# Modeling Impacts of Farming Management on $CH_4$ and $N_2O$ Emissions

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for
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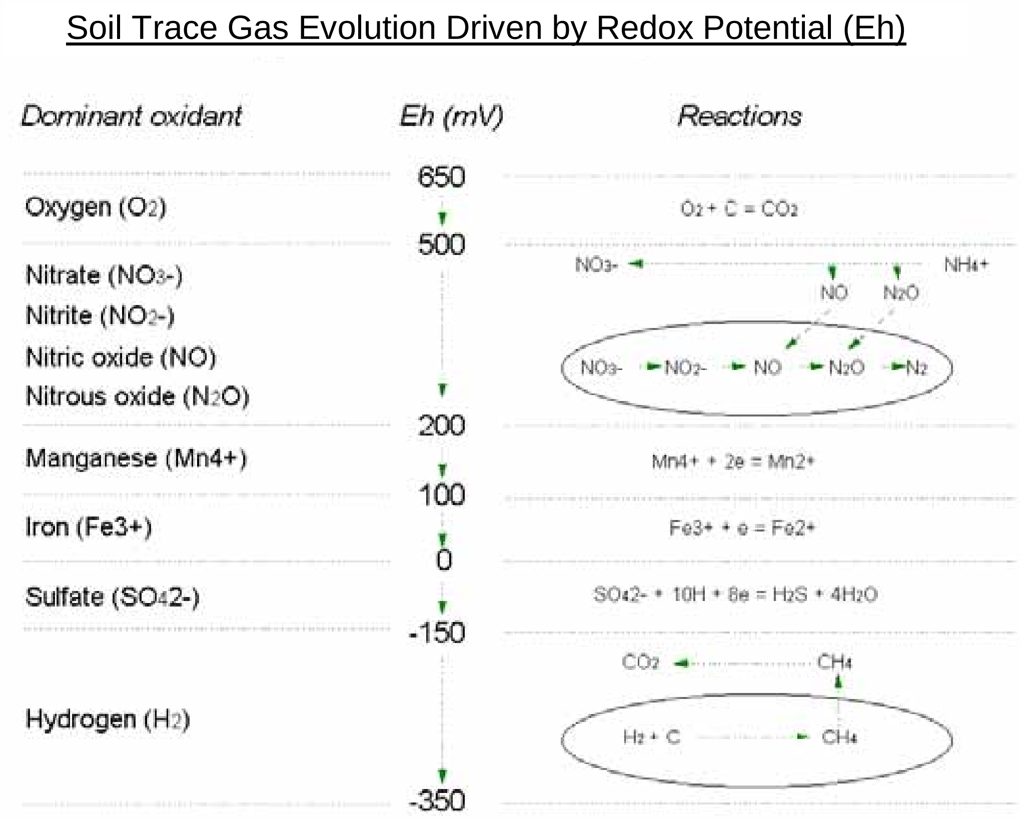
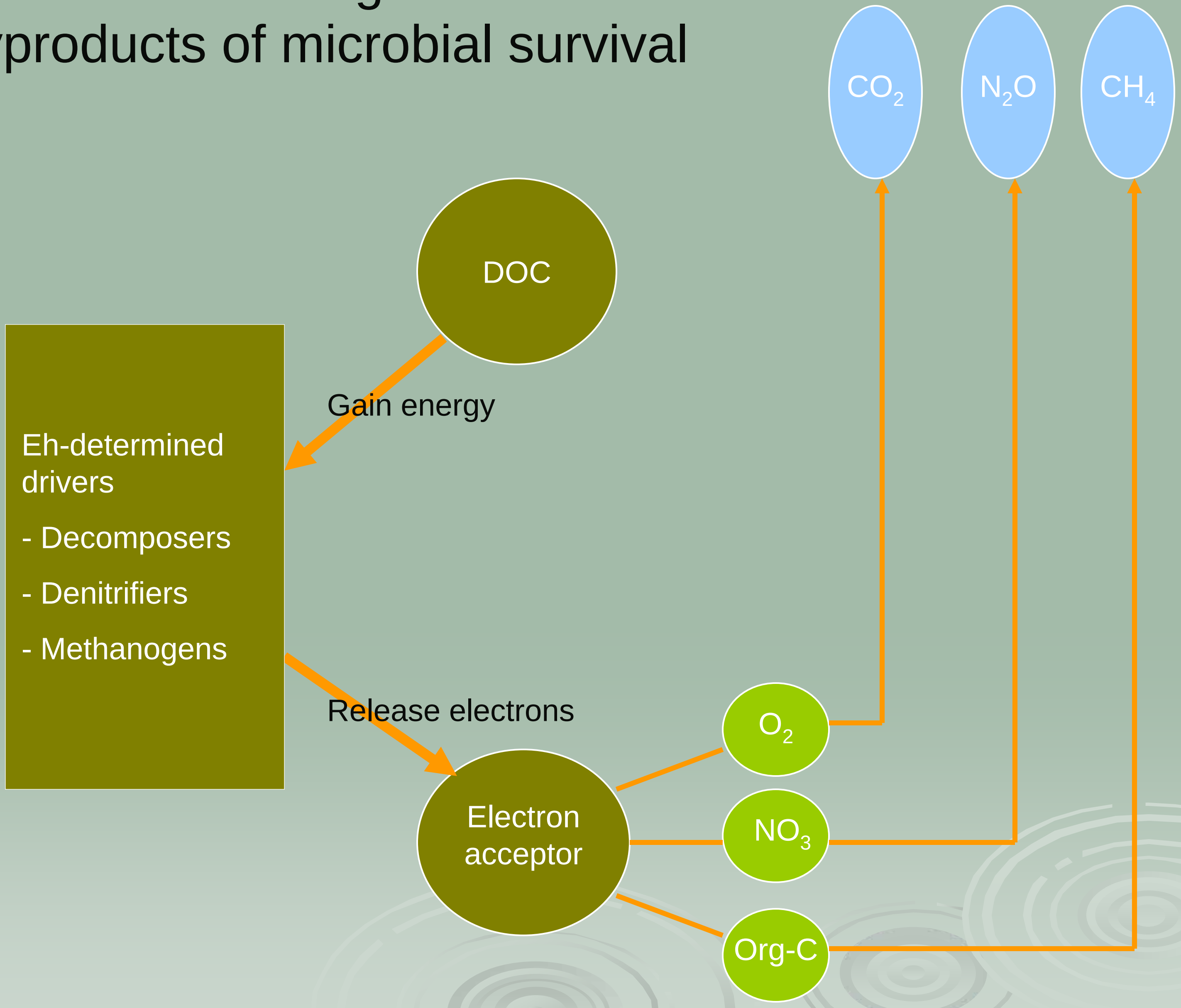
# Scientific Basis



