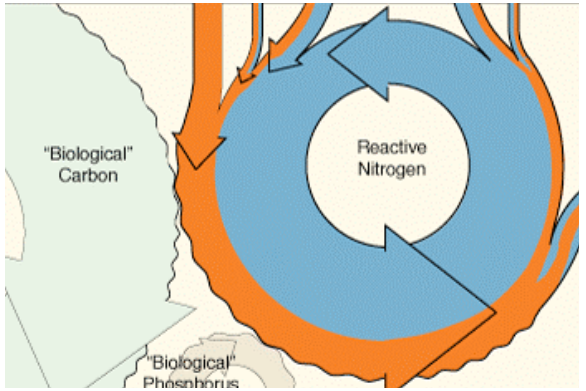



# Connecting the wheels - on the role of nitrogen for the global carbon cycle

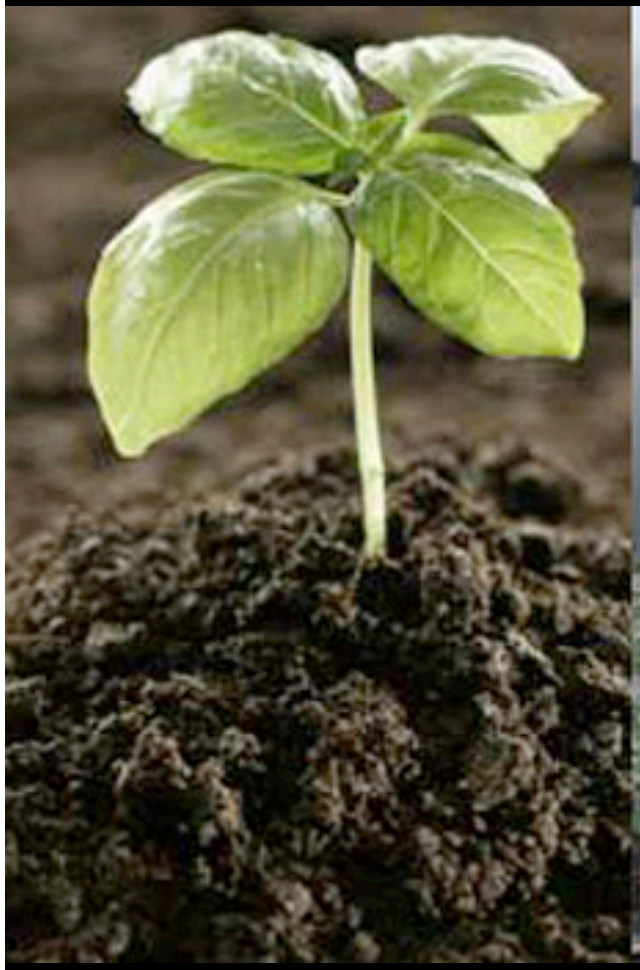
**Nicolas Gruber**

*Environmental Physics, ETH Zürich, Switzerland.*

*Acknowledgments:*

Jim Galloway, Xin Jin, Peter Thornton

# Human perturbations of the nitrogen and carbon cycles

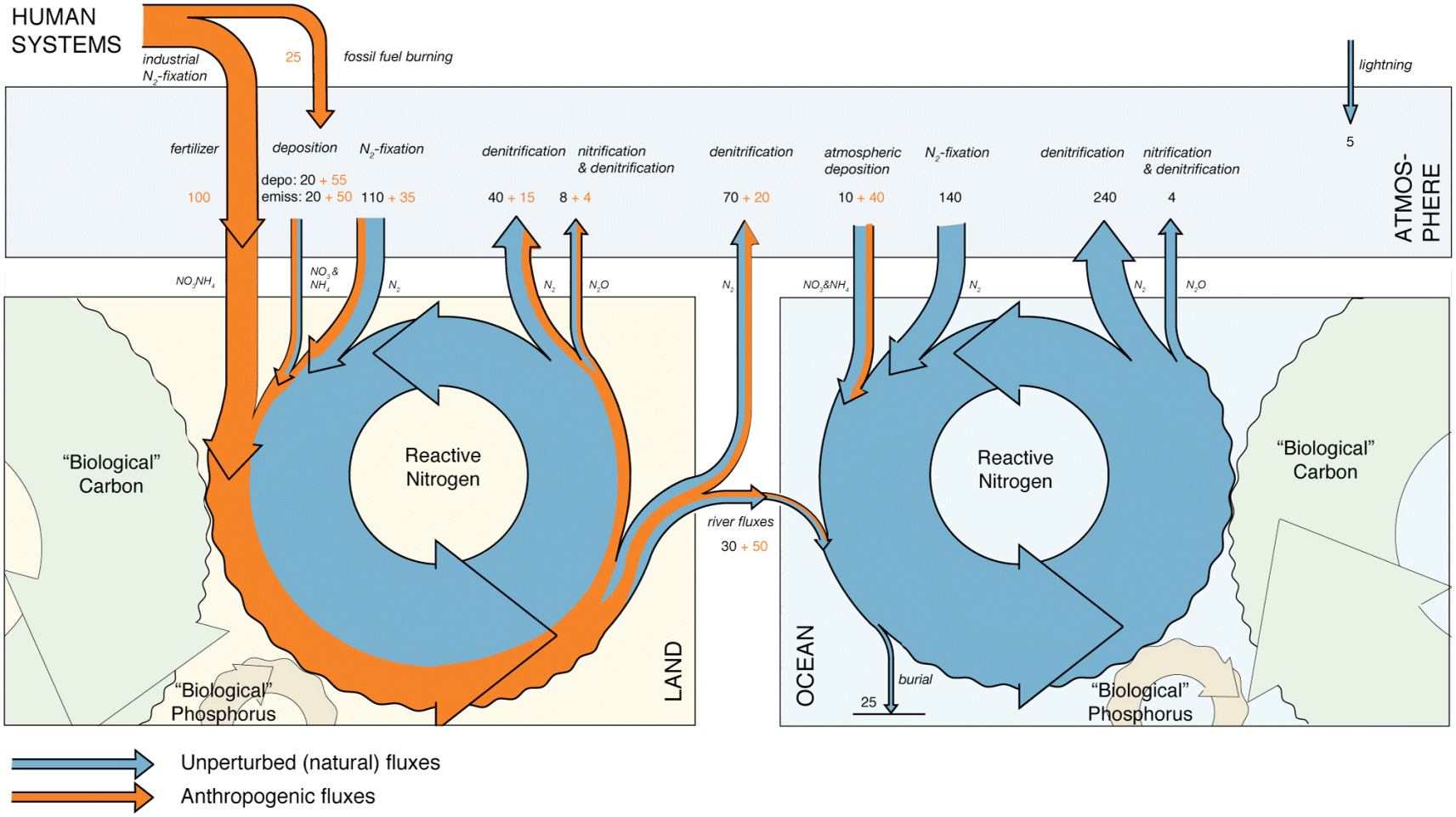


*Fertilization*

*Eutrophication*

*Fossil-fuel burning*

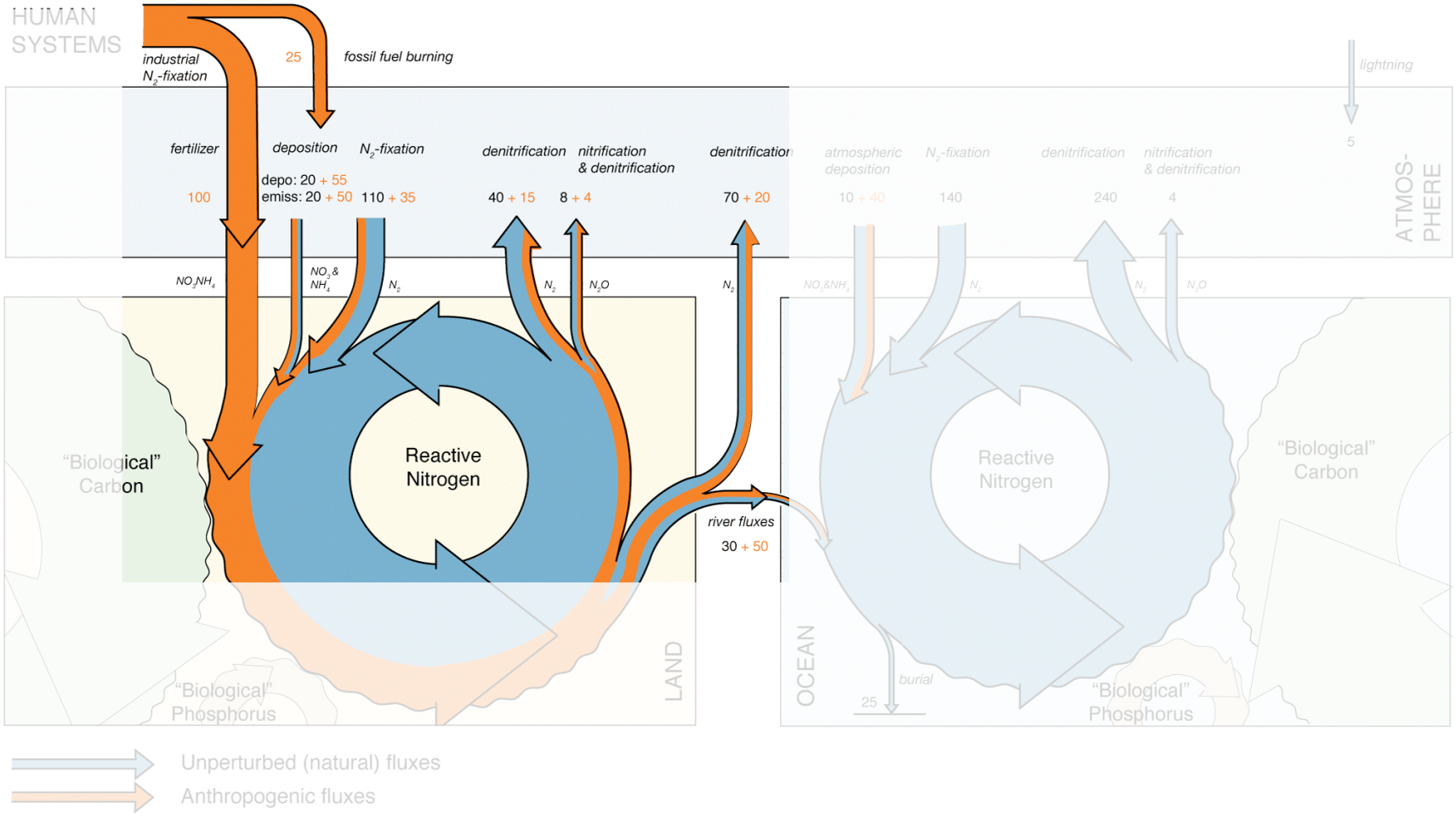
