The global Nitrogen cycle at the beginning of the 21st century

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CAPER March 2013

OBSERVATIONS

- There are no mechanistic global N models integrating atmos, terrest and marine systems
- The three Nr communities (atmos, terrestrial, marine) operate independently.
- Some aspects of the global N cycle are simulated in mechanistic detail (atmos chem of NOy, ozone) fully coupled to climate models
- Terrestrial N cycling at site, catchment and regional scale is in progress…(also marine)

OUTLINE

- This synthesis is the result of a Royal Society discussion meeting Dec 2011
- A global budget for ~2010
- Anthropogenic and natural contributions
- Processing Nr in the atmosphere, terrestrial ecosystems and the oceans
- European Nitrogen
- How will the global N budget change through the 21st Century?
- Where is all the N we have fixed?

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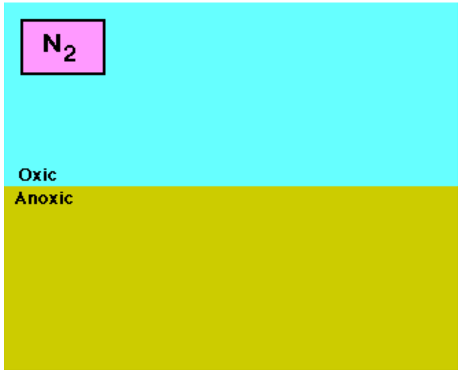
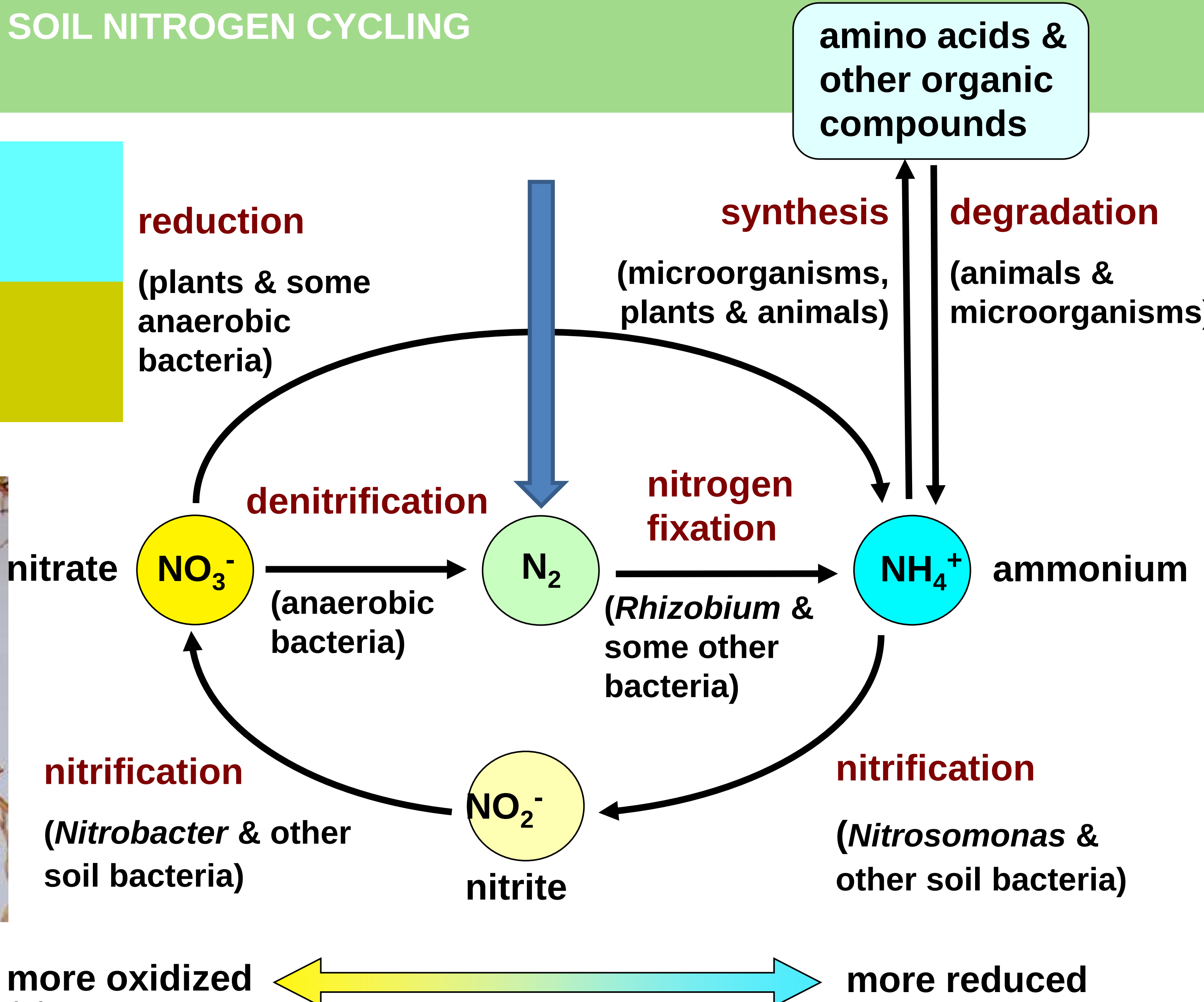
SOIL NITROGEN CYCLING





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Pre- industrial N fixation…….a reference

Pre-industrial terrestrial biological Nitrogen fixation 58 Tg-N y^{-1}

Marine BNF 140 Tg-N y^{-1}

Lightning fixation of nitrogen 5 Tg-N y^{-1}

……………………………………………………………………..

