Compilation of a N_2O emission inventory from tropical rainforest soils

Using a detailed biogeochemical model to scale from site to global scales

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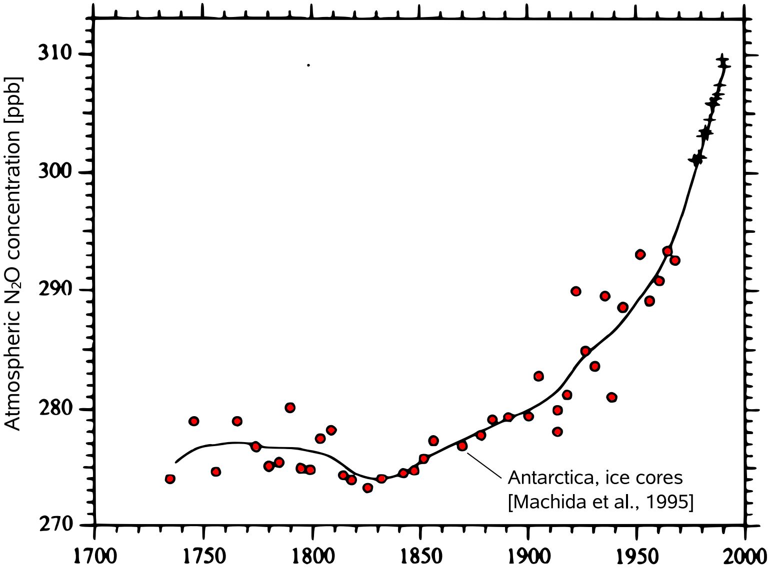
Atmospheric concentration of N_2O



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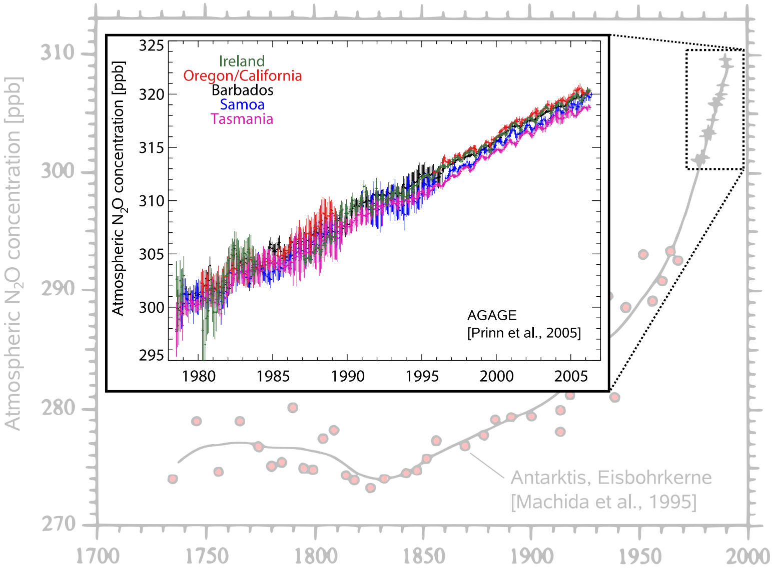
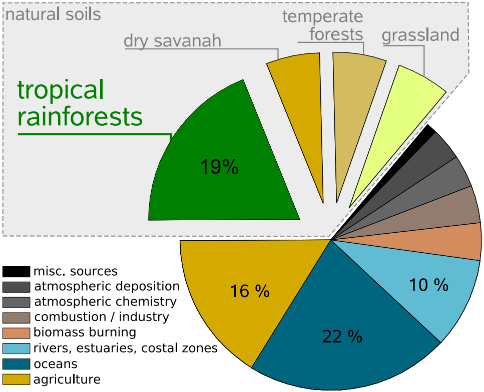