# The global nitrogen cycle and its human perturbation




*The global nitrogen cycle is very dynamic, with many source and sink terms, leading to a relatively short residence time in the land and ocean systems.*

*Gruber and Galloway, 2008*

# The global nitrogen cycle and its human perturbation

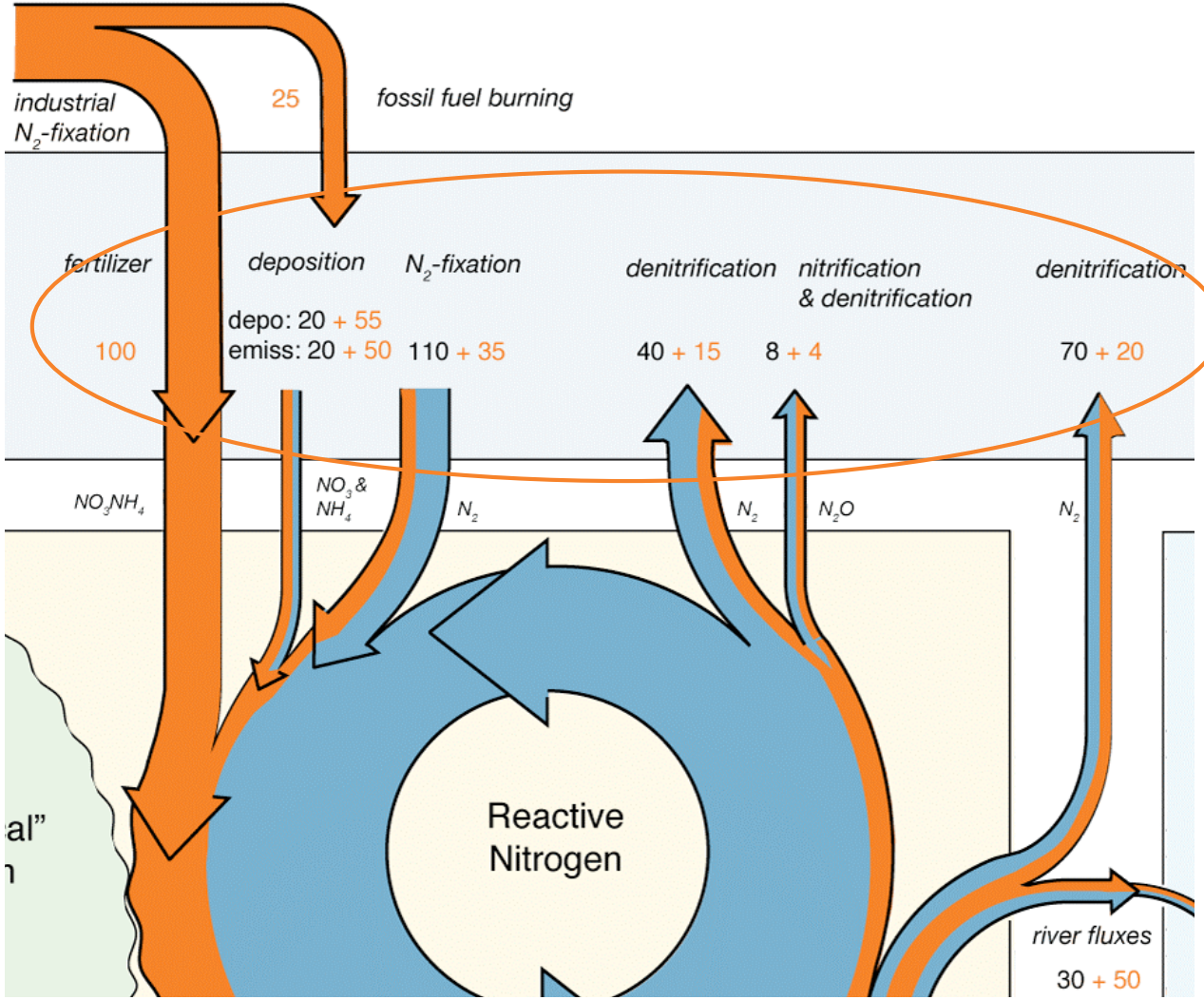



*The global nitrogen cycle is very dynamic, with many source and sink terms, leading to a relatively short residence time in the land and ocean systems.*