Total Global natural sources of Nr 203 Tg-N y^{-1}

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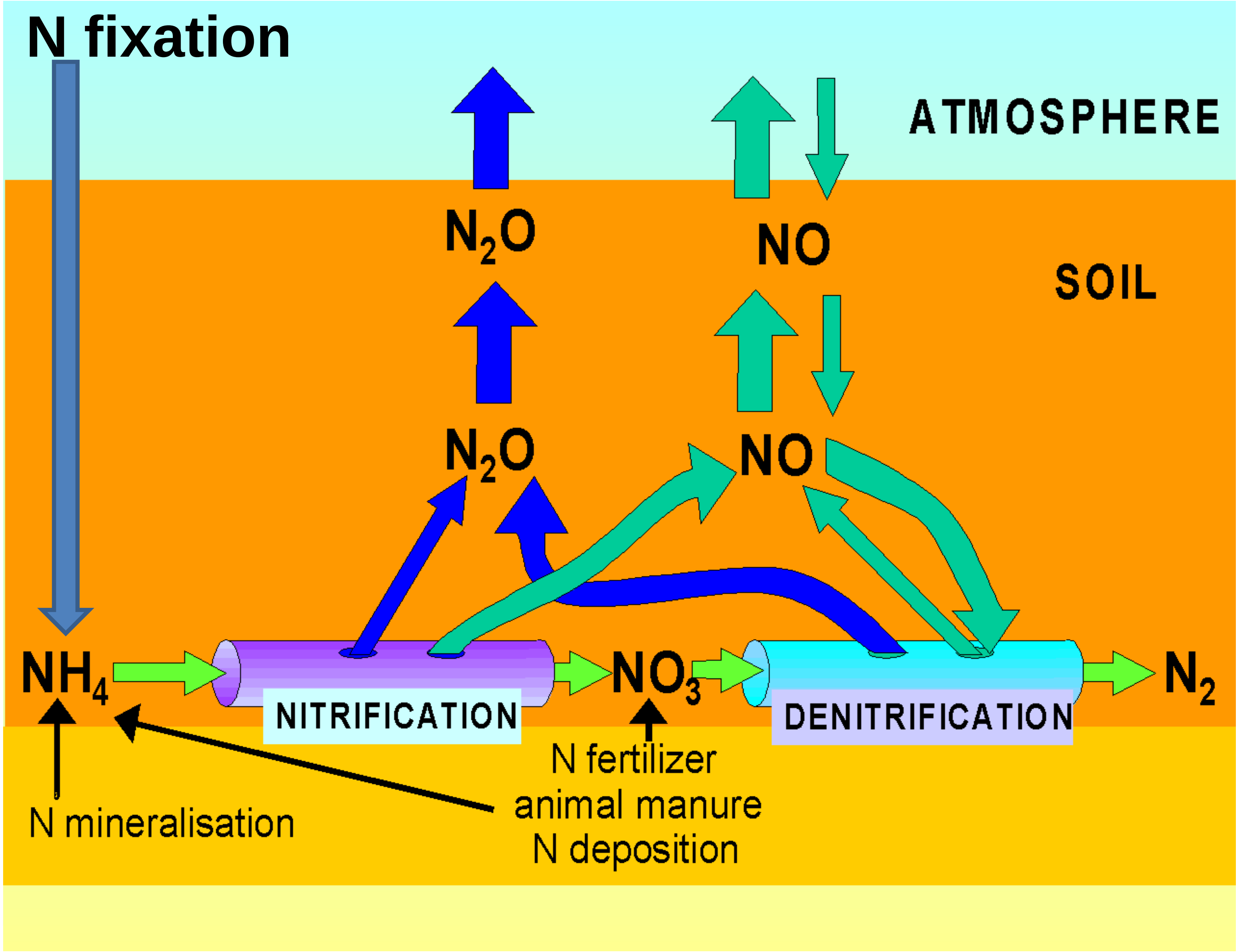
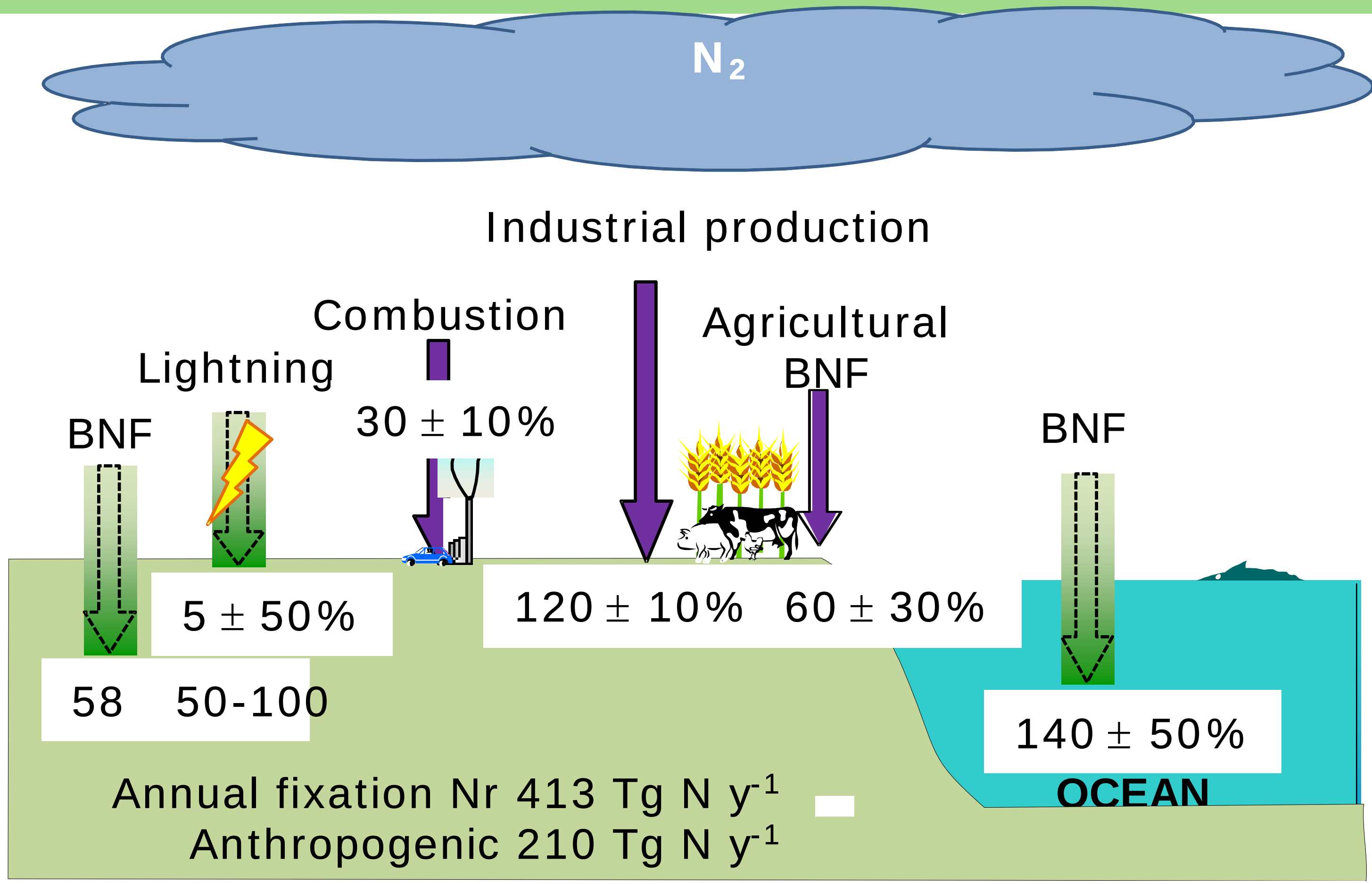

N fixation
ATMOSPHERE
SOIL
N2O
NO
N2O
NO
NH4
NITRIFICATION
NO3
DENITRIFICATION
N2
N fertilizer
animal manure
N deposition
N mineralisation

