N-cycle: biogeochemistry

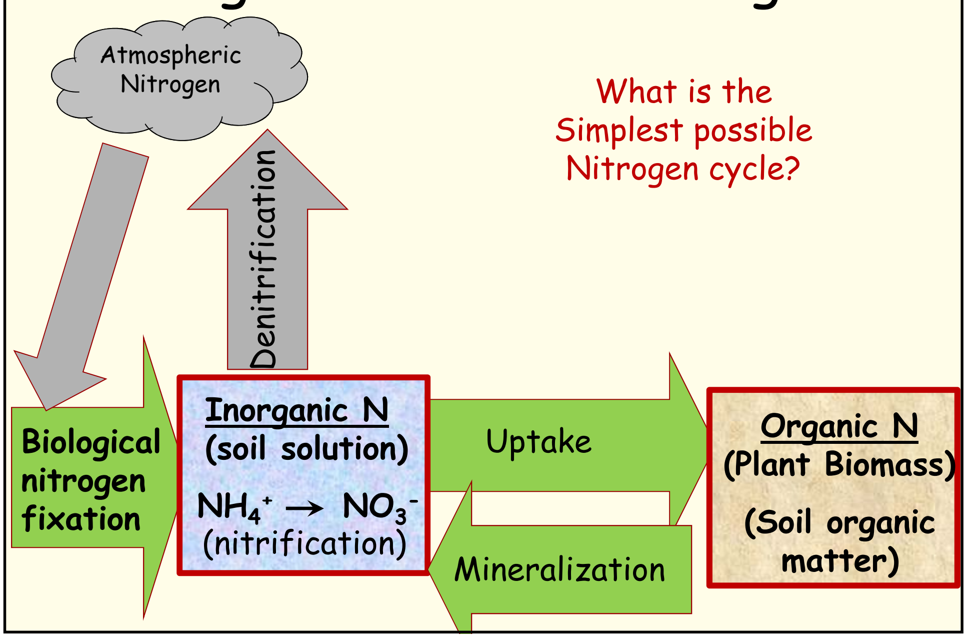
SWES 410/510
April 4, 2014

I. N cycling
   A. simplest possible
   B. Global N budget
   C. Effects of N-cycling ('the Nitrogen Cascade')

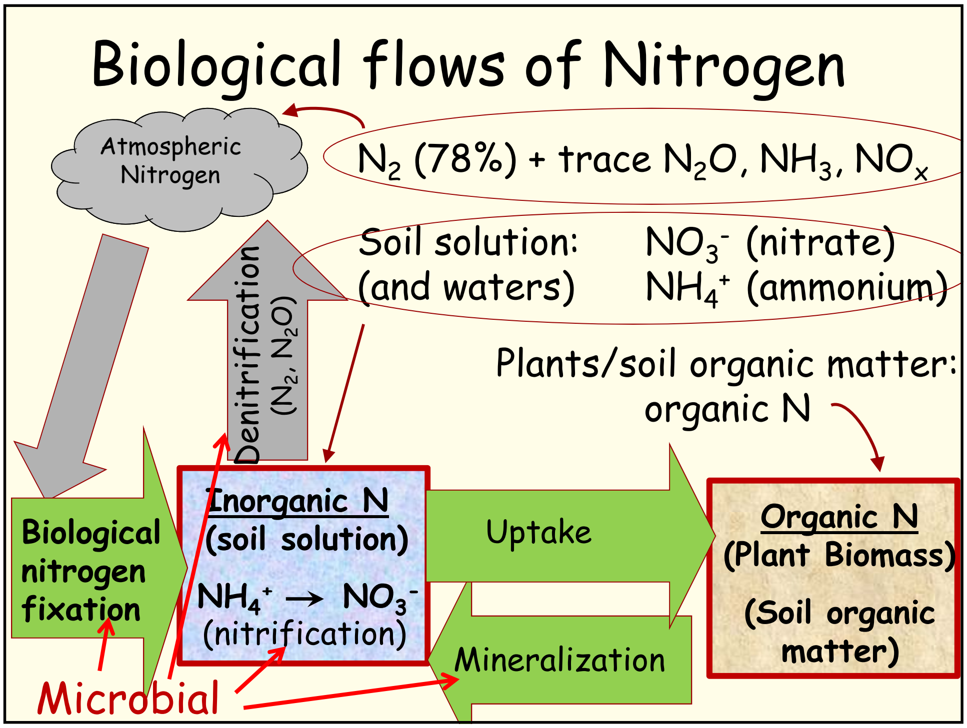