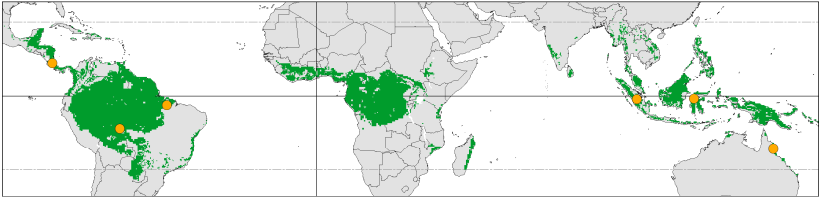
Sources of N_2O



[Data: Lee et al., 1997; IPCC 2007]

- Tropical rainforest soils biggest terrestrial source
- Large uncertainty of total soil N_2O source strength (3.3 - 9.0 Tg yr^{-1})

Existing N_2O emission measurements



- No daily measurements (exception: Australia)
- Environmental parameter and weather data often missing or unsufficient
- Need for concise datasets of high temporal resolution

Inventory methodologies

Bottom-up (I): empirical up-scaling

+ simple methodology, very common (IPCC standard procedure)
– too simple?, no temporal variability, no process-interactions, very dependant on datasets

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+ global scale, estimate of total landsurface exchange
− spatial resolution, no single sources, verification

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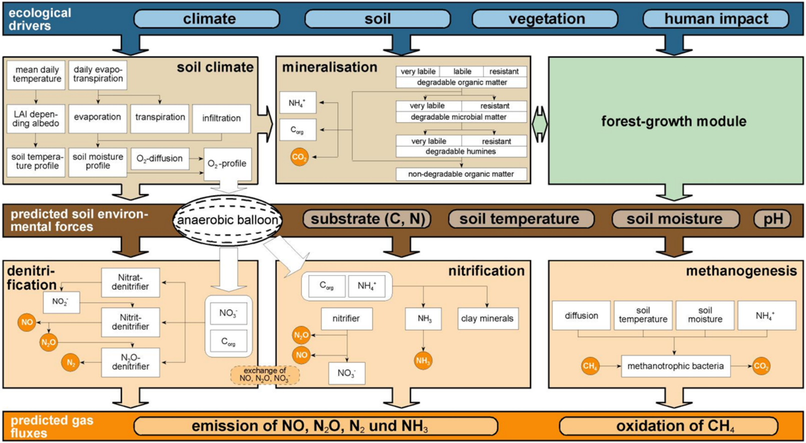
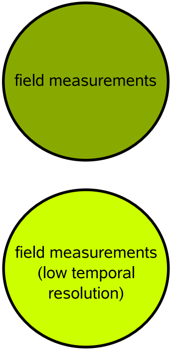
Bottom-up (II): biogeochemical modelling

+ explicit spatial units, realistic process functioning, temporal resolution
– high complexity of models, need for detailed measurements and GIS data

ForestDNDC


ecological drivers
climate
soil
vegetation
human impact
soil climate
mean daily temperature
daily evapo-transpiration
LAI depending albedo
evaporation
transpiration
infiltration
soil temperature profile
soil moisture profile
O_2-diffusion
O_2-profile
mineralisation
very labile
labile
resistant
degradable organic matter
degradable microbial matter
degradable humines
non-degradable organic matter
NH_4^+
C_{org}
CO_2
forest-growth module
predicted soil environmental forces
anaerobic balloon
substrate (C, N)
soil temperature
soil moisture
pH
denitrification
Nitrat-denitrifier
Nitrit-denitrifier
N_2O-denitrifier
NO_2^-
NO
N_2O
N_2
NO_3^-
exchange of NO, N_2O, NO_3^-
nitrification
nitrifier
NH_3
clay minerals
methanogenesis
diffusion
soil temperature
soil moisture
CH_4
methanotrophic bacteria
predicted gas fluxes
emission of NO, N_2O, N_2 und NH_3
oxidation of CH_4

Study structure



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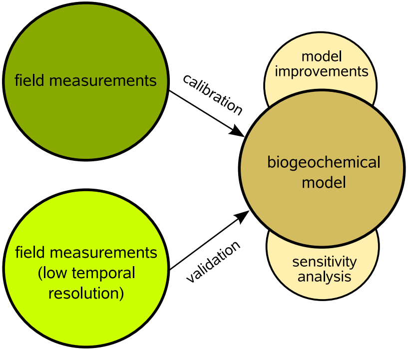