Nitrogen fixation 2010



BNF – Biological Nitrogen Fixation

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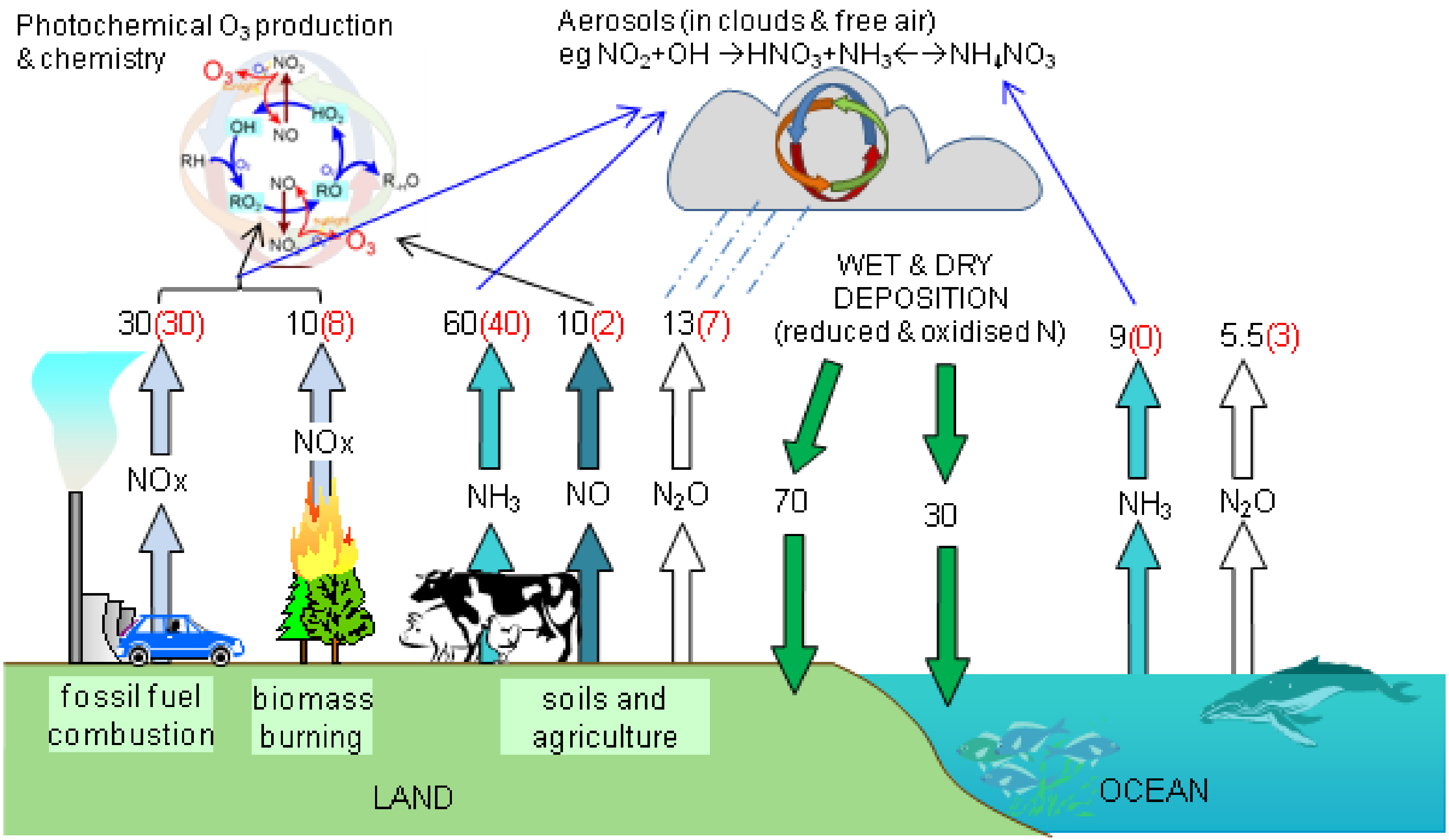
WE NOW HAVE COMPLEX CTM (⟶EARTH SYSTEM MODELS)

- Emissions
- Atmospheric transport and diffusion
- Chemical transformation
- Deposition (wet and dry) of most compounds
- Ecosystem specific parameters

- So we are getting there
- Earth system models have representations of both oxidized and reduced nitrogen
- And are vital to explore climate –nitrogen cycle interactions