II. Nitrous Oxide (N_2O) budgets

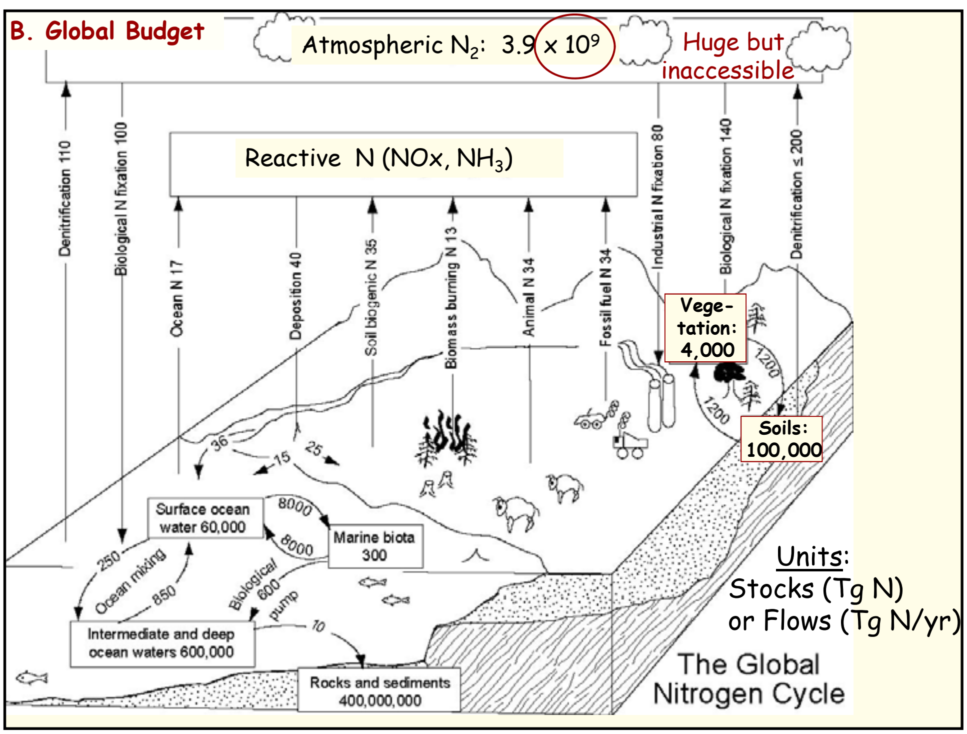
III. Data-Model Intercomparison studies of C-cycle feedbacks to climate

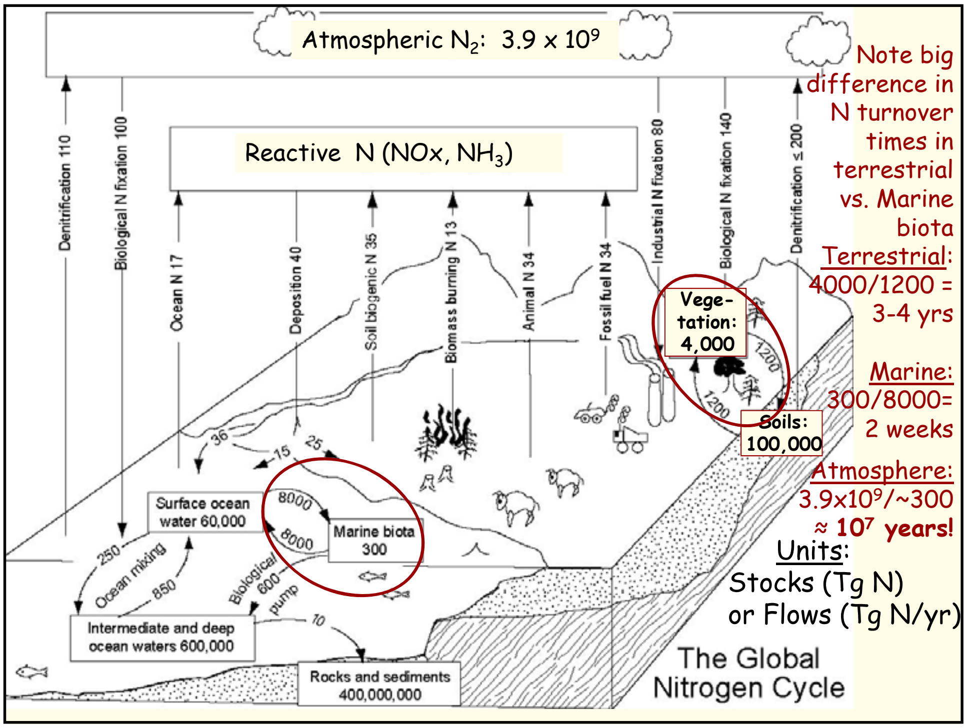
Biological flows of Nitrogen



What is the Simplest possible Nitrogen cycle?