*Gruber and Galloway, 2008*

# Anthropogenic perturbation of the global N-cycle

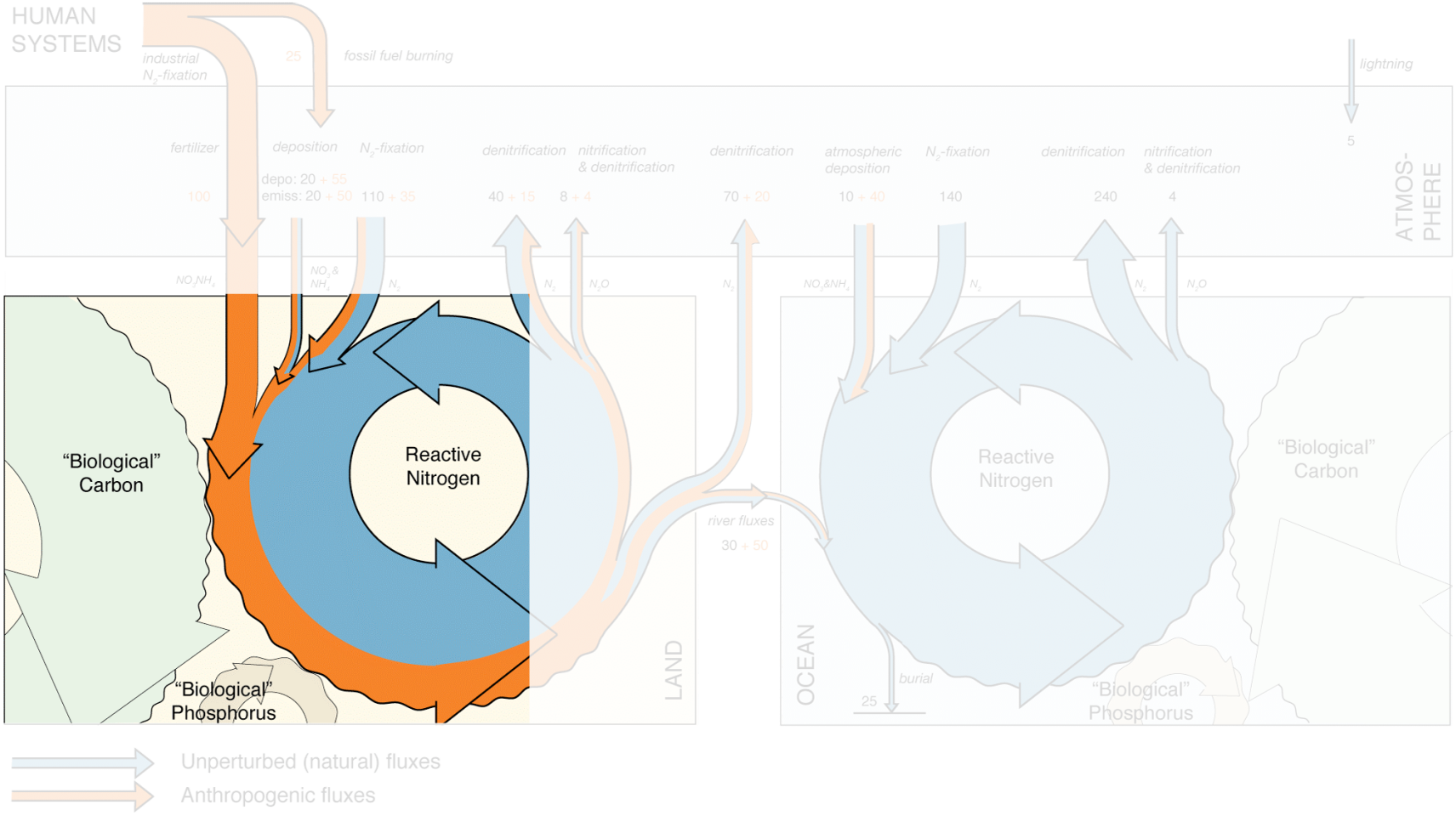
Human systems




*Industrial $N_2$-fixation and fossil fuel burning has more than doubled the input of reactive nitrogen into land ecosystems.*

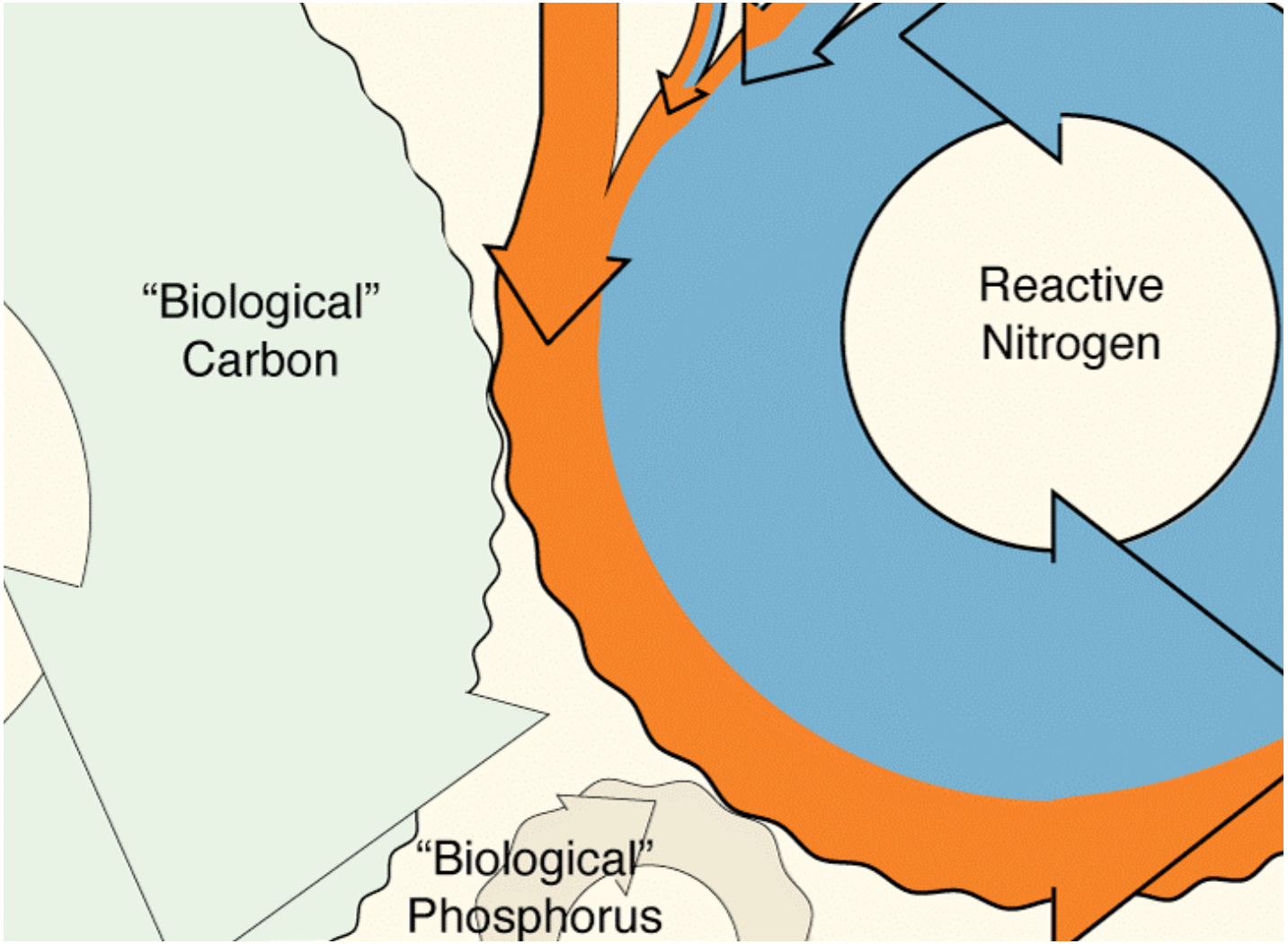
*Gruber and Galloway, 2008*

# The global nitrogen cycle and its human perturbation




*Gruber and Galloway, 2008*

# Connecting the wheels




*The cycling of reactive nitrogen and that of carbon are tightly connected. Changes in one invariably lead to changes in the other.*