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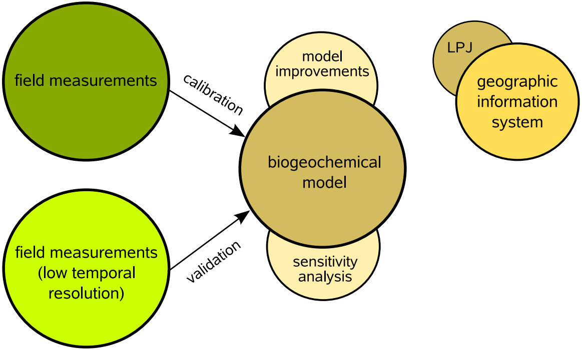

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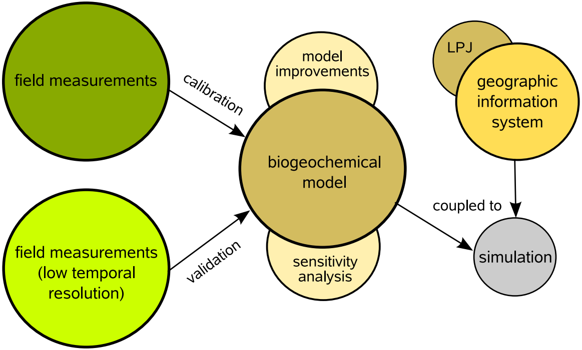

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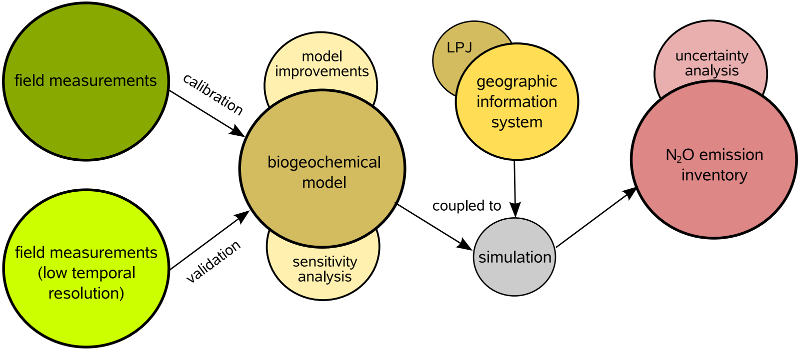

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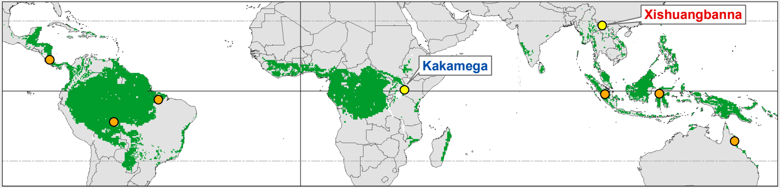
Field measurements



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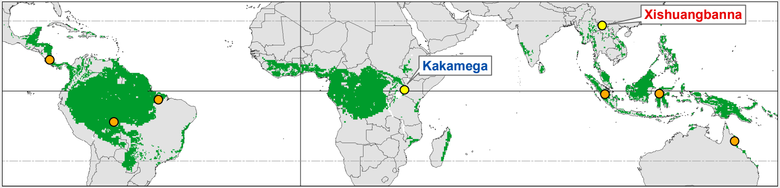

Kakamega Forest, Kenya 2004

- relict of former equatorial Guinea-Congo rainforest
- 1500m a.s.l, loamy soils, deeply weathered
- 20.4°C mean annual temperature
- 1530mm mean annual precipitation