Biological flows of Nitrogen
Atmospheric Nitrogen
N2 (78%) + trace N2O, NH3, NOx
Soil solution: (and waters)
NO3- (nitrate)
NH4+ (ammonium)
Denitrification
(N2, N2O)
Plants/soil organic matter: organic N
Biological nitrogen fixation
Inorganic N (soil solution)
NH4+ → NO3-
(nitrification)
Uptake
Organic N (Plant Biomass)
(Soil organic matter)
Mineralization
Microbial


B. Global Budget
Atmospheric N2: 3.9 x 10^9
Huge but inaccessible
Reactive N (NOx, NH3)
Denitrification 110
Biological N fixation 100
Ocean N 17
Deposition 40
Soil biogenic N 35
Biomass burning N 13
Animal N 34
Fossil fuel N 34
Industrial N fixation 80
Biological N fixation 140
Denitrification ≤ 200
Vege-tation: 4,000
Soils: 100,000
1200
1200
36
15
25
Surface ocean water 60,000
8000
8000
Marine biota 300
250
Ocean mixing
850
Biological 600 pump
10
Intermediate and deep ocean waters 600,000
Rocks and sediments 400,000,000
Units:
Stocks (Tg N)
or Flows (Tg N/yr)
The Global Nitrogen Cycle



Atmospheric N_2: 3.9×10^9
Reactive N (NOx, NH_3)
Denitrification 110
Biological N fixation 100
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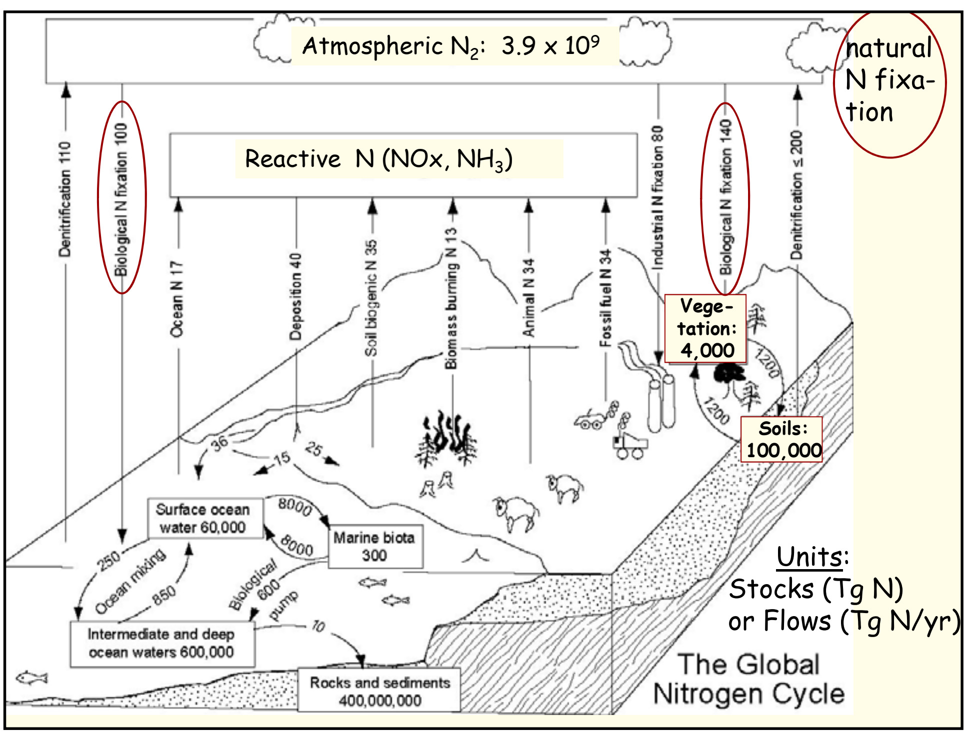
The Global Nitrogen Cycle
Note big difference in N turnover times in terrestrial vs. Marine biota
Terrestrial: 4000/1200 = 3-4 yrs
Marine: 300/8000= 2 weeks
Atmosphere: 3.9×10^9/~300 ≈ 10^7 years!
Units:
Stocks (Tg N)
or Flows (Tg N/yr)