*Gruber and Galloway, 2008*

# Outline

1. Introduction: The global N-cycle
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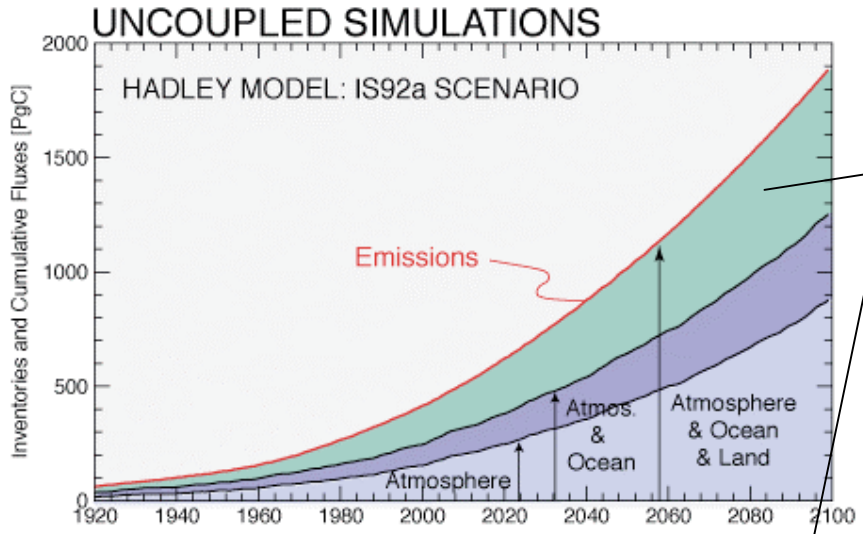
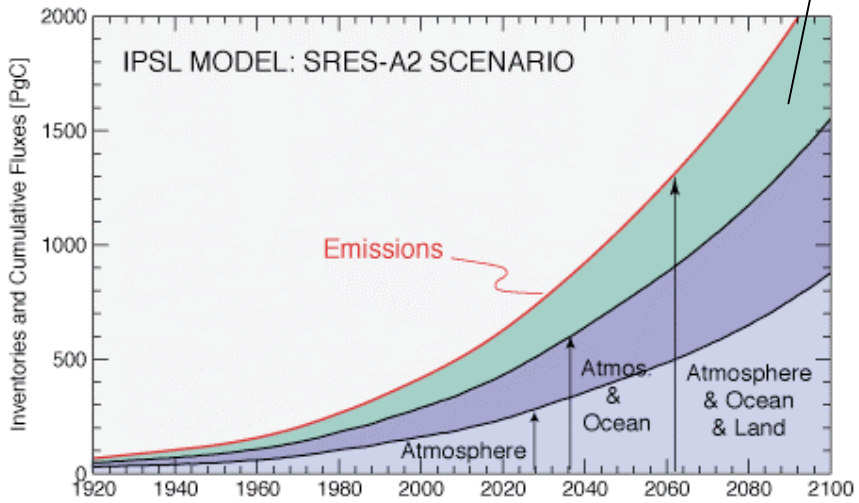
4. Summary and conclusions