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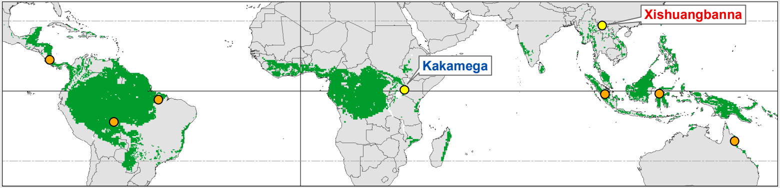

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Xishuangbanna, SW-China 2005

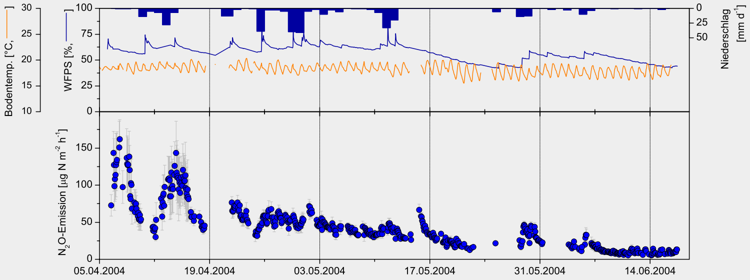
- seasonal tropical rainforest
- 770m a.s.l., sandy soils, gravel
- 21.8°C mean annual temperature
- 1493mm mean annual precipitation (strongly seasonal)

Detection of N_2O emissions from soils

Methodology

- Fully-automated detection of N_2O, CH_4 and CO_2 (*static chamber method*)
- Simultanuous recording of environmental factors (WFPS, soil temp.)
- Quantification of spatial heterogenity by manual measurements on other sites

Kakamega Forest, Kenya



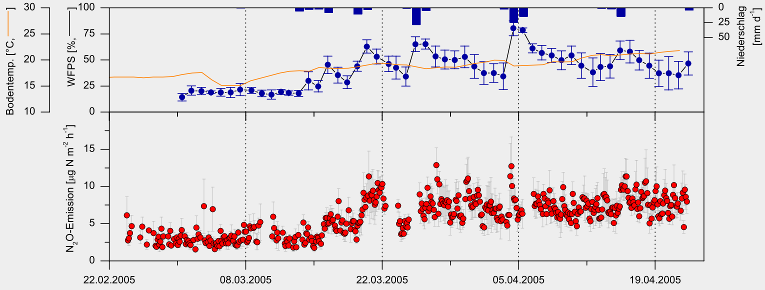
Site characteristics

- Carbon rich soils
- Measurements at start of wet season

Emission characteristics

- Significant emission pulses
- Decline of N_2O emissions even when WFPS remains high

Xishuangbanna, SW-China



Site characteristics

- Nutrient-poor site
- Measurements in dry-wet transition (severe drought before)

Emission characteristics

- Very low emission level
- Low emission dynamic

Dominant controls

Short-term dynamics of N_2O emission

- WFPS is dominant control at both sites
- WFPS controls emission timing but not the integrative N_2O emission sum
- Soil temperature is of secondary importance for emission variability (small daily temperature amplitude in tropics)

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Mid-term dynamics of N_2O emission

- Amount and availability of substrate important for N_2O emission strength
- Physicochemical properties control general emission potential

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ForestDNDC-tropica

Based on ForestDNDC-tropica [Kiese et al., 2005], PnET-N-DNDC [Stange et al., 2000]:

- Reworked vertical soil carbon profile
- Implementation of new pedotransfer functions
- Reworked model initialization (vegetation, biomass)
- Adaptation of model code for cluster environment
- Restructuring and recalibration (Site-parallel Bayesian Calibration) of model

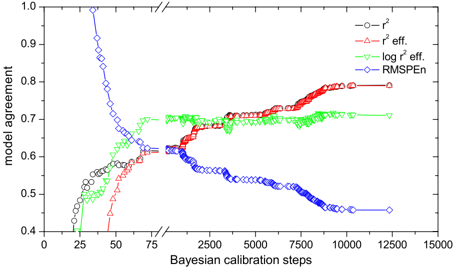
Bayesian Calibration

- Re-calibration of model internal parameters (pV)
- *Metropolis Hastings random walk*