ATMOSPHERIC PROCESSING



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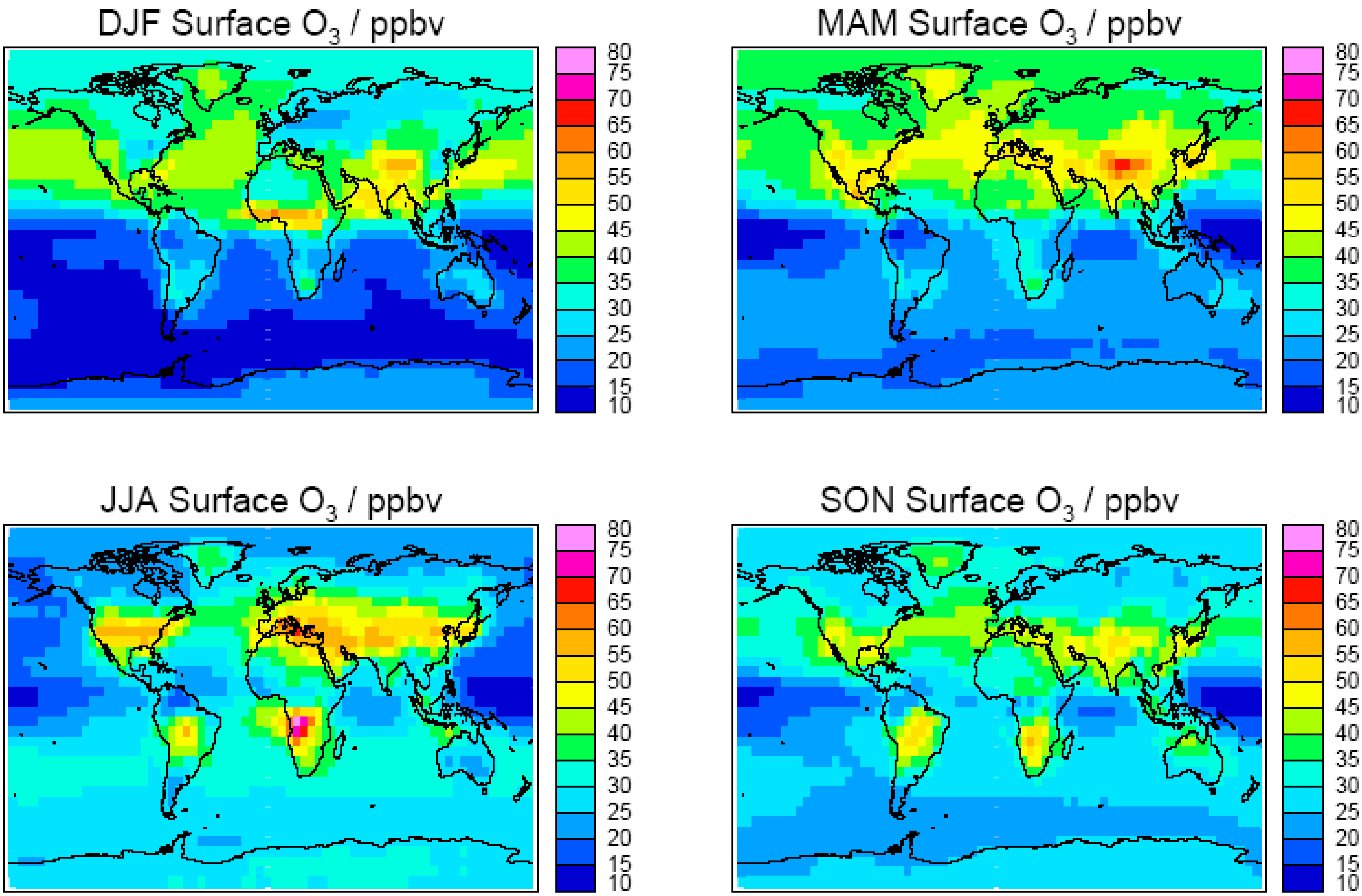
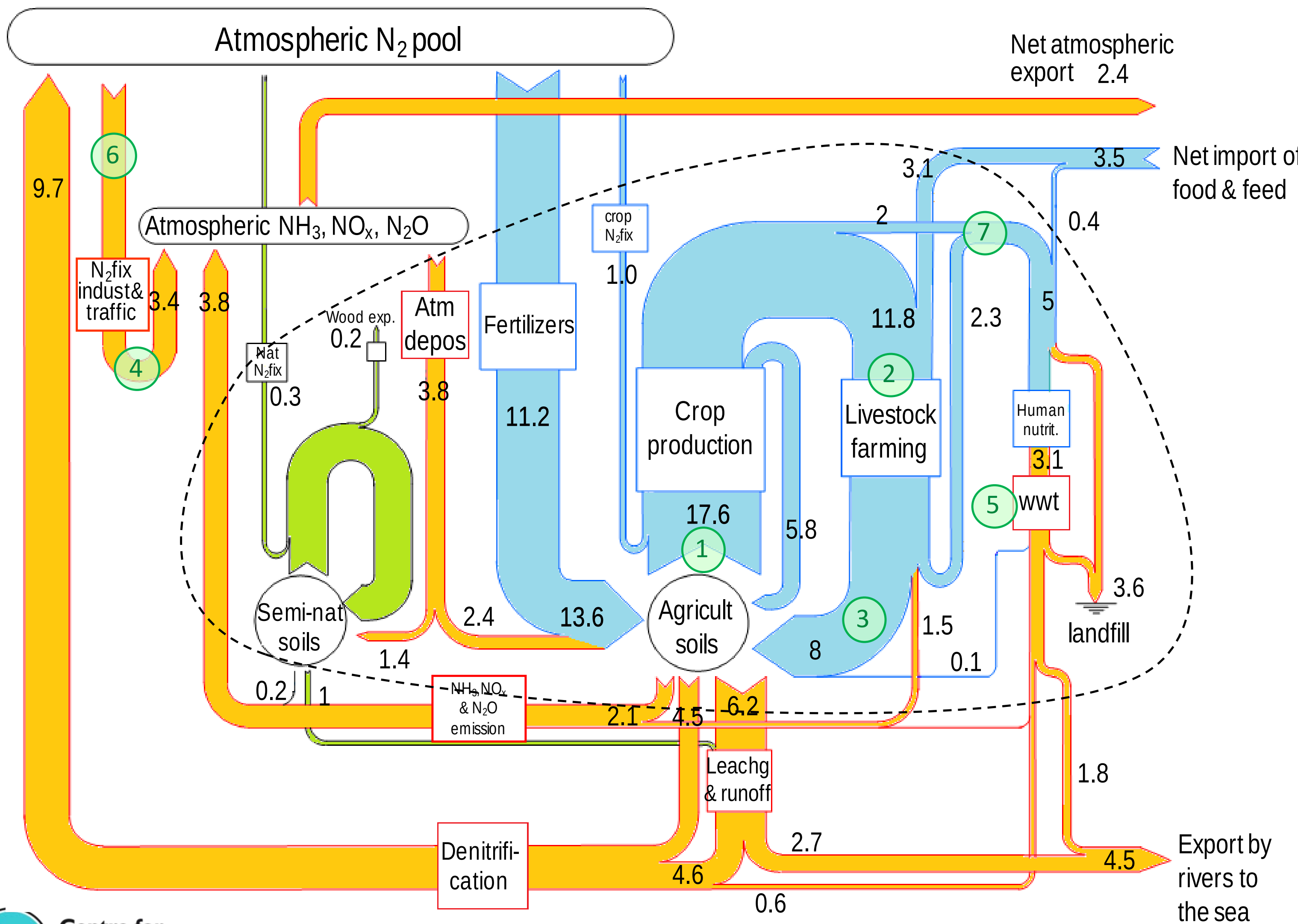
SEASONAL VARIATION OF SURFACE OZONE



Ensemble mean of 26 ACCENT Photocomp models

Terrestrial Nr cycling in the EU 27 (from ENA)



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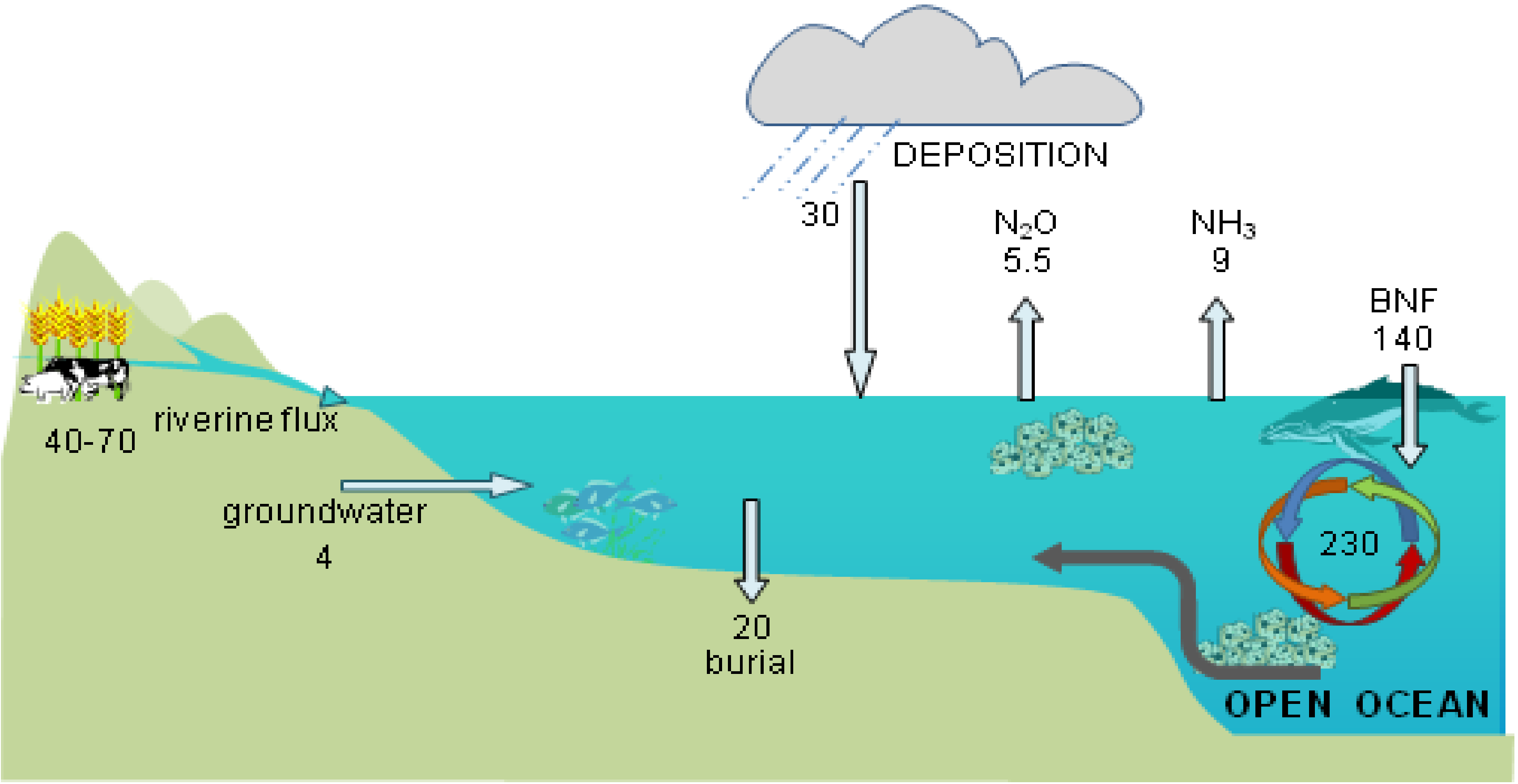
Marine Nr cycle (Voss)