# Projected behavior of the global carbon sinks

HADLEY




IPSL

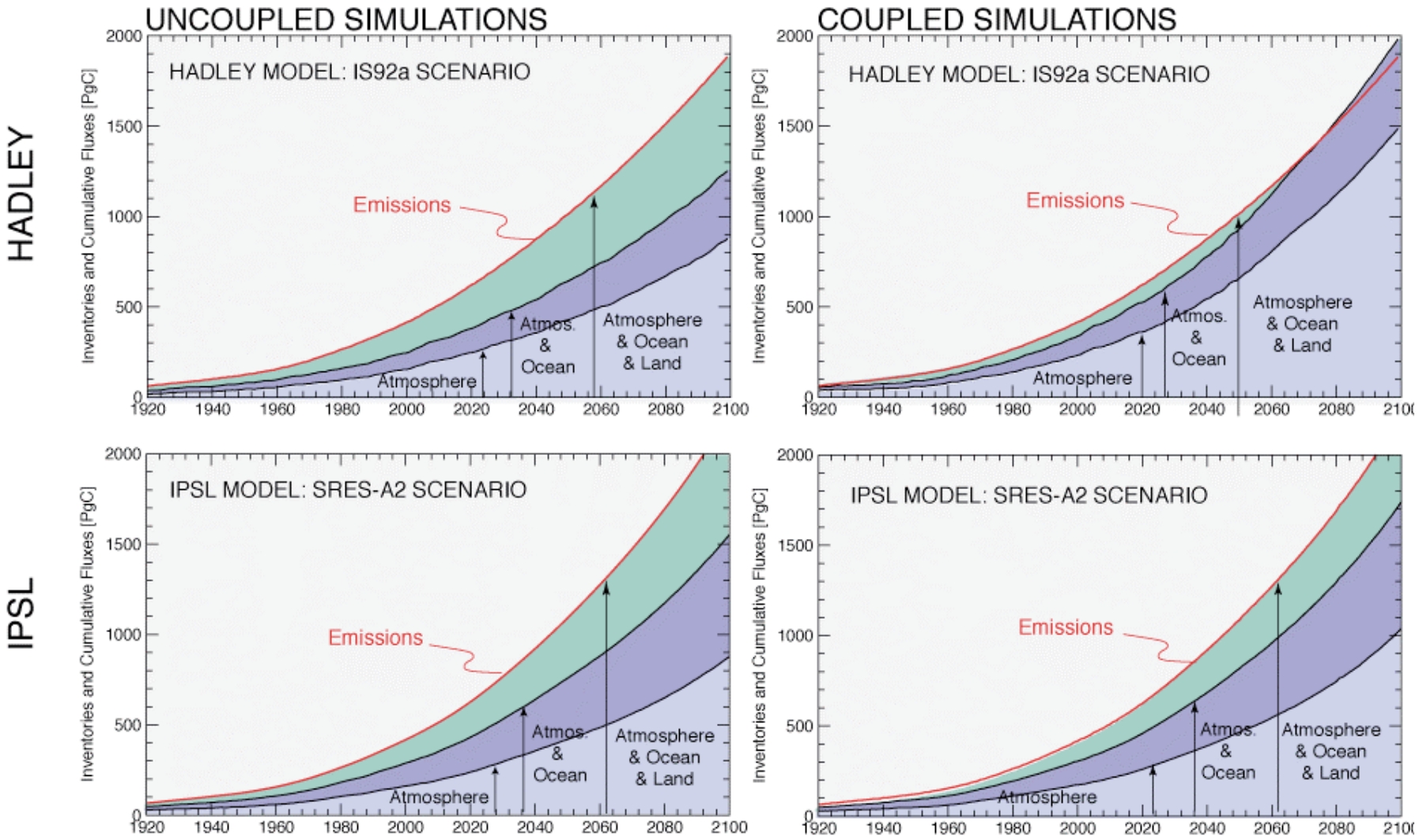



*LAND UPTAKE:*

*Strong $CO_2$ fertilization effect*

*Gruber et al. (2004)*

# Projected behavior of the global carbon sinks

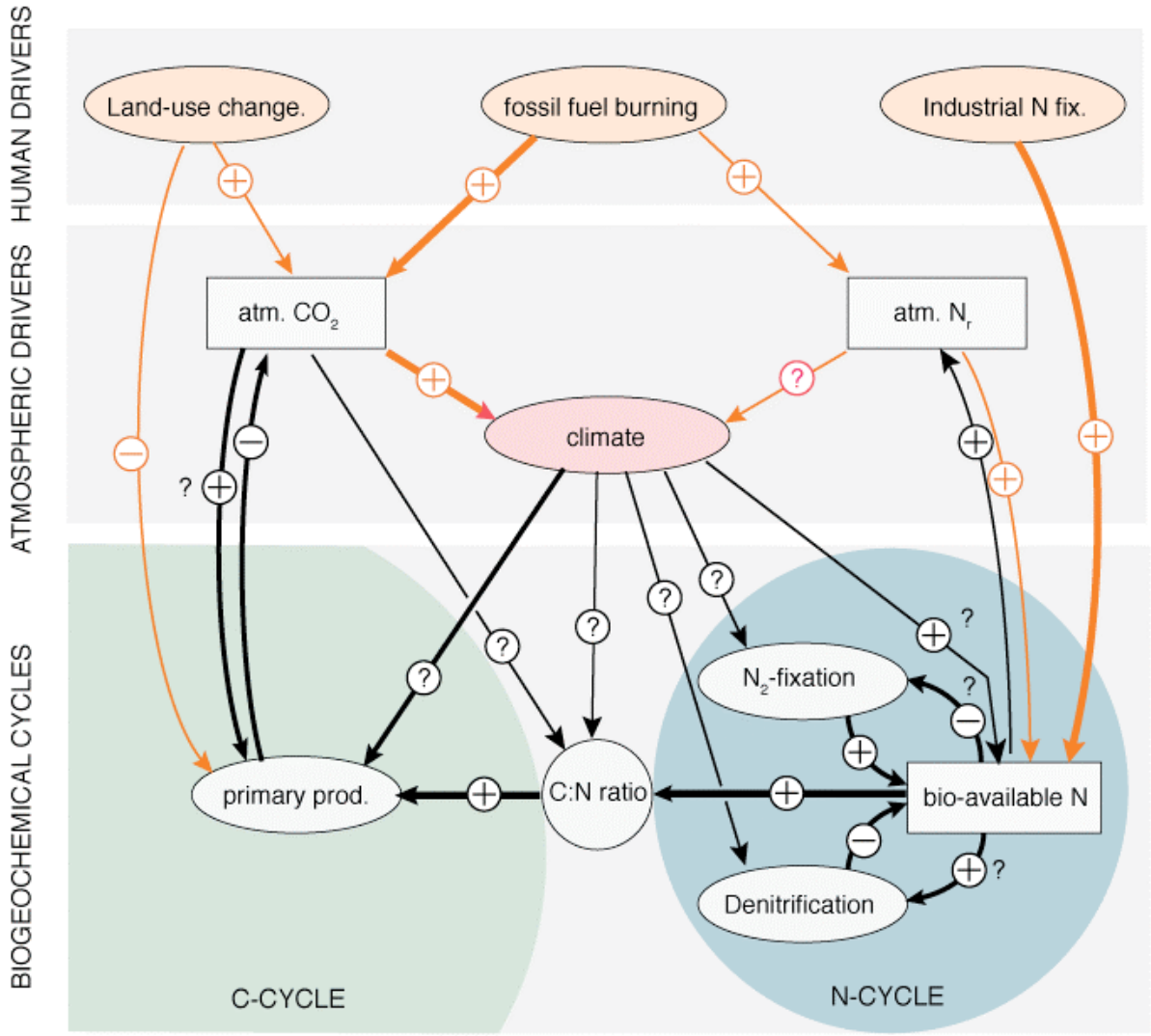





*Gruber et al. (2004)*

# Carbon-nitrogen-climate interactions

*Conceptual diagram*

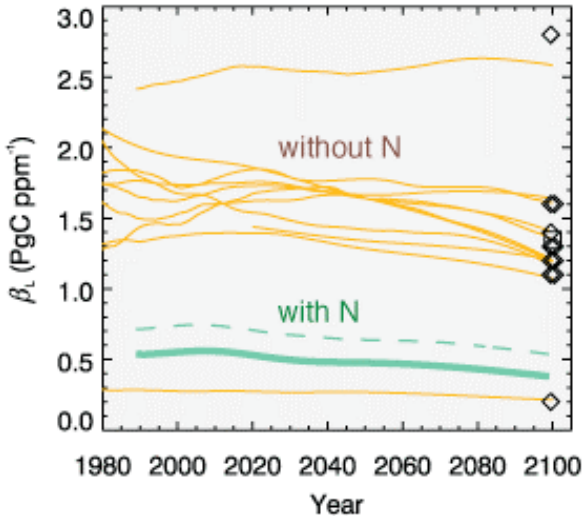



*Gruber and Galloway, 2008*