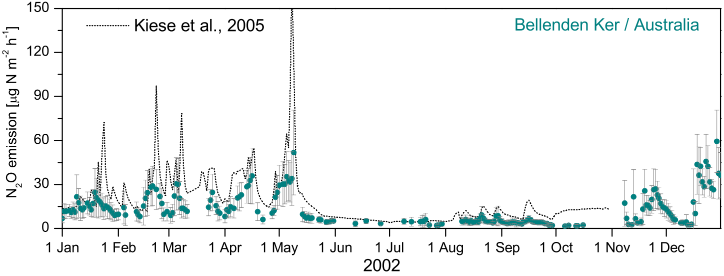
$$\Theta' = \Theta_t + \epsilon \qquad (1)$$

$$\beta = \frac{p(D|\Theta')p(\Theta')}{p(D|\Theta_t)p(\Theta_t)} \qquad (2)$$

- also enables to calculate parameter uncertainty of pV



Calibration results



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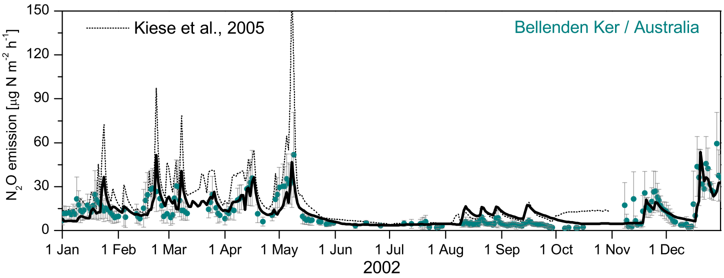

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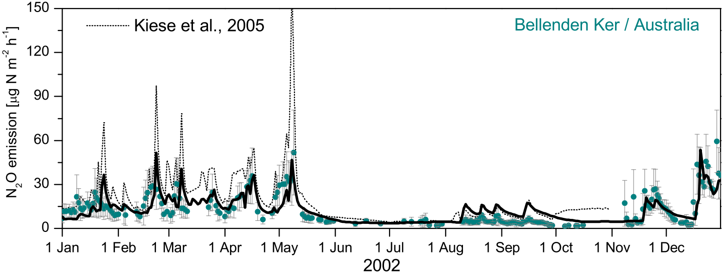

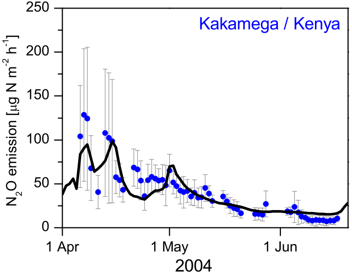

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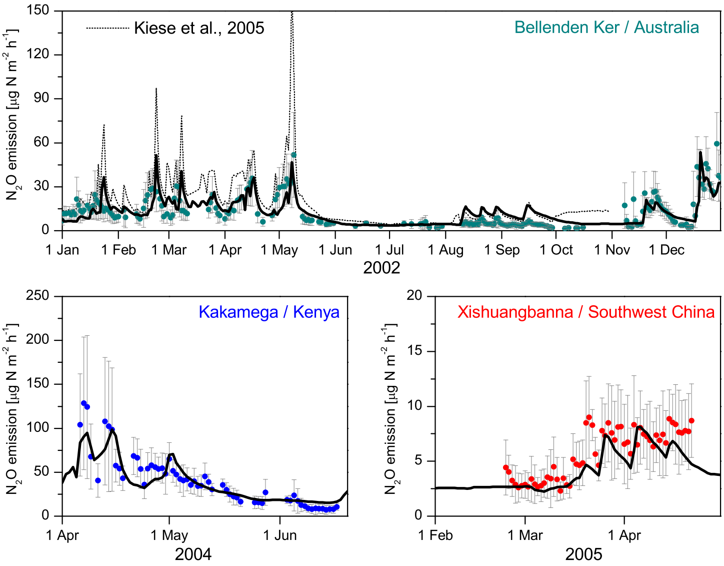
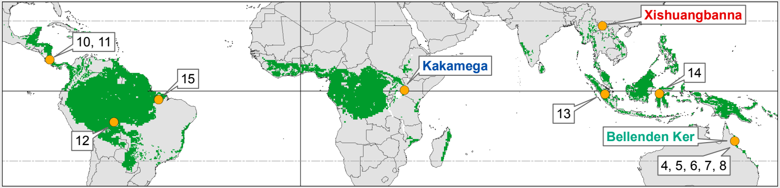
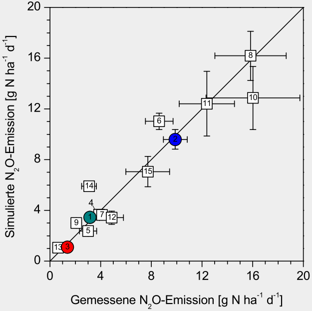