Atmospheric N_2: 3.9×10^9
natural N fixa-tion
Reactive N (NOx, NH_3)
Denitrification 110
Biological N fixation 100
Ocean N 17
Deposition 40
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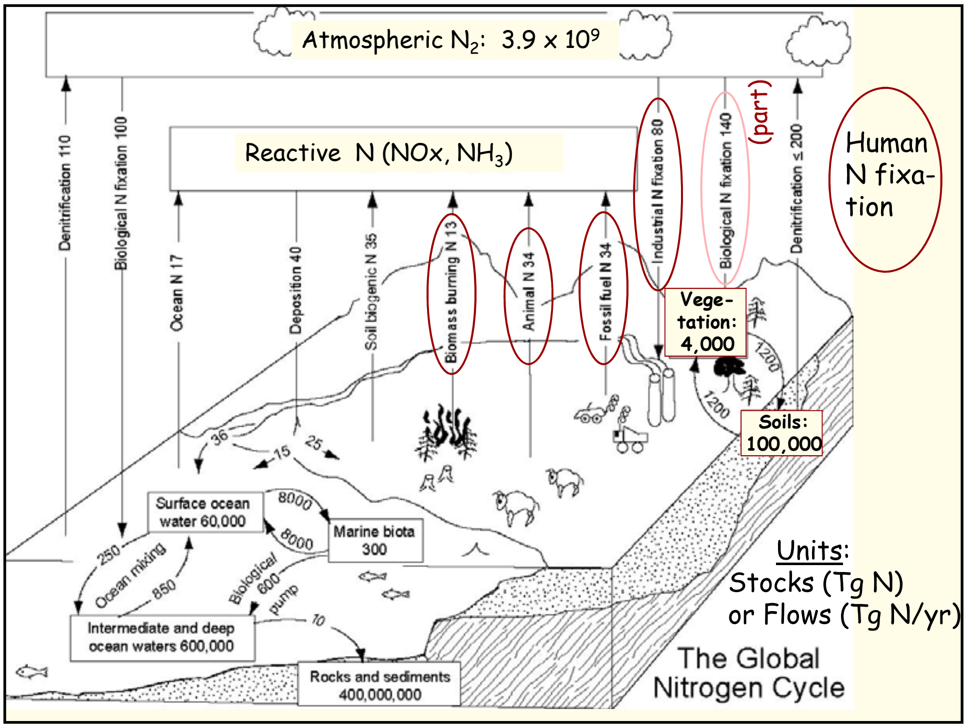

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Biological N fixation 100
Ocean N 17
Deposition 40
Soil biogenic N 35
Biomass burning N 13
Animal N 34
Fossil fuel N 34
Industrial N fixation 80
Biological N fixation 140
(part)
Denitrification ≤ 200
Human N fixa-tion
Vege-tation: 4,000
Soils: 100,000
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Surface ocean water 60,000
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Marine biota 300
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Ocean mixing
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Biological pump
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Intermediate and deep ocean waters 600,000
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Units:
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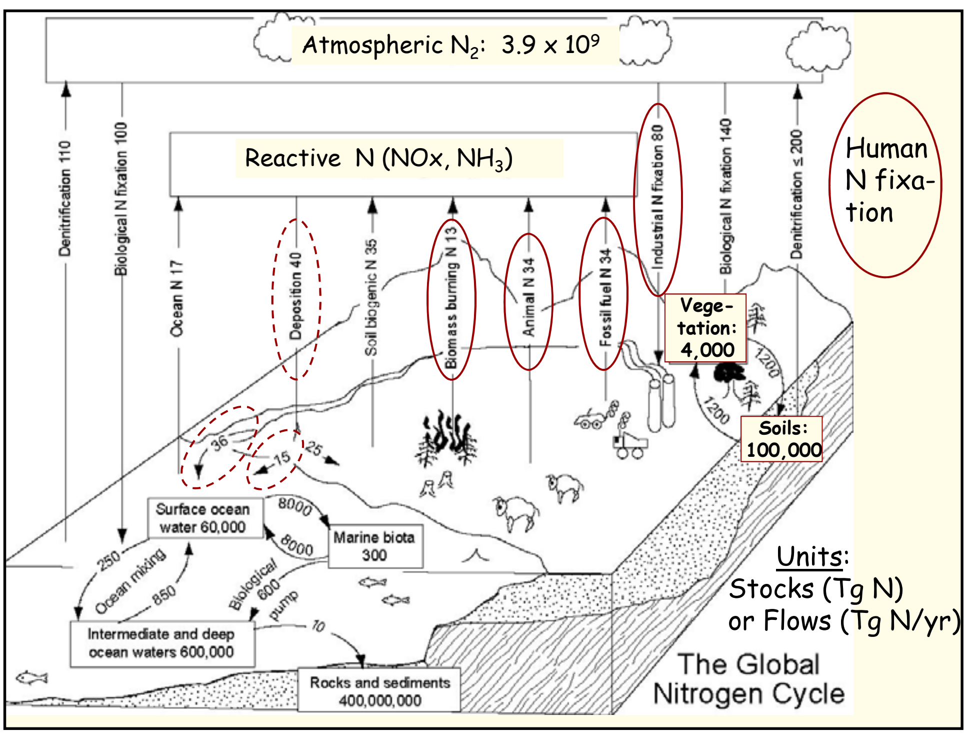
The Global Nitrogen Cycle



