fuel CO_2 emissions were summed over categories {Gas, Liquids, Solids, Flaring} for the year 2000 and multiplied by the mean of the ratios for each year (1990-1995) between EDGAR 3.0 fossil fuel NO_x and fossil fuel CO_2 (defined as above).

Synthetic Fertilizer Nitrogen 1925-1947

Value read from figure 25.3 in the reference document

Synthetic Fertilizer Nitrogen 1948-1960

Data not different from source.

Synthetic Fertilizer Nitrogen 1961-2002

Units were converted from metric tonnes N yr^{-1} as found in the original data source to Tg N yr^{-1} as found in this data set.

Manure Nitrogen 1860-1960

Manure totals for 1860-1961 were estimated based on the method described in Nevison [1994] and Nevison et al. [1996]. Briefly, cattle, pig, sheep, and poultry populations were transcribed from FAO Production Yearbooks and converted to N manure using excretion values reported in Souchu and Etchanchu [1990]. Since the manure totals using this method tended to underestimate by 20% the totals estimated using the revised 1996 IPCC excretion values, the 1861-1960 estimates were scaled upward by 20%.

Manure Nitrogen 1961-2004

Populations of {cattle, pigs, sheep, chickens, ducks, geese, turkeys, asses, camels, goats, horses, mules}

were divided into 5 categories: {cattle, pigs, sheep, poultry, “other” }

for each of the following 8 world regions:

1) Africa
2) North America Developed
3) Western Europe
4) Latin America + Caribbean
5) Oceania
6) Eastern Europe (sum of Eastern Europe, USSR, and USSR in Europe)
7) Near East (sum of Near East in Asia, Iraq and Israel)
8) Far East and Asia (sum of Far East, Japan and USSR in Asia)

Each livestock population was multiplied by the appropriate, regionally specific nitrogen excretion value given in Table A-1 (pp. 4.45-4.47) of the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Section 4, Agriculture, Workbook (Volume 2 (http://www.ipcc-nggip.iges.or.jp/public/gl/invs5.htm). According to the excretion values in Table A-1 dairy cattle produce substantially more N manure than non-dairy cattle. Since FAOSTAT does not distinguish between dairy and non-dairy, the partitioning given in Table A-1 for 1990s conditions was assumed over the entire 1961-2004 period. Cattle typically account for about half of global manure nitrogen production.

Crop N fixation 1860 and 1995

(1860) 1900 estimate, applied to 1860;

(1995) early 1990s

Crop N fixation 1900

Data not different from source.

N_2O mixing ratio 1756-1964

Data not different from source.

N_2O mixing ratio 1900-1992

Data not different from source.

N_2O mixing ratio 1988-1999

The source data is a global monthly average. We averaged these monthly values to present an annual global mean for the stated year.

N_2O mixing ratio 2000-2004

The source data is a global monthly average. Occasionally a monthly value was interpolated from neighboring months by the data owners. We averaged these monthly values to present an annual global mean for the stated year.

N_2O mixing ratio 1978-2003

The source data is a global monthly averaged. We averaged these monthly values to present an annual global mean for the stated year.

4. Data Access:

This data set is available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) or the EOS Data Gateway.

Data Archive Center:

Contact for Data Center Access Information:

E-mail: uso@daac.ornl.gov
Telephone: +1 (865) 241-3952
FAX: +1 (865) 574-4665

Product Availability:

Requested data can be provided electronically on the ORNL DAAC's anonymous FTP site or on CD-ROM.

5. References:

Battle, M., M. Bender, T. Sowers, P. P. Tans, J. H. Butler, J. W. Elkins, J. T. Ellis, T. Conway, N. Zhang, P. Lang and A. D. Clarket (1996), Atmospheric gas concentrations over the past century measured in air from firn at the South Pole, *Nature*, *383*(6597), 231-235.

Galloway, J. N., and E. B. Cowling (2002), Reactive Nitrogen and The World: 200 Years of Change, *Ambio*, *31*(2), 64-71.

