NZ science teacher

2010

Featuring: Nitrogen

Nitrogen in foods

Nitrogen, soils and the NZ environment

Reactive nitrogen in the environment

Agricultural nitrous oxide emissions

Global nitrogen cycle

Plus:

Science and "Creative Destruction"

Teaching controversial issues in science

Futures focus in science classrooms

Allan Wilson and Out of Africa model

NZASE

New Zealand Association of Science Educators

Number 125

ISSN 0110-7801

global nitrogen cycle and the impact on the atmosphere of agricultural intensification

Food production is at the heart of defining sustainability for humanity, i.e. the "capacity to endure" for the long-term, which implies there is little or no damage to the environment and a "healthy" Earth system is maintained. In this issue on nitrogen, *Mike Harvey* from NIWA explores the linkage between the greenhouse gas nitrous oxide (N_2O) and sustainable agriculture.

What do atmospheric measurements of N_2O tell us?

Nitrous oxide concentrations have been measured in clean air coming off the ocean at the NIWA monitoring station at Baring Head[1] near Wellington since 1998; at the beginning of the record the concentration was about 313ppb (parts per billion[2]). Since then, there has been a steady rise in concentration, and by 2010 the concentration had increased by about 9ppb to 322ppb. However, to gauge the significance of this rise, we need to compare to measurements made elsewhere around the globe. There is a global network of in situ greenhouse gas measurements co-ordinated by the World Meteorological Organisation (WMO) under their Global Atmosphere Watch (GAW) programme.

The GAW programme promotes systematic inter-calibrated observations of global atmospheric composition. Figure 1 shows the sites reporting N_2O measurements to the network. Because of its remote location on the globe, New Zealand (right on the edge of the map!) makes an important contribution to this network through its atmospheric observatories operated by NIWA at Baring Head (near Wellington) and at Lauder (in Central Otago). Figure 2 shows the steady rise in concentration measured globally over the last decade. This summary plot of monthly averages comes from a group of stations that form part of the US National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) network of sites that measure trace compounds in the atmosphere once an hour. The steady rise tells us that there must be an imbalance and that we are adding nitrous oxide to the atmosphere faster than it is being removed. Concentrations in the Northern Hemisphere are consistently higher than in the Southern Hemisphere indicating that there is a greater source of this gas in the North.

1 More detail on Baring Head is given in the NZ Science Teacher V120 issue on carbon.
2 ppb is molecules of N_2O per thousand million molecules (mole fraction) in dry air. This is 1000 times smaller than the ppm unit used for CO_2 measurement.