Model validation



	Field site	Source
Calibration		
1	Bellenden Ker (AU)	Kiese et al. (2003)
2	Kakamega (KE)	This study
3	Xishuangbanna (CN)	This study
Validation		
4	Bellenden Ker (AU)	Kiese et al. (2003)
5, 6	Kauri Creek (AU)	Breuer et al. (2000)
		Kiese & Butterbach-Bahl (2002)
7, 8	Massey Creek (AU)	Breuer et al. (2000)
9	Lake Echeam (AU)	Breuer et al. (2000)
10	La Selva (CR)	Keller & Reiners (1994)
11	Guacimo (CR)	Liu et al. (2000)
12	Central Rondônia (BR)	Neill et al. (1995)
13	Jambi Province (ID)	Ishizuka et al. (2002)
14	Wuasa (ID)	Purbopuspito et al. (2006)
15	Pará (BR)	Verchot et al. (1999)



Data integration (I)

Problem: Initialization of vegetation

Modell-internal initialization developed for Australian rainforests and not applicable to global scale as such

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Solution: Simulation of local vegetation conditions

The **L**und-**P**otsdam-**J**ena Dynamic Global Vegetation Model

- Simulation of potential vegetation
- 1000 year spin-up simulation
- explicit output of leaf, steam and root mass

Data integration (II)

Development of a Geographic Information System

climate
ECMWF RA-40
0.5° x 0.5° / daily
temp. (min / max),
precipitation, PAR

soil
FAO, ISRIC-WISE
0.25° x 0.25°
SOC, pH, texture,
bulk density, ...

Geographic Information System [0.25° x 0.25°]

forest (I)
distribution:
GLC 2000,
Blasco et al., 2000
0.25° x 0.25°

forest (II)
biomass:
stem, root, leaf mass
simulated with
LPJ-DGVM

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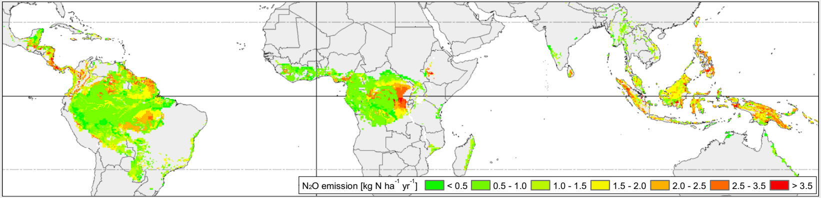
N_2O emission inventory

Mean annual N_2O emission (1991–2000)



- Mean annual global source strength: 1.3 ± 0.3 Tg N yr^{-1}
- Pronounced spatial variability (climatic and edaphic effects)

What's the uncertainty?