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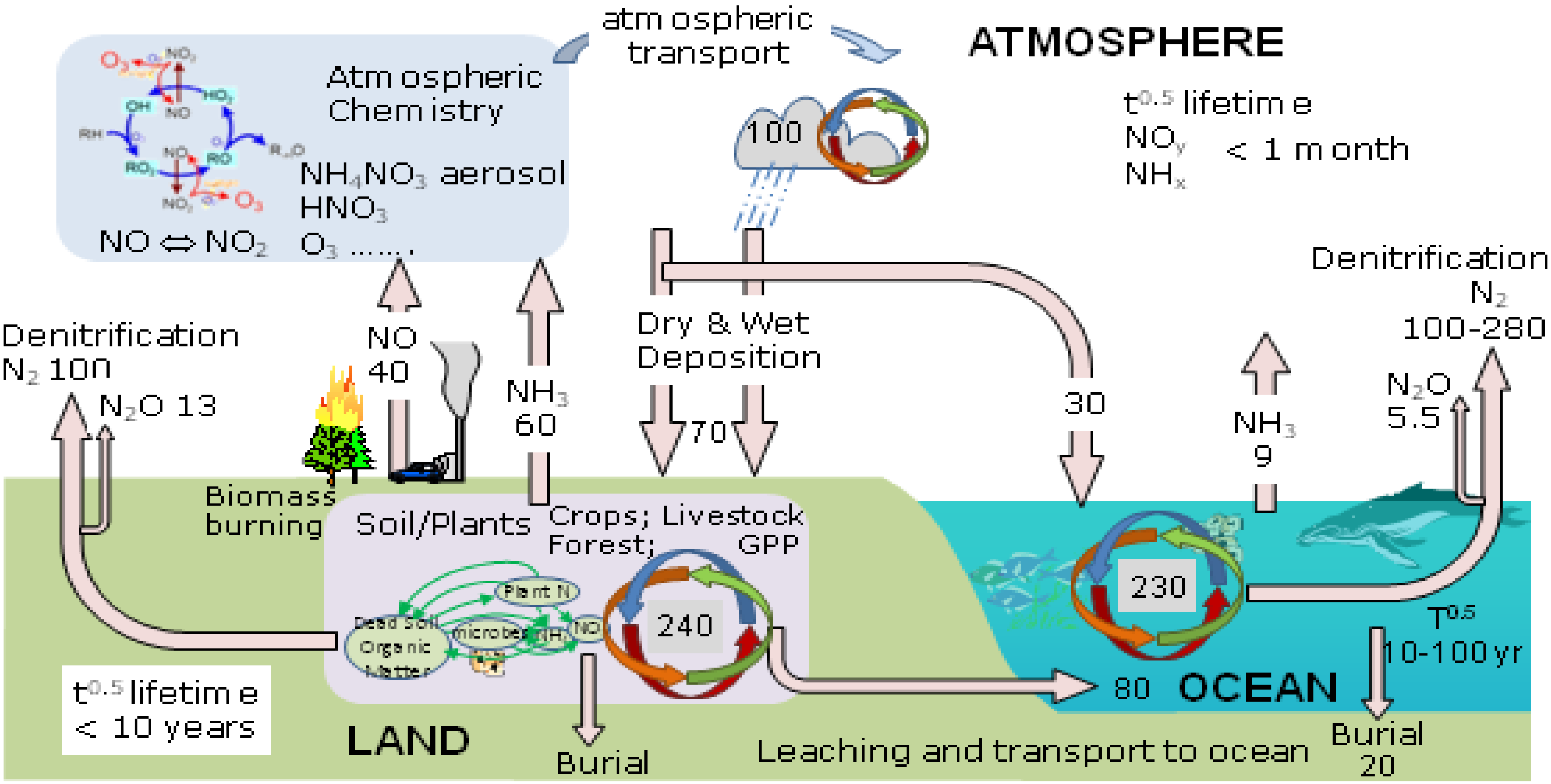
PROCESSING REACTIVE NITROGEN



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Nitrogen cascade

Transformation	*Pathway*	*Environmental Effect*
N_2 Fixation – Haber-Bosch Process N_2 –> NH_3	Industry	Energy intensive process, production of CO_2 plus all the consequences of the N_r as it cascades through soils, the atmosphere and aqueous phases
N Fertilizer on crops	Agricultural lands	Provision of food for human consumption
NH_4 nitrified to –> NO_3 NO in soil –>Atmosphere Oxidation of NO –> NO_2 –> HNO_3	NO emission from soil to atmosphere and ozone production during VOC degradation	Ozone effects on vegetation or human health (Royal Society 2008, Sitch et al 2007)
Aerosol formation, HNO_3 –>NO_3	In atmosphere	Planetary albedo, human health (Shindell et al 2012)
Wet +dry deposition NO_3 to soil –> vegetation NO_3 –>R-NH_2	Removal from atmosphere and transfer to plant biomass	Eutrophication ,acidification (Stevens et al 2011)
Consumption by herbivores – excreted as urea R-NH_2 –>$CO(NH_2)_2$	plant biomass –>animal protein –>excreted and returned to soil	Eutrophication x (Stevens et al 2011)
Urea converted to NH_3 in soil and released to atmosphere	Soil to atmosphere flux of NH_3	Eutrophication
NH_3/NH_4 uptake by vegetation	Removal from atmosphere by dry deposition to vegetation	Eutrophication
Decomposition R-NH_3 -> NH_4	Vegetation to soil	Eutrophication
NH_4 nitrified to NO_3 transferred to river/estuary/open ocean	Soil to ground water –>river –> ocean	Eutrophication
Ocean uptake in phyto/zooplankton	Shelf seas to open ocean	Eutrophication
Denitrification in ocean sediments NO_3 –> N_2	Returns to atmosphere as N_2 and N_2O	climate change

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Where has the Nr gone?

Terrestrial, cryosphere and ocean storage
Denitrification back to the Atmospheric N reservoir
How well do we know the average lifetime within the Nr stores?

N ACCUMULATION

- Atmosphere N_2O
- Terrestrial ecosystems OM
- Aquifers NO_3
- Ocean column OM and NO_3
- Ocean floor OM
- Cryosphere NO_3

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OM = Organic Matter

2000 TO 2100 TRENDS (WHAT IS THE FUTURE?)

Two important issues:

1. ‘Best’ estimates of projected emissions of NO_x ,NH_3, and N_2O
2. Influence of climate change on the N cycle (emissions).