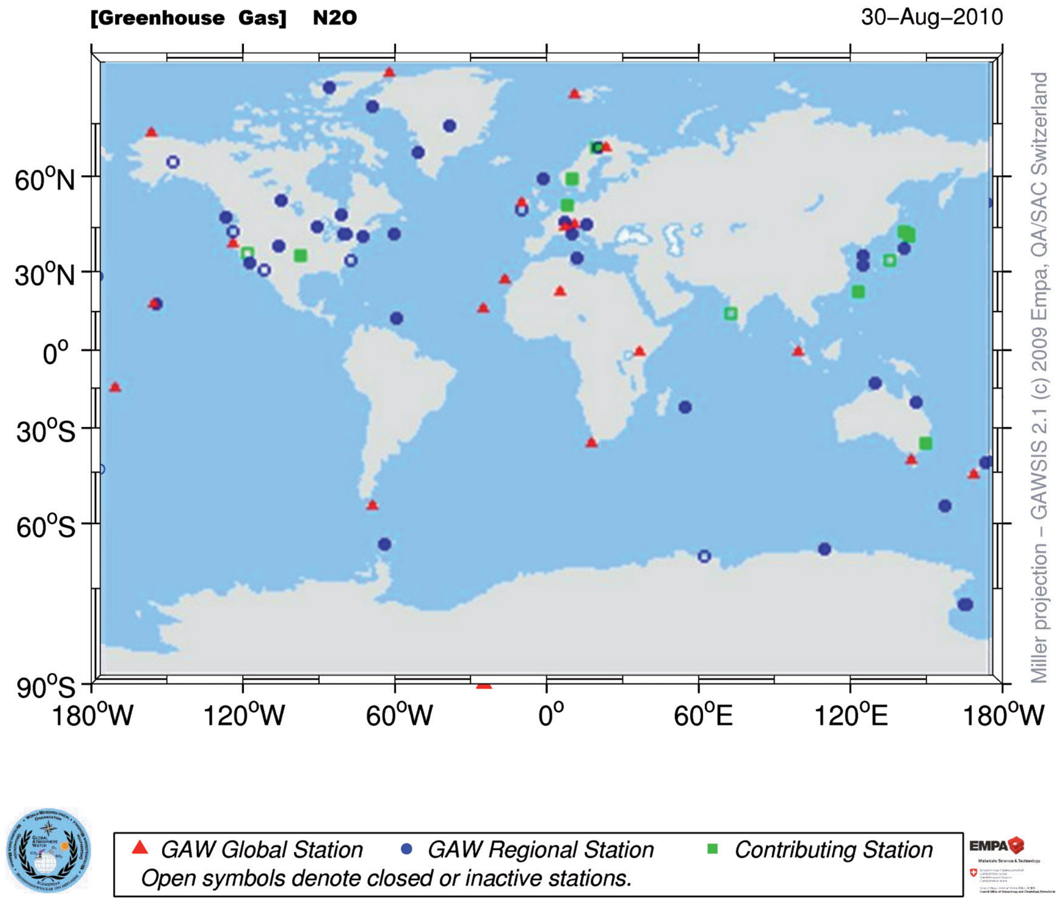

Figure 1: The WMO Global Atmospheric Watch (GAW) stations that report N_2O measurements.
Source: http://gaw.empa.ch/gawsis/default.asp

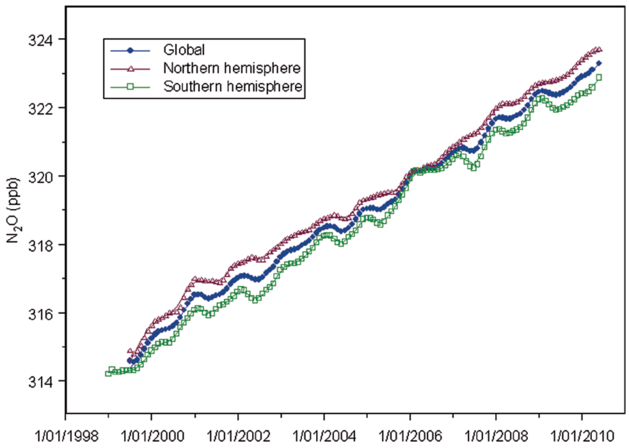

Figure 2: Nitrous Oxide (N_2O) hemispheric and global monthly means from the NOAA/ESRL halocarbons in situ programme. From measurements made at Barrow, Alaska; Summit, Greenland; Niwot Ridge, Colorado; Mauna Loa, Hawaii; American Samoa; South Pole. This work was funded in part by the Atmospheric Chemistry Project of NOAA's Climate and Global Change Program. ftp://ftp.cmdl.noaa.gov/hats/n2o/insituGCs/CATS/global/

Can we look back in time at historical atmospheres?

Small bubbles of air become trapped in the polar ice sheets as the ice accumulates. By careful drilling down into the ice sheet and extracting air trapped in the bubbles, it is possible to look at past composition of the atmosphere, at the time when the bubbles were sealed into the ice. Figure 3 shows results of this look back in time. There is evidence (inset) that the N_2O concentration starts to rise more steeply after 1700, at the time when agriculture was starting to become more productive and mechanised. Prior to this, the natural sources and sinks of N_2O in the atmosphere are thought to have been roughly in equilibrium, at about 10 Tg N_2O-N per year.

Why are increasing emissions of concern?

Nitrous oxide is a long-lived GHG with an atmospheric lifetime of >110 yrs.

Nitrous oxide is a potent GHG with a greenhouse warming potential of ~300 times greater than CO_2 (over 100 year time horizon).

Natural sources and sinks are thought to have been roughly in equilibrium prior to the industrial revolution. Since the industrial revolution, the N_2O source has increased by 40-50% and the gas has accounted for about 6% of the enhanced greenhouse effect attributed to long-lived gases.

In addition to its greenhouse effect, N_2O is also important as an ozone depleting substance through its role as a source of reactive nitrogen to the stratosphere.

Where are the natural sources and sinks?