# Results from a coupled carbon-nitrogen-climate model

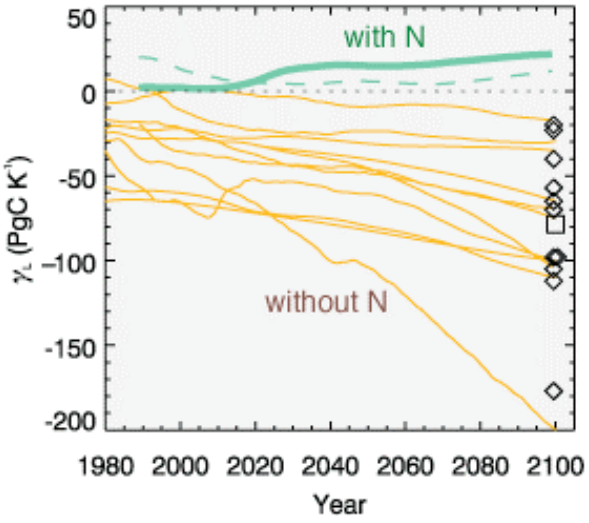
*NCAR CCSM with interactive N-cycle*

Sensitivity of land biosphere to **$CO_2$**



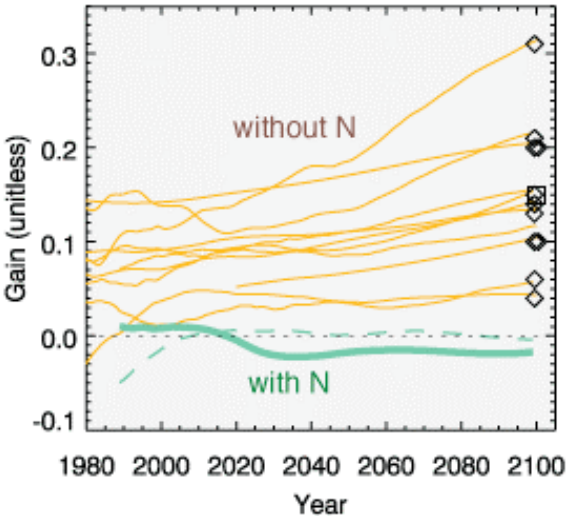

*Low fertilization effect*

Sensitivity of land-biosphere to **temperature**




*Low temperature sensitivity*

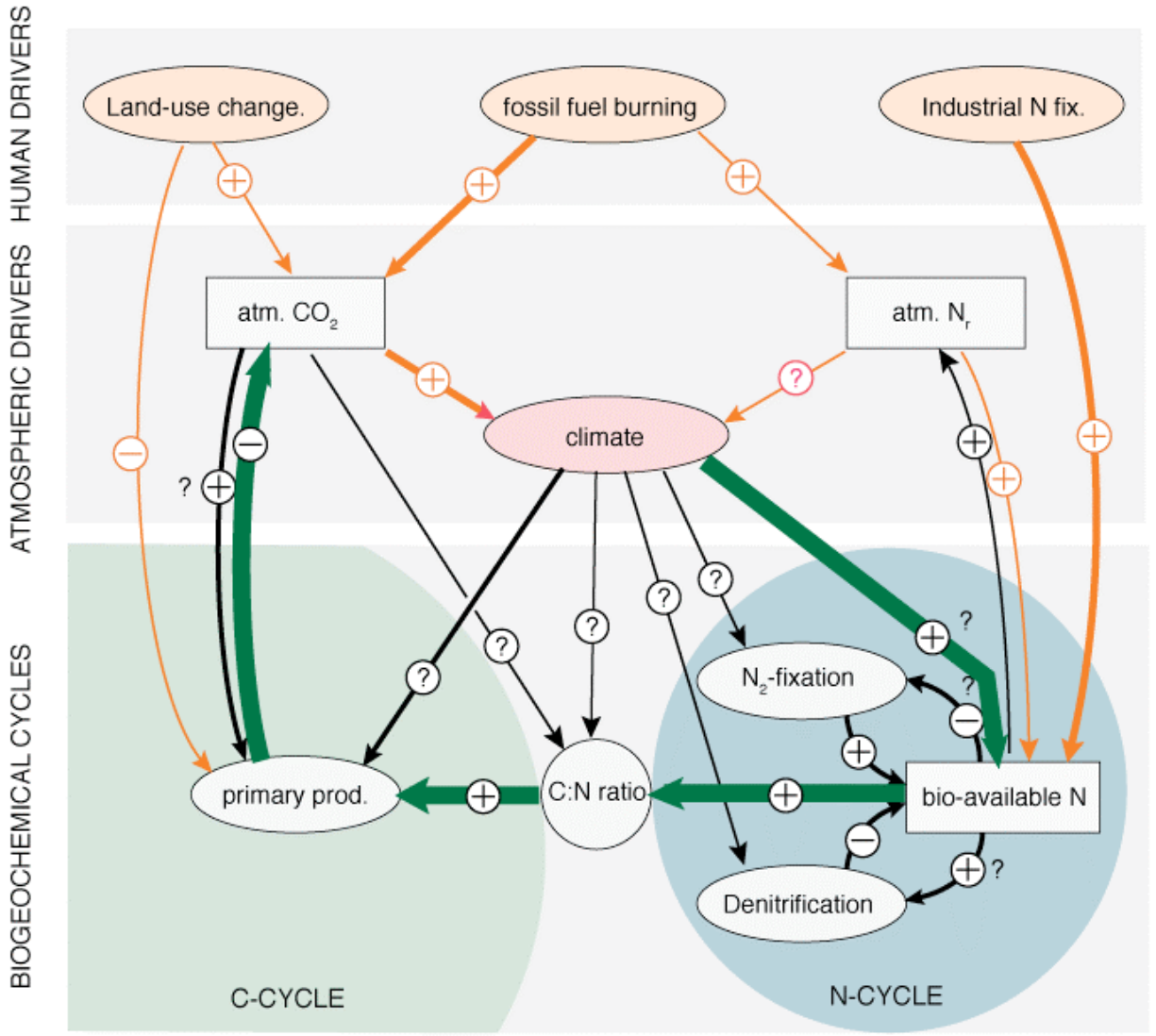
Gain, i.e. overall climate "sensitivity" of land biosphere