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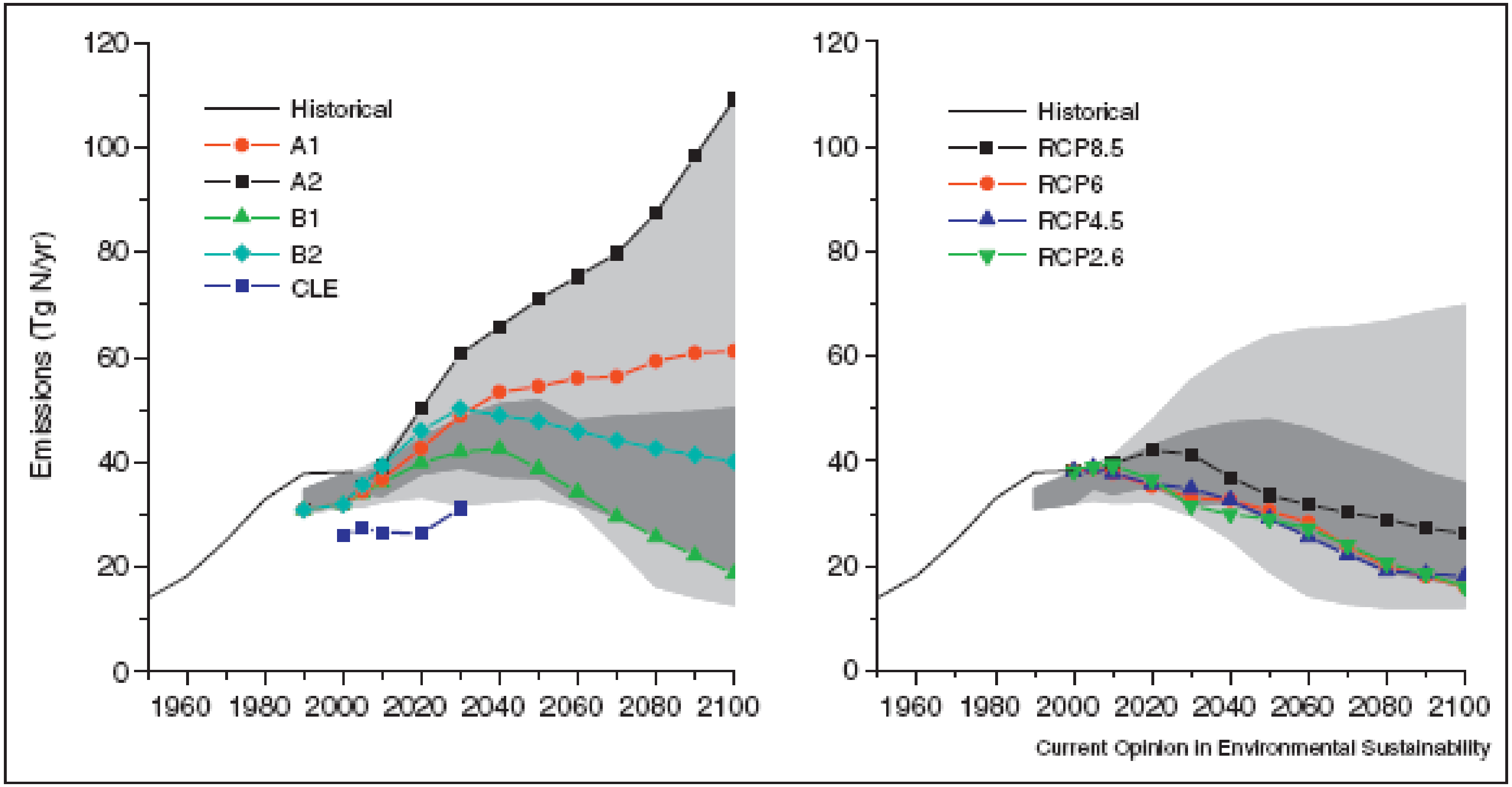
NO_x EMISSIONS (VAN VUUREN et al 2011)



Future NO_x emissions according to various scenarios (light grey area covers the 10–90th percentile; dark grey area the 25–75th percentile). The right hand panel only includes scenarios without climate policy (22 scenarios); the left hand panel includes the full set of scenarios (with and without climate policy) (40 scenarios). The graph also shows the scenarios of the IPCC-SRES set [37], the IIASA-CLE scenario (both sets do not include climate policy) [26] and the RCPs (including climate policy) [40].

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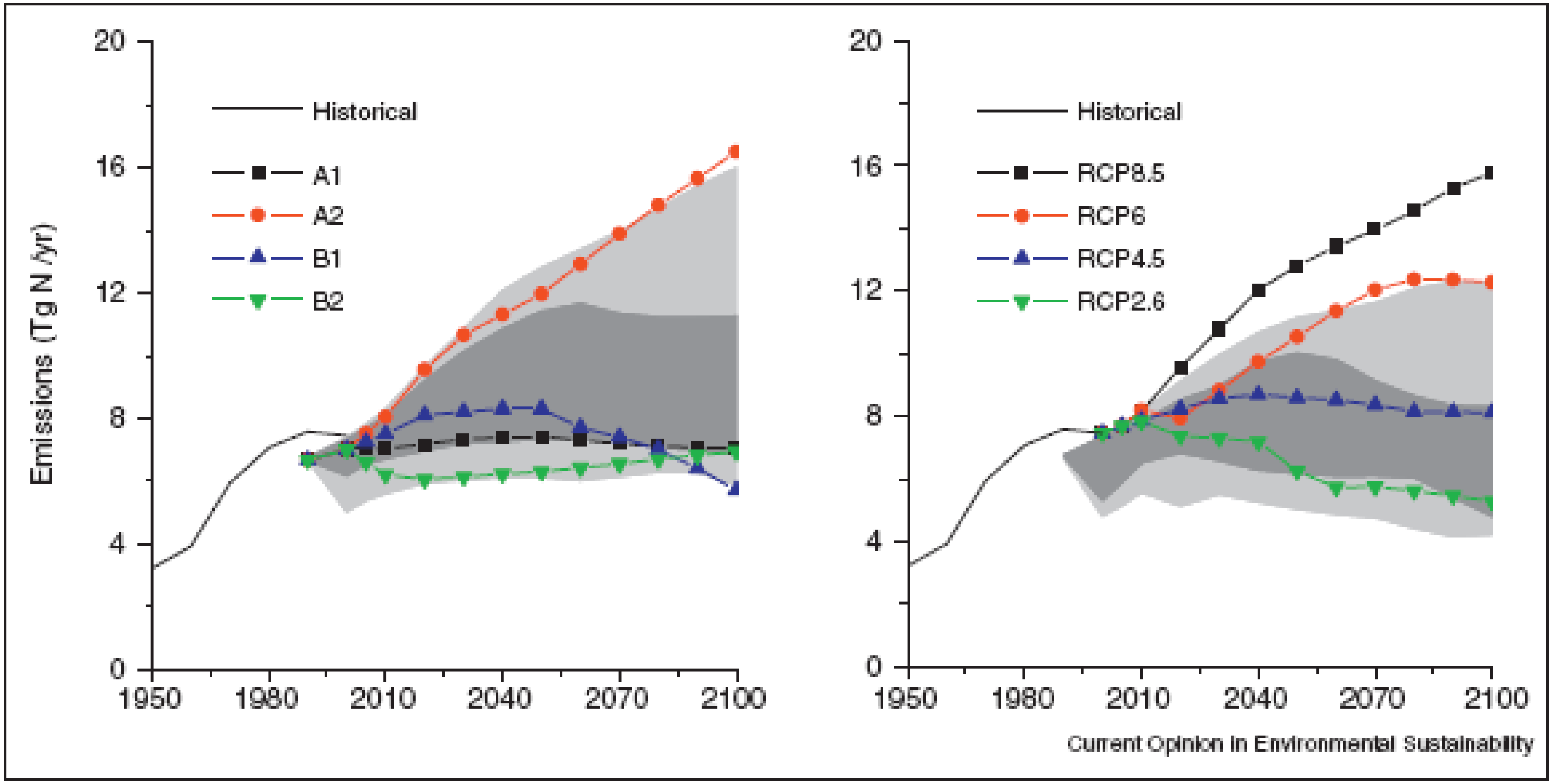
N_2O EMISSIONS 1950-2100 (VAN VUUREN et al 2011)