Figure 4 shows how nitrogen cycles between the atmosphere and land (or ocean surface). Conversions within the natural cycle of nitrogen are facilitated by micro-organisms i.e. bacteria and archea. Biological nitrogen fixation by micro-organisms known as diazotrophs can take nitrogen from the atmosphere and convert it to ammonium, which provides nitrogen in a form that is available for plant growth. Nitrifying micro-organisms in soil and ocean oxidise the ammonium into more mobile forms of nitrite and nitrate and some N_2O can be released in this process.

In anoxic environments, denitrifying organisms utilise oxygen from the nitrate and these conversions result in the

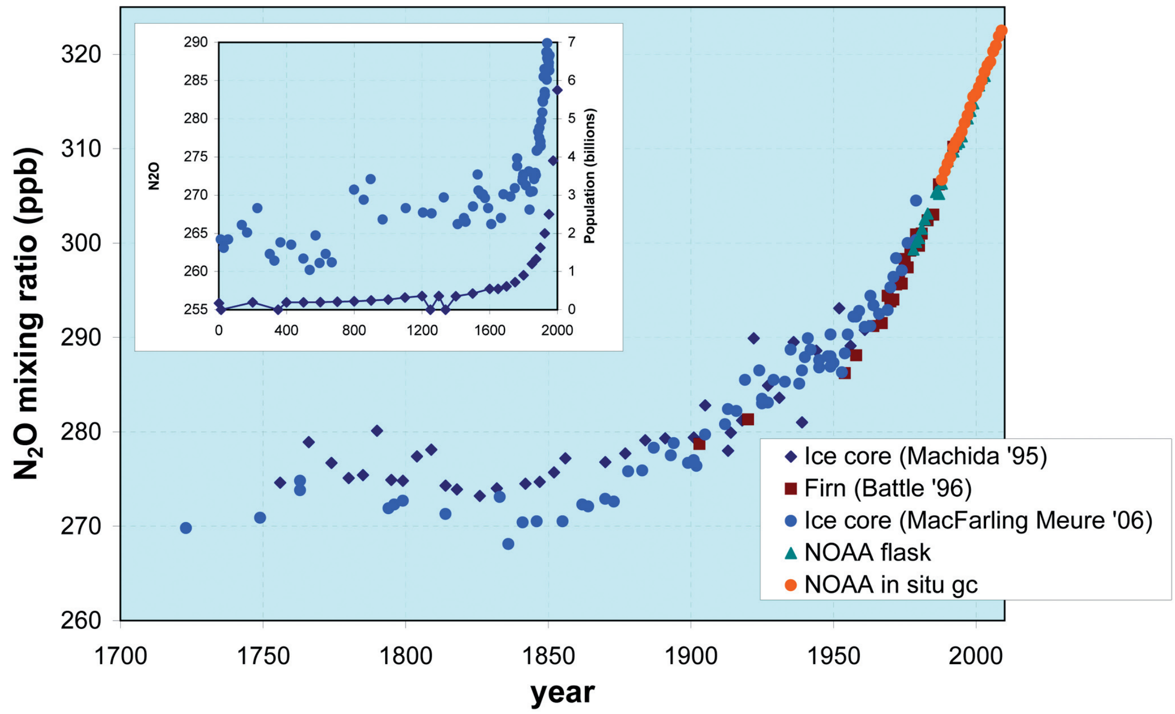

Figure 3: Average levels of N_2O in the atmosphere since 1700 (Year 0 in inset), expressed in ppb. Contemporary measurements commenced in 1978 at the laboratories of the NOAA, and earlier measurements are based on air extracted from Antarctic ice and firn (compacted snow) which traps and preserves the air of historical atmospheres. Contemporary data are available through the World Data Centre for Greenhouse gases: http://gaw.kishou.go.jp/wdcgg/. The historical sources have been compiled by Holland et al. [2005] and are available online from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. http://daac.ornl.gov/. Extension of the record back 2000 years B.P. has been achieved from samples retrieved from ice cores collected at Law Dome, Antarctica [MacFarling Meure et al., 2006].