*Low climate sensitivity*

*Adapted from Thornton et al. (submitted)*

# Carbon-nitrogen-climate interactions: Mechanism

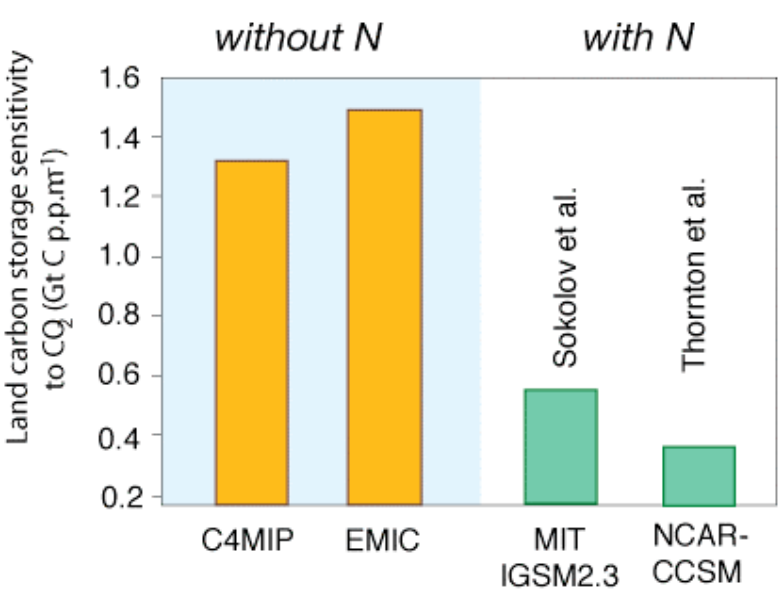



*Enhanced remineralization of soil-nitrogen led to enhanced growth*

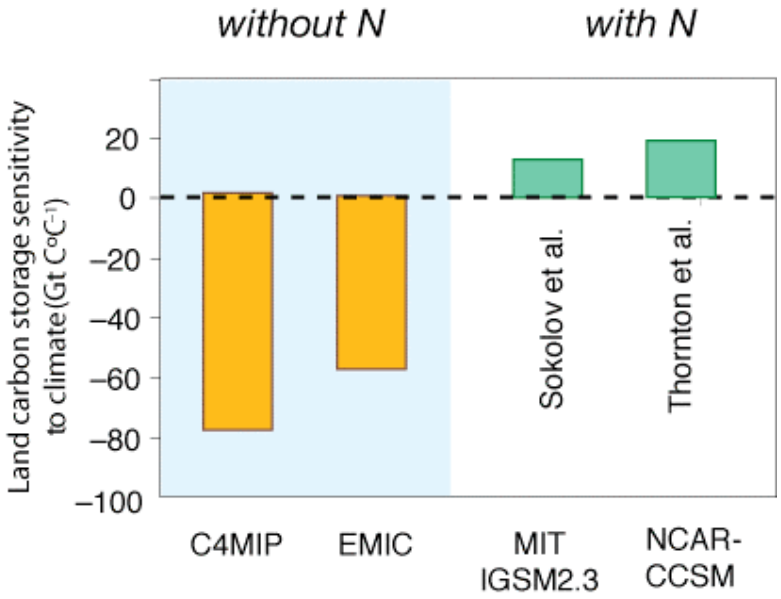
*Gruber and Galloway, 2008*

# Carbon-nitrogen-climate interactions

Sensitivity of land biosphere to **$CO_2$**




Sensitivity of land-biosphere to **temperature**




*The consideration of nitrogen-carbon interactions appears to fundamentally alter the response of the land biosphere to $CO_2$ and temperature changes!*

# Outline

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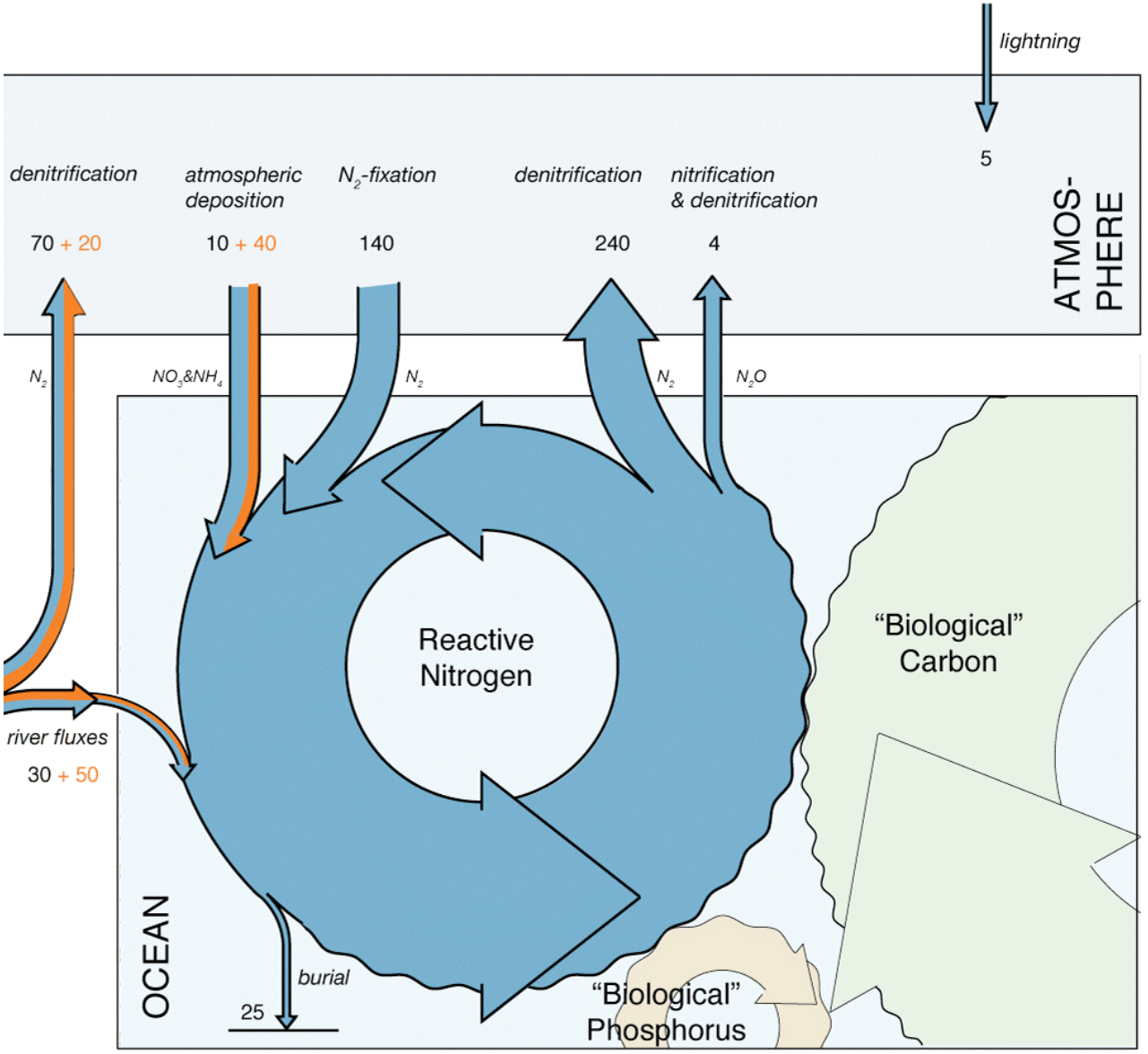
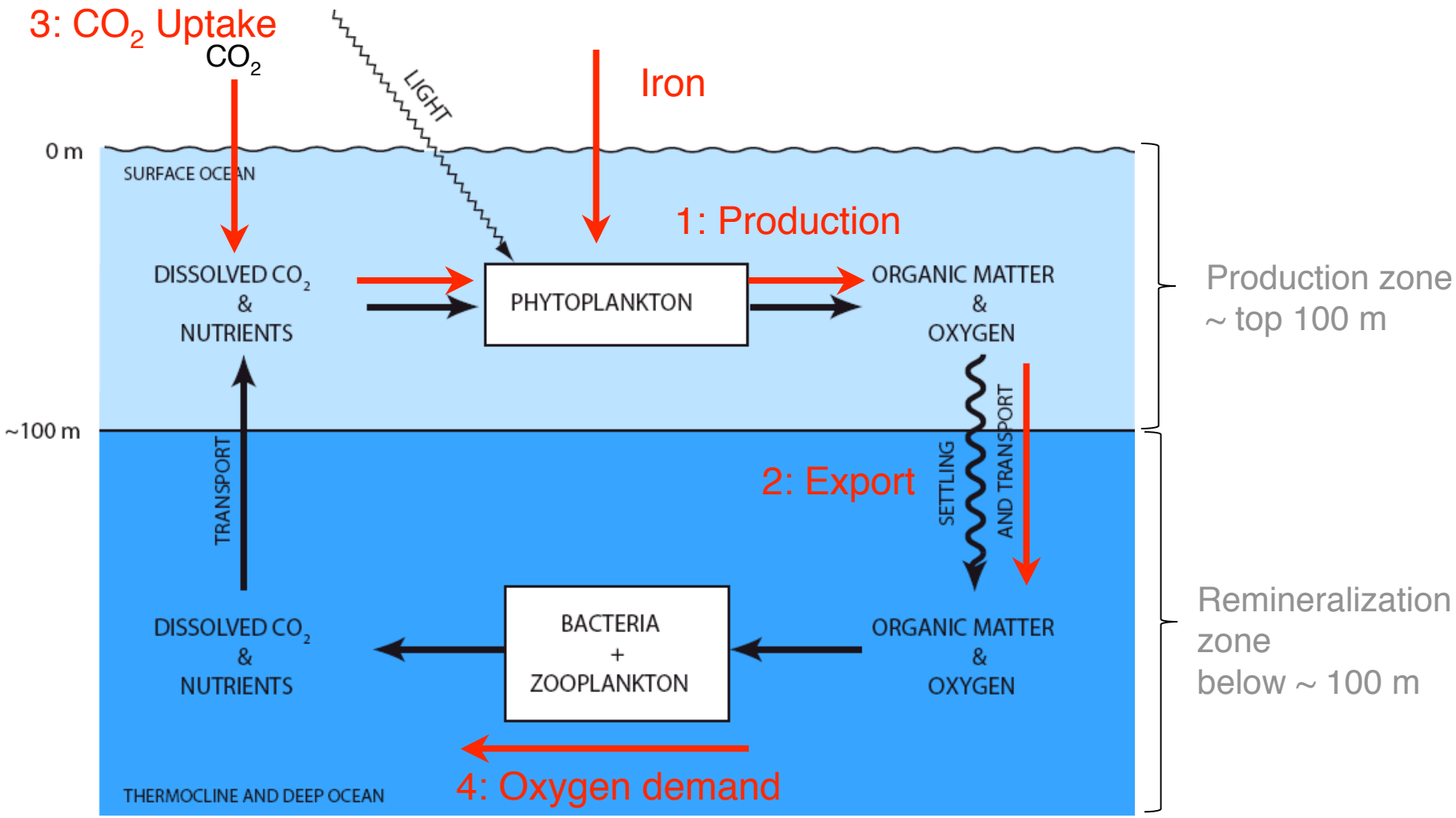
# Nitrogen - carbon coupling in the ocean