Future N_2O emissions according to various scenarios (light grey area covers the 10–90th percentile; dark grey area the 25–75th percentile). The right hand panel only includes scenarios without climate policy; the left hand panel includes the full set of scenarios (with and without climate policy). In addition, the graph shows the scenarios of the IPCC-SRES set and the RCPs (including climate policy) (sources see Figure 1).

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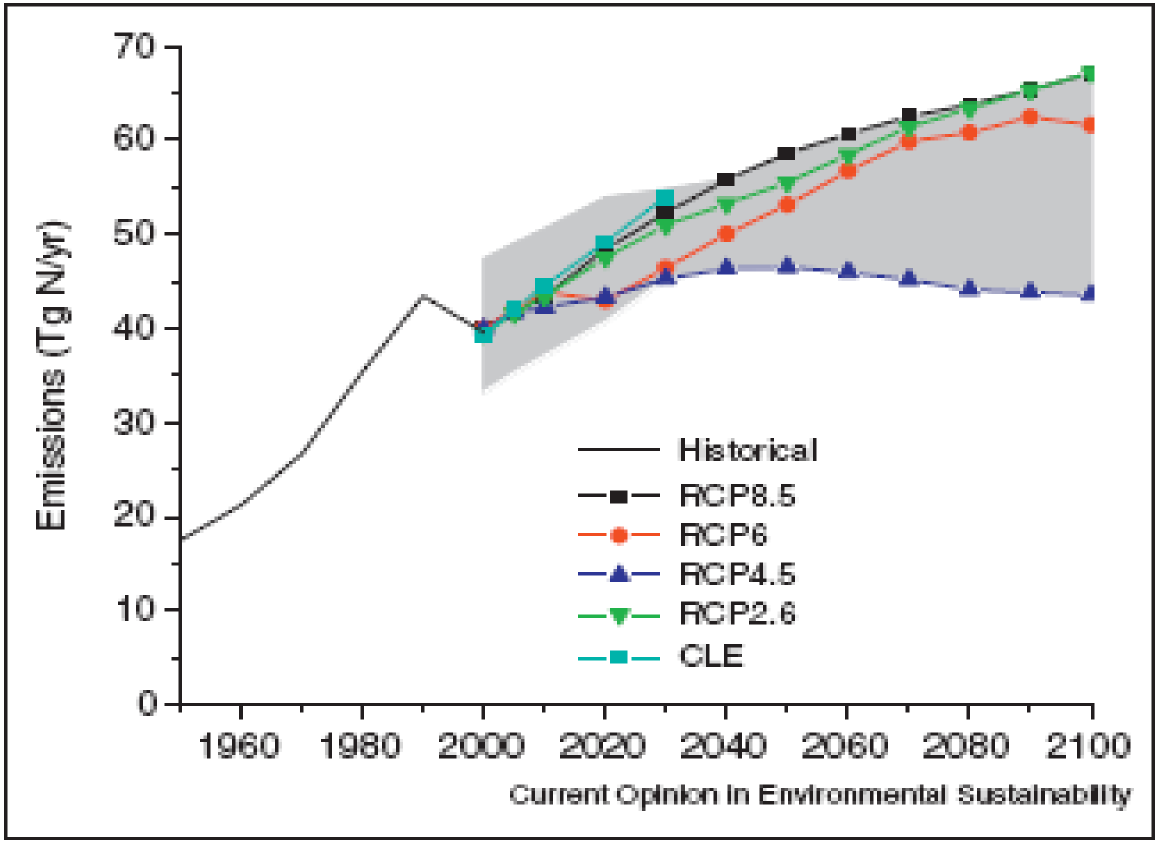
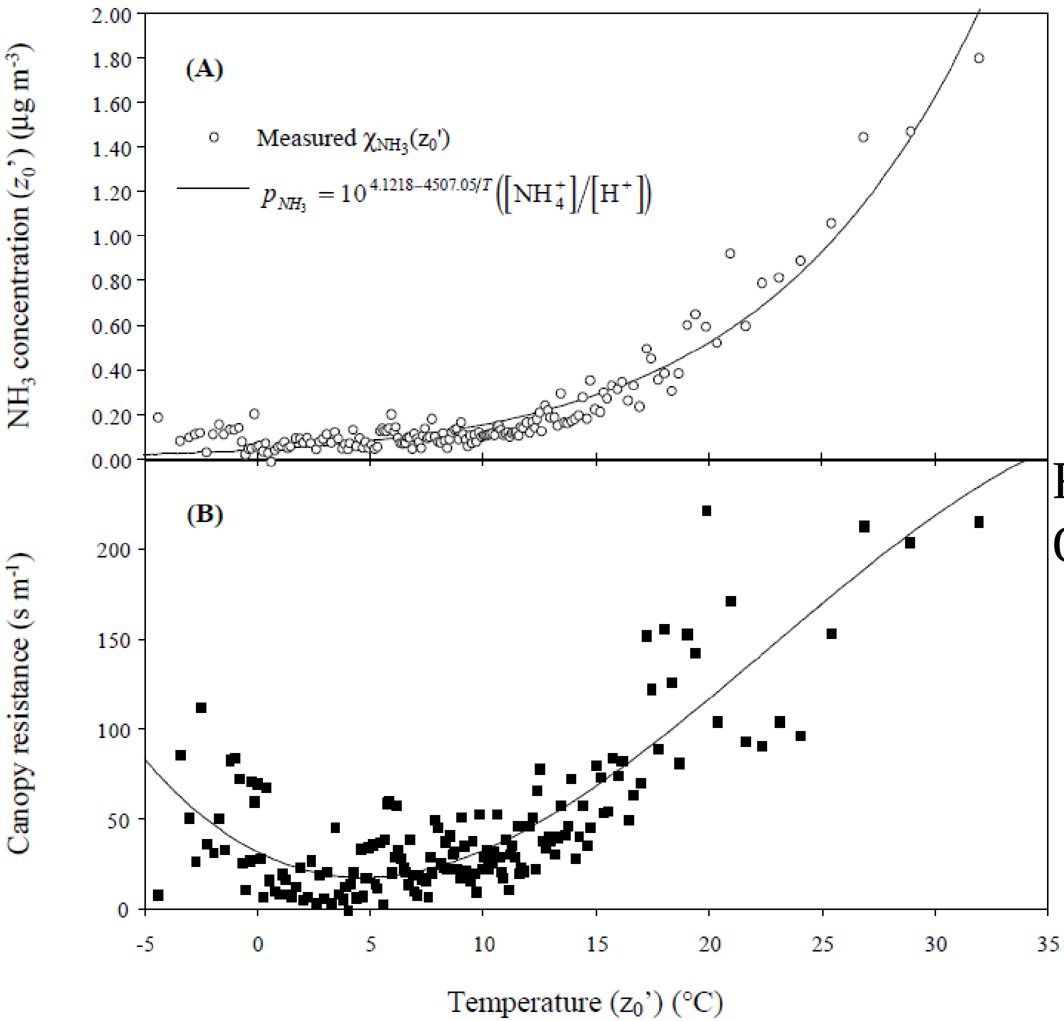
VAN VUUREN et al 2011