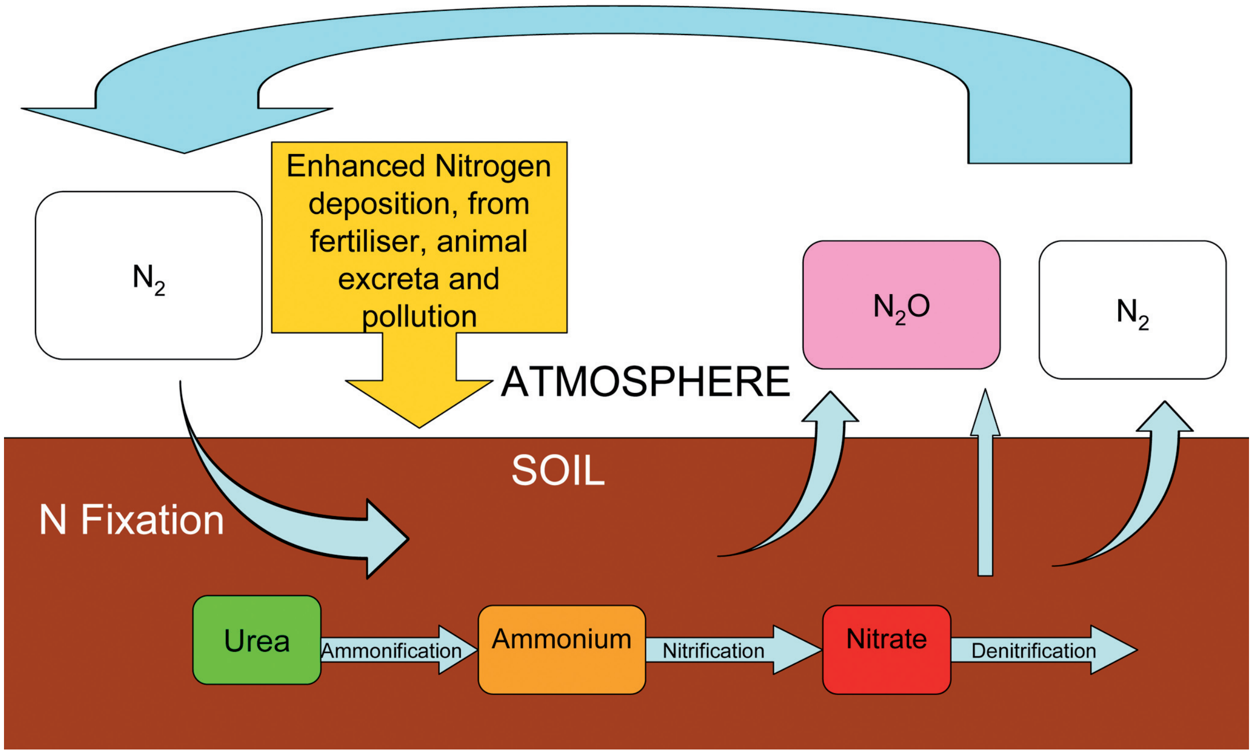

Figure 4: The cycling of nitrogen between atmosphere and soil.