Problem

Parameters of GIS are based on mean values which can be the result of broad parameter distributions in some soil groups

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Solution: The *Latin Hypercube Sampling* methodology

- Parameters: soil, biomass
- Acknowledgement of local climate conditions by grid replicates
- Combinations: $1000 \times 200 \times 5 = 10^6$
- Advanced Monte-Carlo approach (distribution functions)

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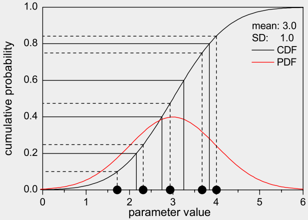

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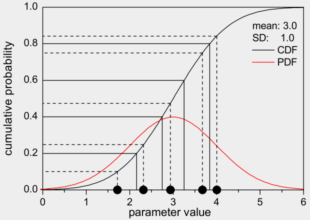

Uncertainty range

Data-induced uncertainty: **0.9 - 2.4 Tg N**

Comparison of N_2O inventory results

	N_2O source strength [Tg N yr^{-1}]		Area [10^6 km^2]
Empirical up-scaling			
Matson und Vitousek (1990)	**1.8**	(2.4)	14.8
Breuer et al. (2000)	**2.6**	(3.6)	14.9
Stehfest und Bouwman (2006)	**1.5**	(1.2)	8.5

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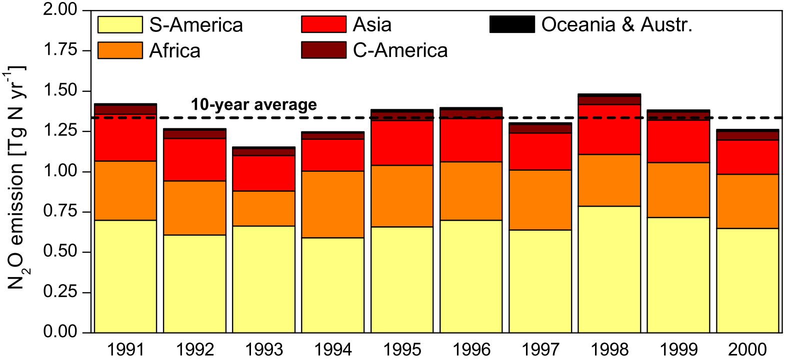
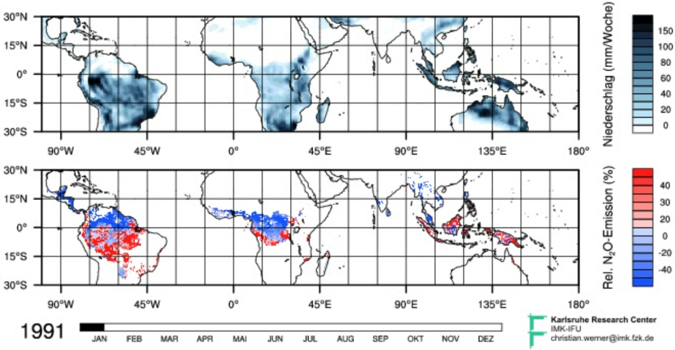
Model-based up-scaling			
Bouwman et al. (1995)	**1.5**	(2.3)	16.8
Potter et al. (1996)	**1.3**	(1.3)	10.2
Melillo et al. (2001)		(2.4)	5.4
This study	**1.3**		10.9

Inter-annual variability of N_2O emissions



Seasonal variability of N_2O emissions



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Summary

Results

- Acquisition of detailed N_2O emission datasets for model calibration
- Model improvements (ForestDNDC-tropica) and first-time application for global tropical rainforests
- Compilation of N_2O emission inventories for the years 1991-2000 in daily resolution
- Uncertainty assessment for inventories

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Using a GIS-coupled modelling approach for up-scaling it was shown that

- tropical rainforest soil emit 1.3 Tg N yr^{-1}
- N_2O emissions vary substantially at the spatial scale
- N_2O emissions occur with inter- und intra-annual variability
- N_2O emissions are controlled by precipitation at the global scale

Outlook

Future work

- Verification of inverse models
- Compilation of more N_2O emission datasets with high precision
- Improvements to model parametrization (e.g., tropical savannah biome)
- Simulation of *Global Change* effects
- Coupled modelling (e.g., for future climate change)

Thank you.

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