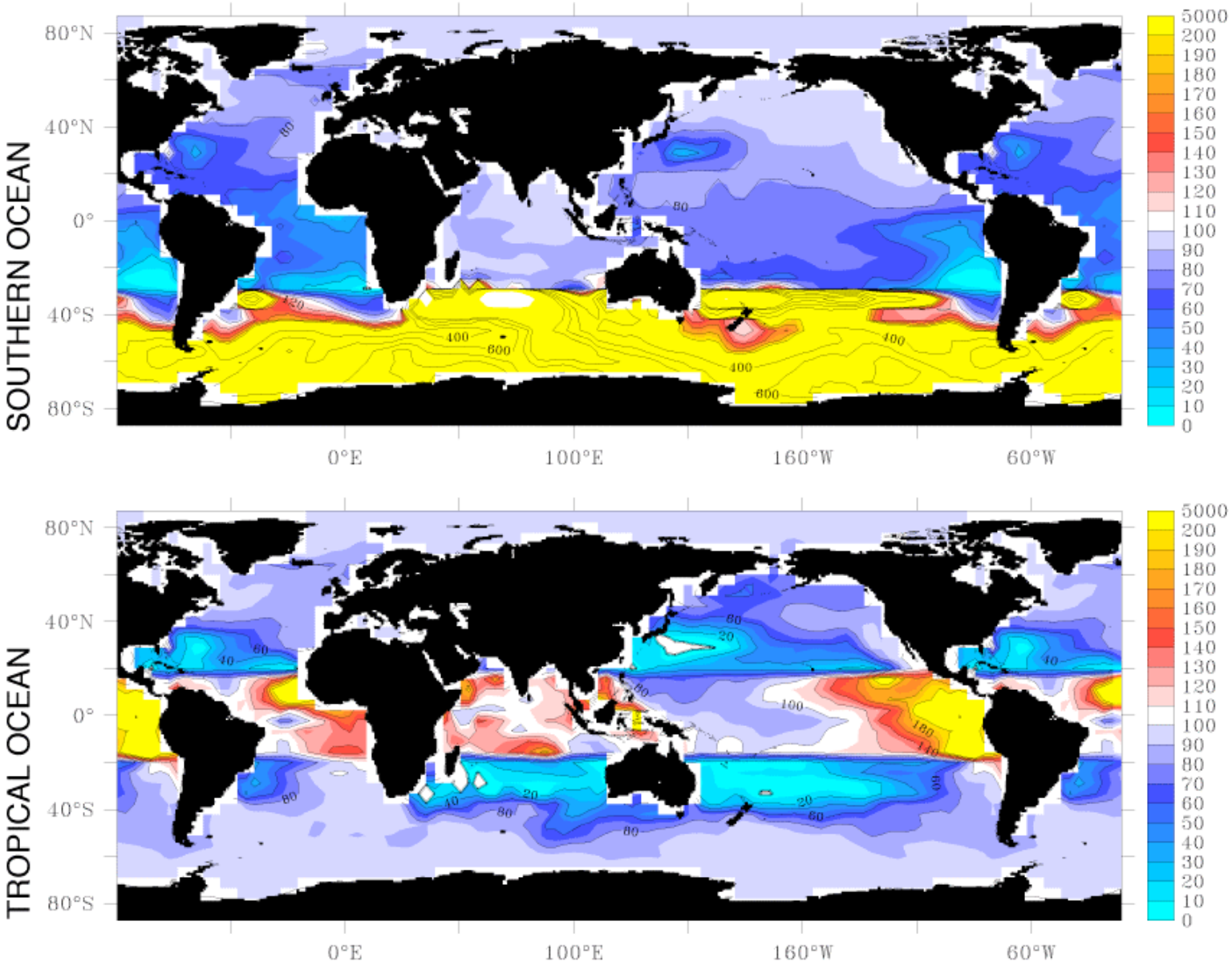

Gruber and Galloway, 2008

# Iron fertilization: How does it work?




*Sarmiento & Gruber (2006)*

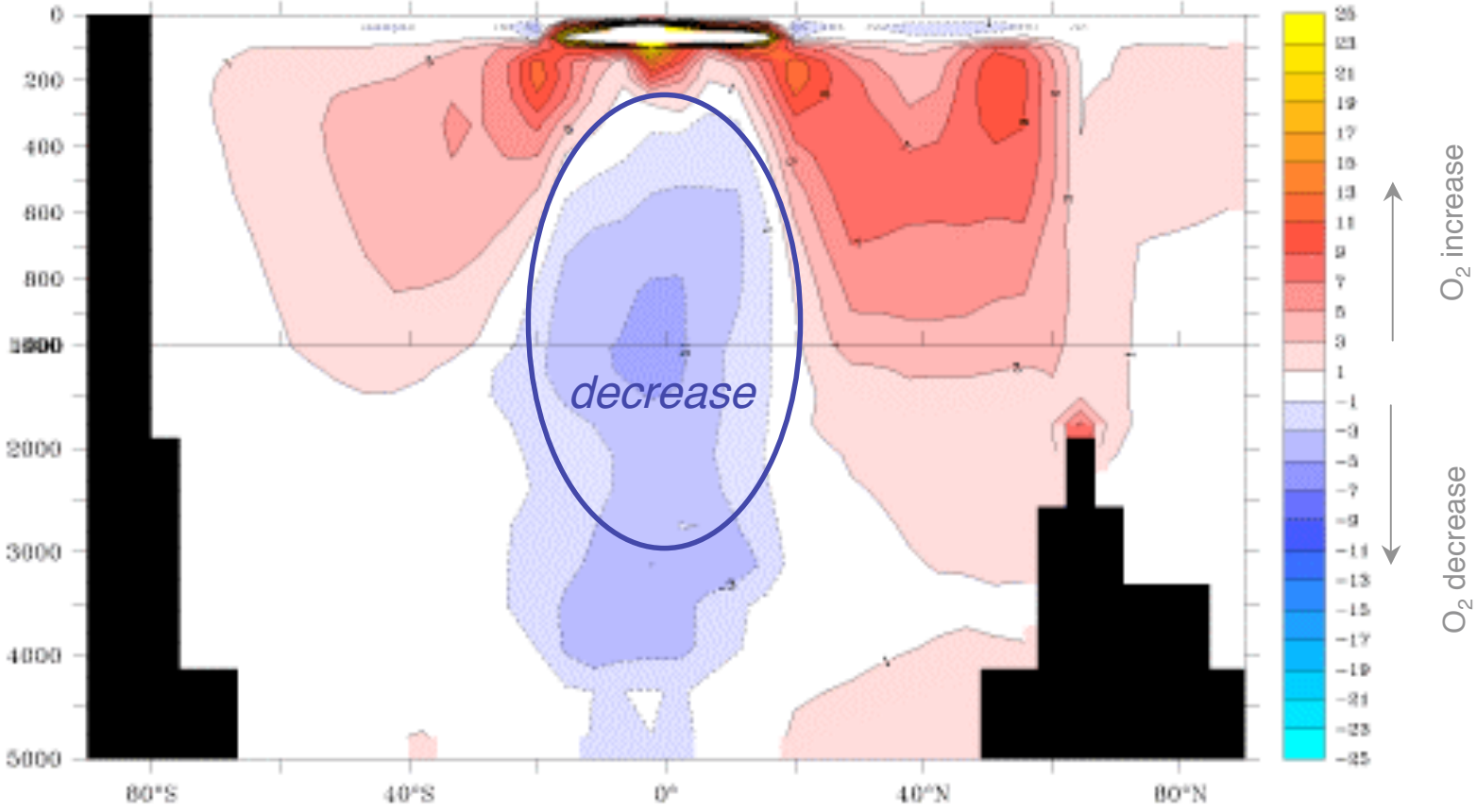
# Impact of large-scale Fe-fertilization on productivity




*Jin and Gruber (2003)*

# Changes in the oxygen distribution

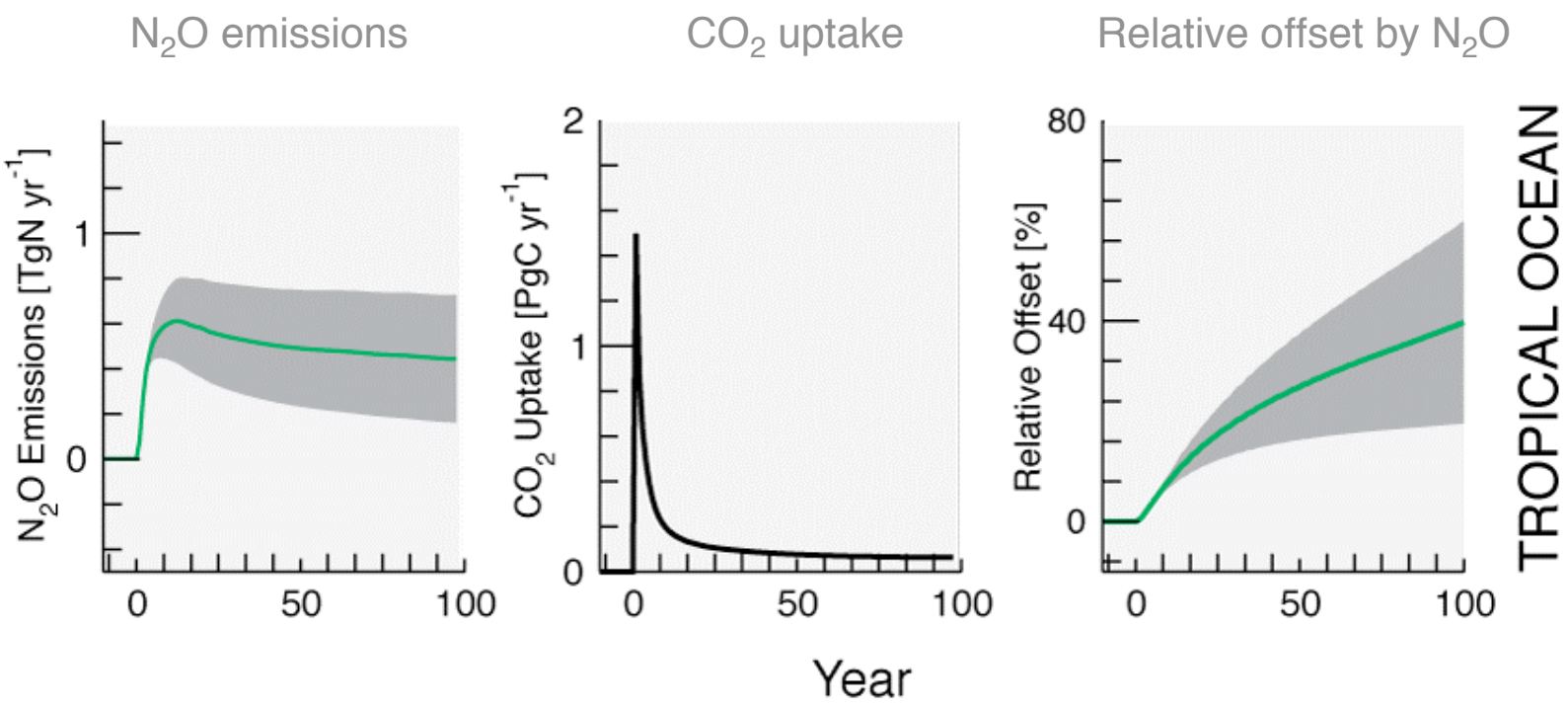
*Zonal mean section of oxygen (mmol $m^{-3}$)*




*Oxygen depletion underneath fertilization sites*
*Additional oxygen changes downstream in response to changes in export*

*Jin and Gruber (2003)*

# $N_2O$ offsetting effect of Fe-fertilization in the tropics




*Rapid decrease of $CO_2$ uptake while $N_2O$ production and emission stay high lead to large reduction in benefit*

*Jin and Gruber (2003)*

# Offsetting effect of enhanced $N_2O$ emissions

| Time & Scale of Fertilization | Tropical Ocean<br>*% offset* | Southern Ocean<br>*% offset* |
|---|---|---|
| 100 yr large-scale | 40 (±28) | 13 (±6) |
| 10 yr large-scale | 58 (±67) | 11 (±18) |
| 10 yr patch-scale | 115 (±34) | -7 (±40) |

*Very substantial offsetting effect. In extreme cases, iron fertilization might actually increase global warming*

*Jin and Gruber (2003)*

# Summary and Conclusions

- Consideration of *carbon-nitrogen-climate feedbacks* is fundamental if we want to reliably predict the future response of the Earth system to global climate change.

- Consideration of such feedbacks in the *land biosphere* may fundamentally alter the *magnitude and sign of carbon-climate feedbacks*.

- Such feedbacks also need to be considered in the *ocean*, particularly in the context of some proposed *geo-engineering* solutions.