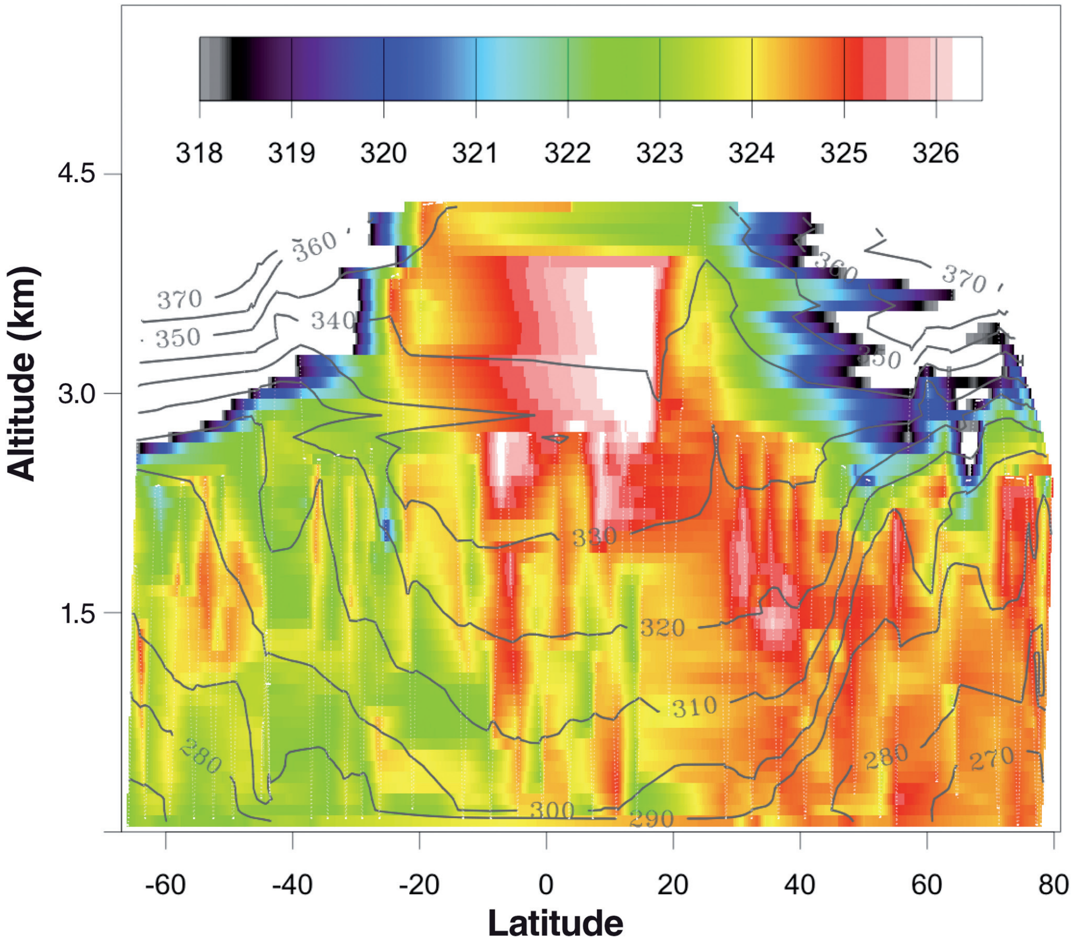

Figure 5: This contour plot shows the concentration of N_2O thorough a south-north slice of the Pacific atmosphere measured by the Hiaper Pole-to-Pole Observations (HIPPO) http://hippo.ucar.edu/ in November 2009. The colour bar shows N_2O concentrations in ppb. The contour lines are potential temperature (Kelvin). The in-situ measurements are made by quantum cascade laser. Data provided by Eric Kort and Steven Wofsy, Harvard University. HIPPO is supported by the National Science Foundation (NSF) and its operations are managed by the Earth Observing Laboratory (EOL) of the National Center for Atmospheric Research (NCAR).

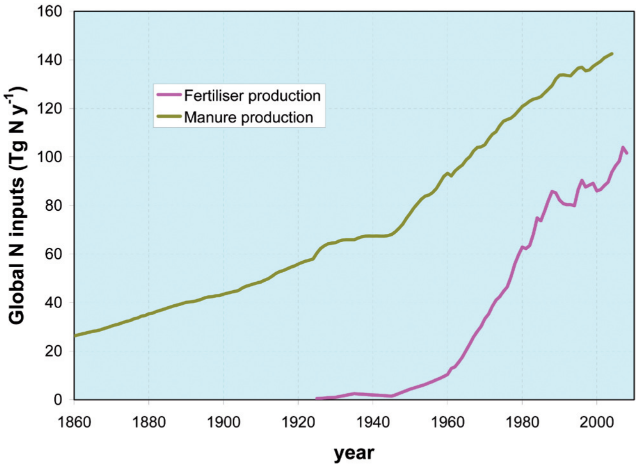

Figure 6: Global production of synthetic fertiliser and manure production. These data have been compiled by Holland et al. [2005] and are available online from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. http://www.daac.ornl.gov. Recent data are provided by the Food and Agriculture Organisation of the United Nations: http://faostat.fao.org

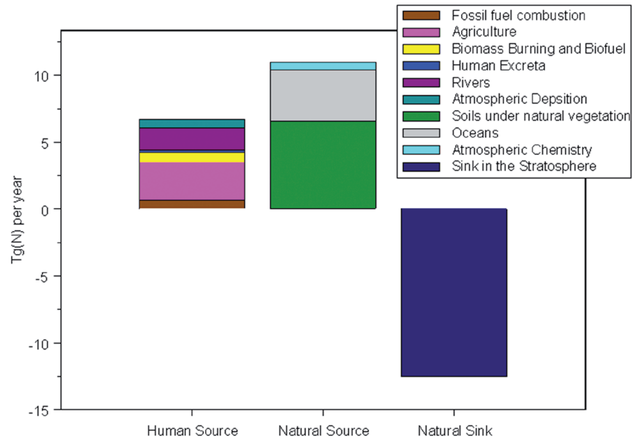

Figure 7: The magnitude of the global sources and sinks of N_2O as summarised by Denman et al. [2007].

production of N_2O and molecular nitrogen which returns to the atmosphere to complete the cycle. Tropical wet soils are thought to be a significant natural source region. Recently, a group of U.S. scientists co-ordinated through the National Center for Atmospheric Research (NCAR) in Boulder, Colorado have been making airborne observations through slices of atmosphere over the Pacific Ocean with the aim of identifying the major source and sink regions of greenhouse gases.