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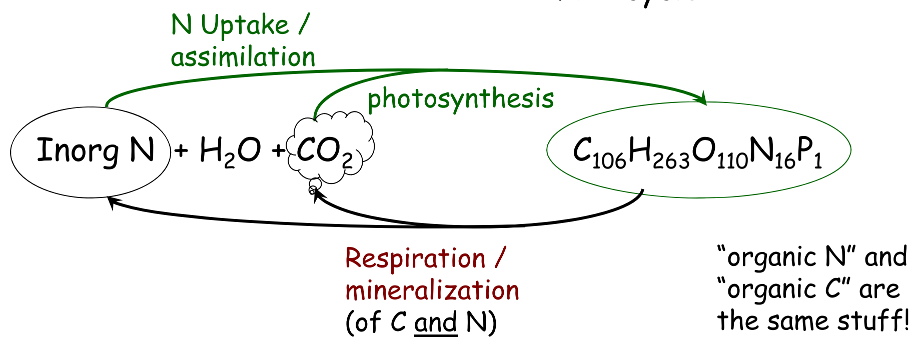
Units:
Stocks (Tg N)
or Flows (Tg N/yr)
The Global Nitrogen Cycle

Stoichiometry (proportional elemental composition, e.g. C:N:P in biomass)

(because biogeochemical cycles do not exist in isolation, but are coupled)

Example: Integrated N-C cycle



Stoichiometry (proportional elemental composition, e.g. C:N:P in biomass)

Stoichiometry:
Greek: *stoikheion* (element)
\+ *metron* (measure)

ecological stoichiometry: definite proportions of elemental combinations, a constraint on biogeochemistry of life, from the cell to the organism to the biosphere

(broader concept than the stoichiometry of balancing a chemical reaction)

Stoichiometry (proportional elemental composition, e.g. C:N:P in biomass)

Originally introduced as an ecological concept by A. Redfield in 1934 in his study of marine phyto-plankton. the *Redfield ratio , C:N:P = 106:16:1*

(relative amounts of C, N, & P in phytoplankton)

Based on what we know now about marine v terrestrial residence times (and other things we know about these systems), what might we infer/guess about terrestrial vs. marine C:N:P ?

Stoichiometry (proportional elemental composition, e.g. C:N:P in biomass)

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Much more recently applied to terrestrial systems:

McGroddy et al. 2004

Forest Foliage C:N:P = 1200:28:1 (Global scale)

Litter = 3000:45:1 (resorption)

(higher C than in marine phytoplankton: reflecting importance of carbon-rich structural components – e.g. cellulose)

C. Global Change and the N-cycle


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Beyond Carbon: Scientists Worry About Nitrogen's Effects

Nir Elias/Reuters

A woman clears away algae in Quindao, China, a buildup caused by too much nitrogen in the Yellow Sea.