Galloway, J. N., F. J. Dentener, D. G. Capone, E. W. Boyer, R. W. Howarth, S. P. Seitzinger, G. P. Asner, C. C. Cleveland, P. A. Green, E. A. Holland, D. M. Karl, A. F. Michaels, J. H. Porter, A. R. Townsend, and C. J. Vöosmarty (2004), Nitrogen Cycles: Past, Present, and Future, Biogeochemistry,70 (2): 153-226, doi:10.1007/s10533-004-0370-0.

Holland, E.A., S.B. Bertman, M.A. Carroll, A.B. Guenther, P.B. Shepson, J. P. Sparks, and J. Lee-Taylor. 2005. U.S. Nitrogen Science Plan Focuses Collaborative Efforts. Eos, Trans. Am. Geophys. Union. 86:253-256.

Howarth, R., Marino, R., and Scavia, D. (2003), Priority Topics for Nutrient Pollution in Coastal Waters: An Integrated National Research Program for the United States. National Ocean Service, pp. 1-24, NOAA.

Machida, T., T. Nakazawa, Y. Fujii, S. Aoki, and O. Watanabe (1995), Increase in the atmospheric nitrous-oxide concentration during the last 250 years, *Geophys Res Lett. 22*(21), 2921-2924.

Marland, G., T.A. Boden, and R. J. Andres (2003). Global, regional, and national fossil fuel CO2 emissions. In Trends: a compendium of data on global change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Nevison, C.D., 1994. A model analysis of the spatial distribution and temporal trends of nitrous oxide sources and sinks, Ph.D. Thesis, Stanford University, 225 pp.

Nevison, C.D., G. Esser, and E.A. Holland, 1996. A Global Model of Changing N_2O Emissions from Natural and Perturbed Soils, Climatic Change, 32, 327-378.

Olivier, J.G.J. and J.J.M. Berdowski (2001) Global emissions sources and sinks. In: Berdowski, J., Guicherit, R. and B.J. Heij (eds.) "The Climate System", pp. 33-78. A.A. Balkema Publishers/Swets & Zeitlinger Publishers, Lisse, The Netherlands. ISBN 90 5809 255 0.

Rabalais, N. N. (2002), Nitrogen in aquatic ecosystems, *Ambio 31*(2), 102-112.

Smil, V., 1990. Nitrogen and phosphorus, in The Earth as transformed by human action, edited by B.L. Turner II et al., Cambridge Univ. Press, New York.

Smil V. 1999. Nitrogen in crop production: an account of global flows. Global Biogeochem. Cycles 13: 647–662.

Souchu and Etchanchu, 1990. The environmental effects of the intensive application of nitrogen fertilizers in Western Europe: Past problems and future prospects, International Institute for Applied Systems Analysis (IIASA) working paper.

T. M. Thompson, J. H. Butler, B. C. Daube, G. S. Dutton, J. W. Elkins, B. D. Hall, D. F. Hurst, D. B. King, E. S. Kline, B. G. Lafleur, J. Lind, D. J. Mondeel, S. A. Montzka., F. L. Moore, J. D. Nance, J. L. Neu, P. A. Romaskin, A. Scheffer, and W. J. Snible (2003), Halocarbons and other Atmopsheric Trace Species, Chapter 5 *in* Climate Monitoring and Diagnostics Laboratory Summary Report #27, NOAA-CMDL, Boulder, CO.

Townsend, A. R., R. W. Howarth, M. S. Booth, C. C. Cleveland, S. K. Collinge, A. P. Dobson, P. R. Epstein, E. A. Holland, D. R. Keeny, and M. A. Malin (2003), Human health effects of a changing global nitrogen cycle, *Frontiers in Ecol.*, *1*(5), 240-246.

Van Aardenne, J.A., Dentener, F.J., Olivier, J.G.J., Klein Goldewijk, C.G.M. and J. Lelieveld (2001) A 1 x 1 degree resolution dataset of historical anthropogenic trace gas emissions for the period 1890-1990. Global Biogeochemical Cycles,15(4), 909-928.

Vitousek, P.M., J.D. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger and D. Tilman (1997a), Human alteration of the global nitrogen cycle: sources and consequences, *Ecol. Appl.*, *7*, 737-750.