Future NH_3 emissions according to various scenarios (light grey area covers the 10–90th percentile; dark grey area the 25–75th percentile). *Source*: CLE [26] and RCP scenarios and the underlying baselines [40].

Temperature response of NH_3 emission



Flechard and Fowler, QJRMS, 1998

Figure 5.10. Temperature response of A- the NH_3 canopy compensation point $\chi_c = \chi_{NH_3}(z_0')$ and B- the canopy resistance $R_c(NH_3)$ at Auchencorth Moss, Feb.-95 - Feb.-96. The fitted curve in the concentration graph is the theoretical temperature response of air concentration of NH_3 in equilibrium with a solution for which the ammonium/hydronium molar concentration ratio is 132.1.

TRENDS 2000 - 2100

1. Emissions of NO_x are projected to increase from current 40 Tg-N per year by 10-20% and then decline remaining in the range 30-60 Tg-N
2. Projected emissions of N_2O are likely to remain stable or increase

3. Projected emissions of NH_3 likely to increase under most scenarios

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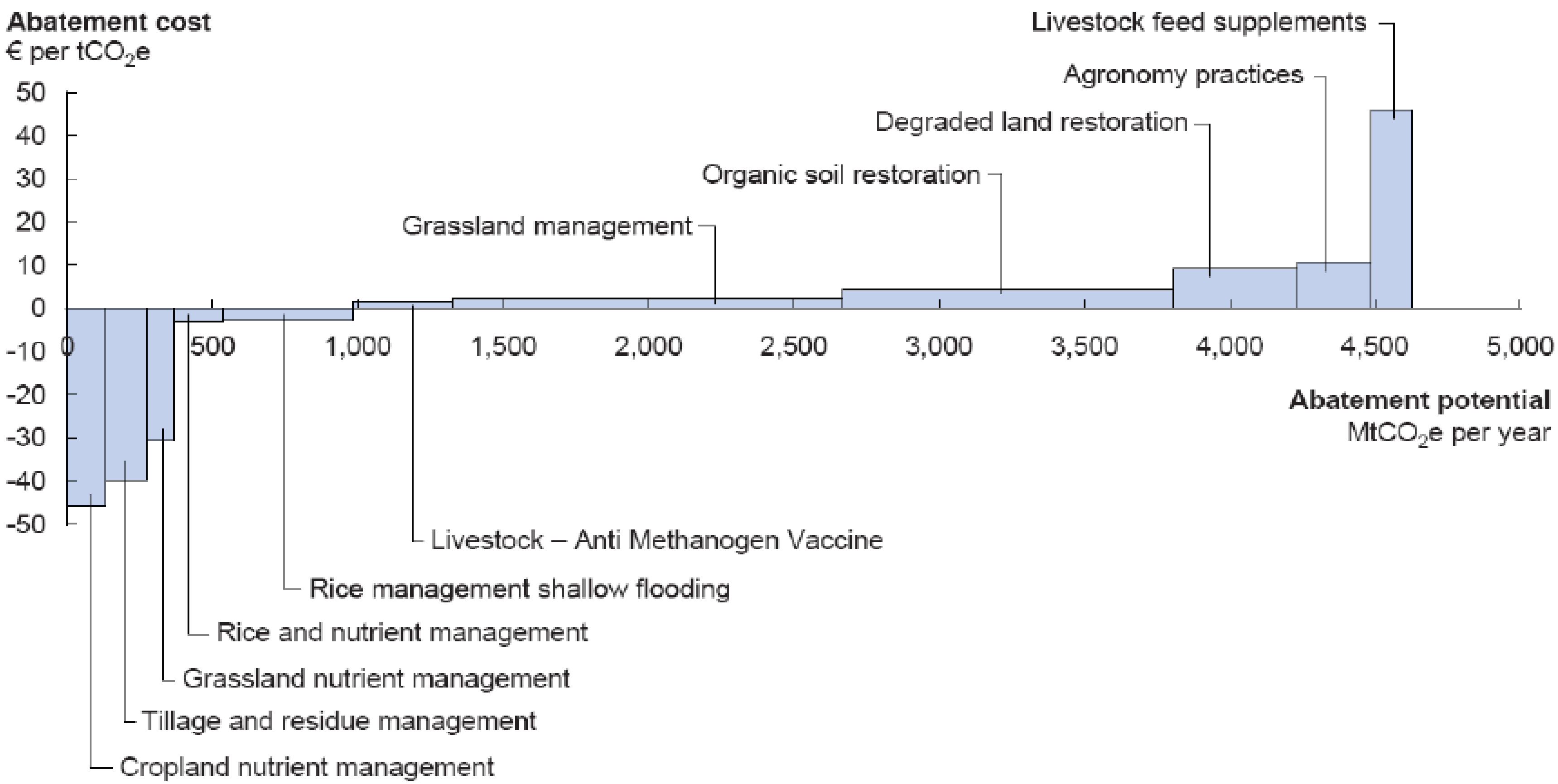
GLOBAL GHG ABATEMENT COST CURVE FOR THE AGRICULTURE SECTOR, 2030



Source: Global GHG Abatement Cost Curve v2.0.

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Conclusions

- Human activity is responsible for about half of all N fixed annually

- Most N inputs to terrestrial and marine ecosystems is returned to the atmosphere as N_2 quite rapidly, but there are important reservoirs of Nr which pose a threat (climate, BD, HH) which are poorly quantified (Aquifers, terrestrial and ocean zones of OM accumulation)

- Validation methods are developing rapidly, but the current global N budget is not significantly constrained by measurements
-

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Conclusions

- The global magnitudes of N_2 fixation and denitrification to N_2 remain very uncertain

- The sensitivity of components of the N cycle to climate change has not yet been systematically tested. However, NH_3 emission and deposition are very sensitive to climate change, and NH3, emissions are likely to increase substantially in response to temperature increases in the range 2 to 5 deg C
- N Inputs of Nr to terrestrial ecosystems are unlikely to decline substantially in the coming decades

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