By RICHARD MORGAN
Published: September 1, 2008

E-MAIL
PRINT
REPRINTS

Correction Appended

TOOLIK FIELD STATION, Alaska — As Anne Giblin was lugging

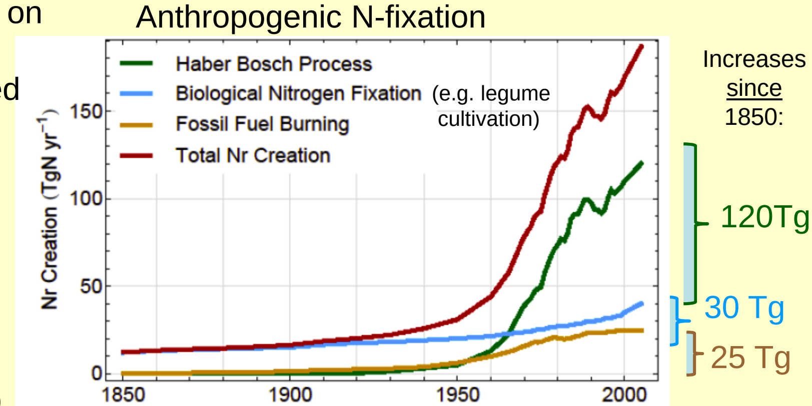
"The nitrogen dilemma is not just thinking that carbon is all that matters. But also thinking that global warming is the only environmental issue. The weakening of biodiversity, the pollution of rivers... Smog. Acid rain. Coasts. Forests. It's all nitrogen."
- Peter Vitousek

C. Global Change and the N-cycle

Human alteration of terrestrial N-cycle is LARGE (> 100% in fixation relative to the terrestrial background rate of 50-100 Tg N/yr):

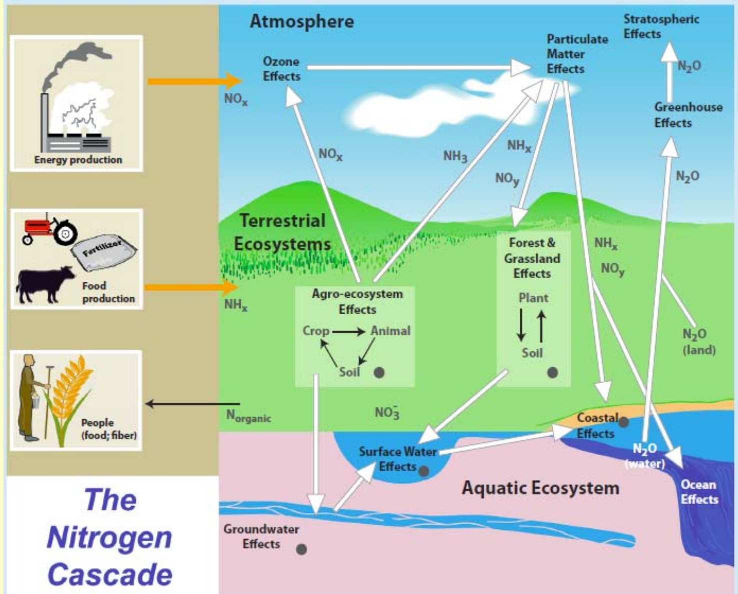
No place on earth unaffected by this

Anthropogenic N-fixation

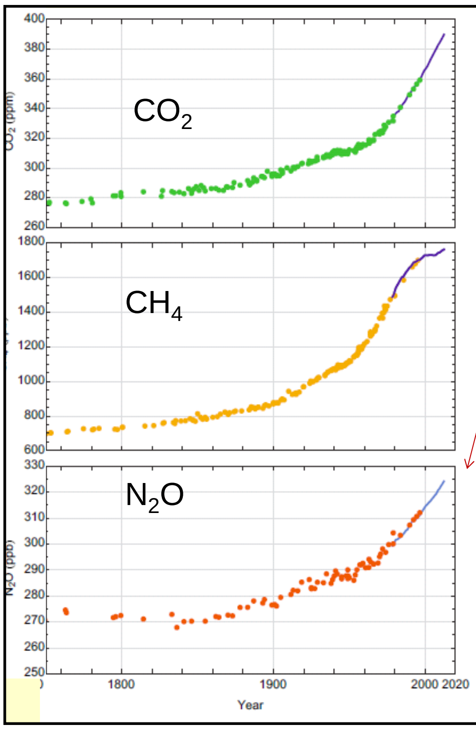


Increases since 1850:

IPCC AR5 (2013)



Box 6.2, Figure 2 | Illustration of the nitrogen cascade showing the sequential effects that a single atom of nitrogen in its various molecular forms can have in various reservoirs after it has been converted from nonreactive N_2 to a reactive form by energy and food production (orange arrows). Once created the reactive nitrogen has the potential to continue to contribute to impacts until it is converted back to N_2. The small black circle indicates that there is the potential for denitrification to occur within that reservoir. NH_3 = ammonia; NH_x = ammonia plus ammonium; NO_3^- = nitrate; NO_x = nitrogen oxides; NO_y = NO_x and other combinations of nitrogen and oxygen (except N_2O); N_2O = nitrous oxide. (Adapted with permission from the GEO Yearbook 2003, United Nations Environmental Programme (UNEP), 2004 which was based on Galloway et al., 2003.)