The experiment called "HIPPO" (Hiaper (the aircraft) Pole-to-Pole Observations http://hippo.ucar.edu/) is providing new insights with Pole-to-Pole slices of atmospheric composition. Figure 5 shows data from the flight in November 2009. In common with measurements at other times of year, the plot shows more N_2O in the Northern Hemisphere than to the South. A significant source of N_2O from tropical land has been lofted and shows up in the figure as elevated concentrations in the tropical mid-troposphere. Nitrous oxide is a relatively stable molecule in the lower atmosphere, and the main loss mechanism is through breakdown (photolysis) by ultraviolet radiation in the stratosphere (upper atmosphere – well above 10km). Uplift in the tropics is likely to be a major path through which N_2O finds its way into the stratosphere.

Fertilisers, global population and the "Green Revolution"

In the early 20th century, a German chemist Fritz Haber, developed the capability of synthetically converting atmospheric nitrogen (which makes up 80% of the atmosphere) into ammonia. The process was industrialised in 1913 by Carl Bosch, and the two were subsequently awarded Nobel prizes. This remarkable development, known as the Haber-Bosch Process, is a key step in the production of synthetic nitrogen fertilisers. Figure 6 shows how production has grown over the 20th century, in particular following World War II. Fertilisers have been a key component of the so-called "*Green Revolution*" of agricultural intensification that has only been possible through the combined scientific and technological advances of high yielding crops from plant breeding programmes, agrochemicals for pest and disease management and synthetic fertilisers. Since World War II, global population has trebled from about 2.3 Billion in 1940 to 6.9 Billion today. Synthetic fertiliser is thought to sustain about one third of the current global human population. The increased fertiliser use, along with intensification of animal farming to feed the growing global population, is driving the sharp increase (Figure 3) that we are now seeing in nitrous oxide in the atmosphere.

How do the natural and anthropogenic emissions compare?

Recent estimates from the Intergovernmental Panel on Climate Change (IPCC) [Denman et al., 2007] are shown in Figure 7. Soils under natural vegetation account for 60% of the natural source of 11 TgN per year; agricultural accounts for 40% of the anthropogenic emissions of 6.7 TgN per year. The sum of these sources exceeds the stratospheric removal, thought to be around 13 TgN per year, leading to accumulation and increasing concentrations in the atmosphere. This is of concern as N_2O has become the third most important greenhouse gas in the atmosphere.

The future: Where to for nitrogen management?

The second "Green Revolution" will need to focus on sustainable intensive food production with lower fertiliser input. Nitrogen use and management is a key component. Integrated studies are developing to look at what governs whole plant nitrogen response in order to develop a better understanding of nitrogen use efficiency. Plant breeding and improved root systems are one key focus of research. However, it is not just plant breeding, but an understanding of the whole production system that is required. For instance, pioneering research at Lincoln University has been looking at improving nitrogen retention in soils through the use of nitrification inhibitors. Biological nitrogen fixation by clover in the pasture can supply the majority of the nitrogen in the clover top growth. Some of this N can be recycled back to the pasture by the grazing animals and is available to support grass growth, reducing the need for additional fertiliser application. If this N can be better held in the soil through the use of inhibitors that limit the conversion to nitrate and reduce leaching, then the need for fertiliser is reduced further still.

For further information contact **m.harvey@niwa.co.nz**

References

Denman, K.L., et al. (2007). Couplings between changes in the climate system and biogeochemistry, in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by S. Solomon, et al., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Holland, E.A., et al. (2005). Global N Cycle: Fluxes and N2O Mixing Ratios Originating from Human Activity, edited, Data set. Available online [http://www.daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.

MacFarling Meure, C., et al. (2006). Law Dome CO_2, CH_4, and N_2O ice core records extended to 2000 years BP. *Geophys. Res. Lett.*, 33(14), L14810.