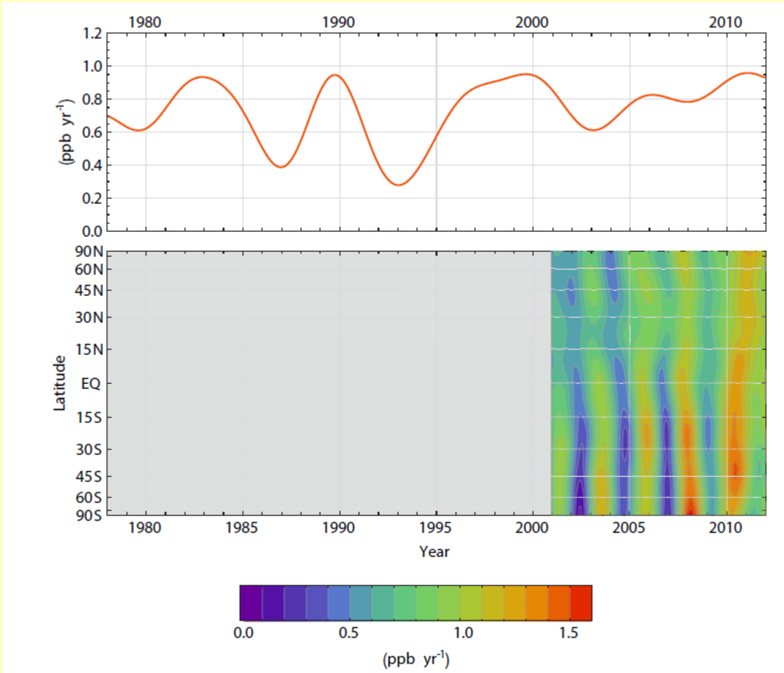
II. Nitrous Oxide Budget

What is causing the increase in atmospheric N_2O?

N_2O a powerful greenhouse gas, and contributor to O_3 depletion):
- Increasing 0.25% per year
- Residence time: 120 years
- Greenhouse effectiveness: 300 x CO_2

Sources:
- Natural: microbial denitrification in soils and oceans;
- Anthropogenic: fertilizer production (enhances denitrification), fossil fuel and biomass burning (combustion byproduct).

Sink:
- Photolysis by UV light in stratosphere



2006 N2O budget

(IPCC 2013)

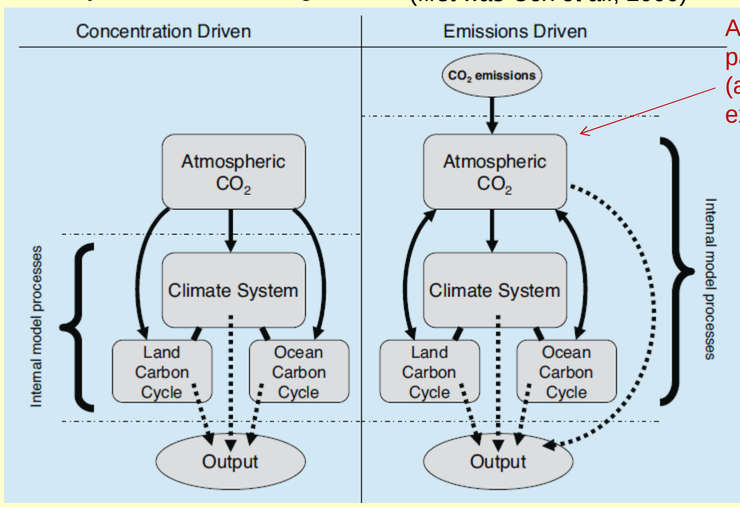
SECTION 2 (N_2O)	AR5 (2006/2011)	2011 (top-down)
Anthropogenic sources		
Fossil fuel combustion and industrial processes	0.7 (0.2–1.8)[a]	
Agriculture	4.1 (1.7–4.8)[b]	
Biomass and biofuel burning	0.7(0.2–1.0)[a]	
Human excreta	0.2 (0.1–0.3)[a]	
Rivers, estuaries, coastal zones	0.6 (0.1–2.9)[c]	
Atmospheric deposition on land	0.4 (0.3–0.9)[d]	
Atmospheric deposition on ocean	0.2 (0.1–0.4)[e]	
Surface sink	−0.01 (0– -1)[f]	
Total anthropogenic sources	**6.9 (2.7–11.1)**	**6.7 (+/- 1.3)**
Natural sources[a]		
Soils under natural vegetation	6.6 (3.3–9.0)	
Oceans	3.8(1.8–9.4)	
Lightning	—	
Atmospheric chemistry	0.6 (0.3–1.2)	
Total natural sources	**11.0 (5.4–19.6)**	**9.1 (+/- 1.0)**
Total natural + anthropogenic sources	**17.9 (8.1–30.7)**	**15.8 (+/- 1.0)**
Stratospheric sink	**14.3 (4.3–27.2)[g]**	**11.9 (+/- 0.9)**
Observed growth rate	**3.61 (3.5–3.8)[h]**	**4.0 (+/- 0.5)**

Note: microbial!

III. Modeling C-Cycle feedback and the effects thereon of N-cycling

Old way of climate modeling

New way of climate modeling
(first was Cox et al., 2000)



Atmospheric CO2 part of the model (as opposed to external driver)

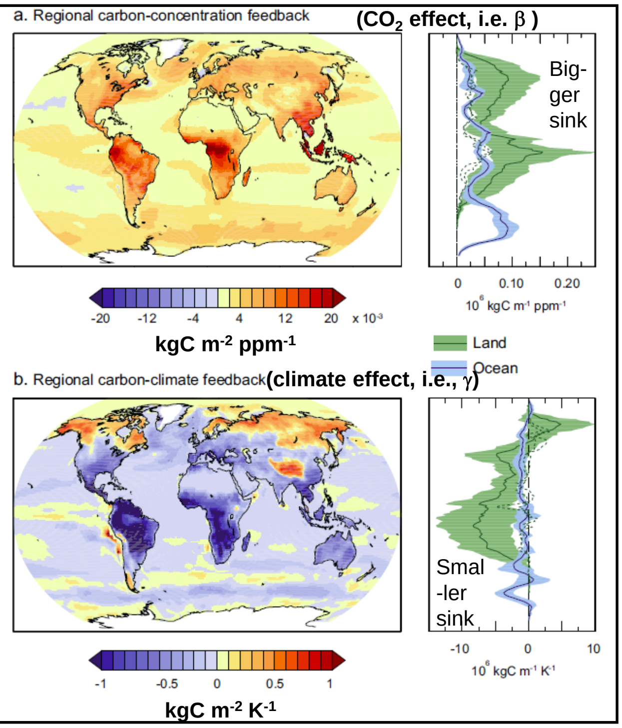
III. Modeling C-Cycle feedback and the effects thereon of N-cycling

Configuration of simulations for partitioning carbon-climate feedback effects

		CO_2 input to radiation scheme	CO_2 input to carbon-cycle scheme	Reason
	Fully coupled			Simulates the fully coupled system
effects of ↑ CO_2 (not including climate)	'Biogeochemically' coupled 'esmFixClim'			Isolates the carbon-cycle response to CO_2 (β) for land and oceans
effects of climate change (not including direct CO_2)	Radiatively coupled 'esmFdbk'			Isolates carbon-cycle response to climate change (γ) for land and for oceans

Model-predicted changes in the fate of anthropogenic CO2 with climate change

(a. CO_2 effect,
b. Climate effect)



IPCC (2013), Ch. 6

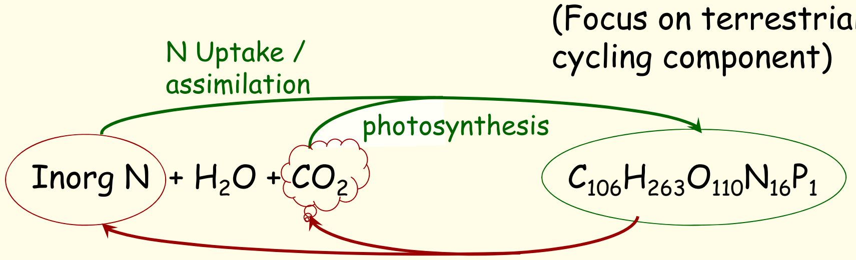
Nitrogen and Carbon dynamics are coupled

Global warming may **accelerate** respiration/mineralization of organic matter,

→ **releasing CO_2** (a positive feedback to warming), but also

→ **releasing inorganic N**, increasing the potential for more carbon uptake (a negative feedback to warming)

Integrated N-C cycle
(Focus on terrestrial cycling component)



"organic N" and "organic C" are the same stuff!