Soil Trace Gas Evolution Driven by Redox Potential (Eh)

# Greenhouse gases are byproducts of microbial survival



$CO_2$

$N_2O$

$CH_4$

DOC

Gain energy

Eh-determined drivers

- Decomposers
- Denitrifiers
- Methanogens

Release electrons

Electron acceptor

$O_2$

$NO_3$

Org-C

# Eh Dynamics: The Nernst Equation

Eh is determined by concentrations of the dominant oxidizing vs. reducing species in a redox reaction system.

$$Eh = Eo + RT/nF * \ln([O]/[D])$$

Eh - redox potential, volts

Eo - standard redox potential, volts

R - gas constant

T - temperature, in kelvins

F - Faraday constant

O - concentration of oxidant, mol

D - concentration of reductant, mol

# Microbial activity: The Michaelis-Menten Equation

Microbial activity is driven by dual nutrients.

$$R = R_{max} * C/(K_a+C) * O/(K_b+O)$$

R - reaction rate

$R_{max}$ - maximum reaction rate

C - concentrations of dissolved organic C

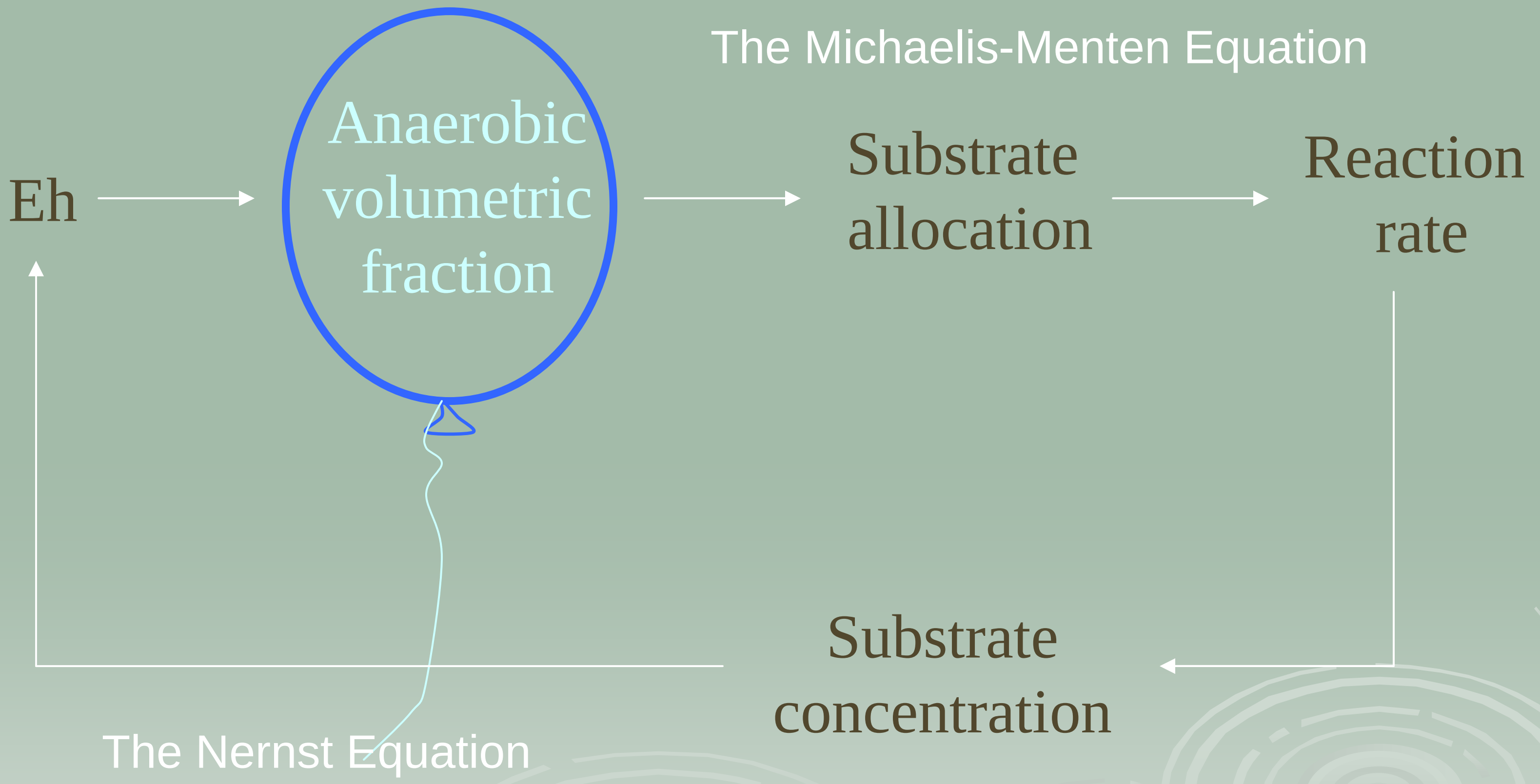
O - concentrations of oxidant

$K_a$, $K_b$ - half-saturation constants for substrate A and B

# Coupled Nernst and Michaelis-Menten equations for calculating Eh evolution and microbial activity in parallel

$$\begin{cases} Eh = Eo + RT/nF * \ln([\mathbf{O}]/[D]) \\ R = R_{max} * C/(K_a+C) * \mathbf{O}/(K_b+\mathbf{O}) \end{cases}$$

# Convert the scientific concept to a computable framework by means of an “anaerobic balloon“



The Michaelis-Menten Equation

Eh

Anaerobic volumetric fraction

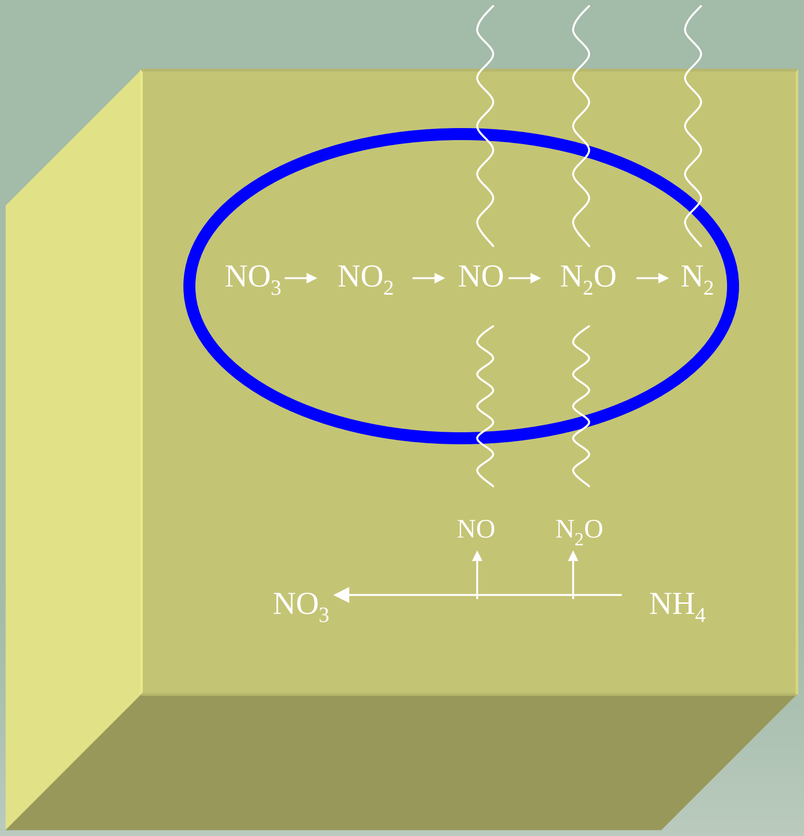
Substrate allocation

Reaction rate

Substrate concentration

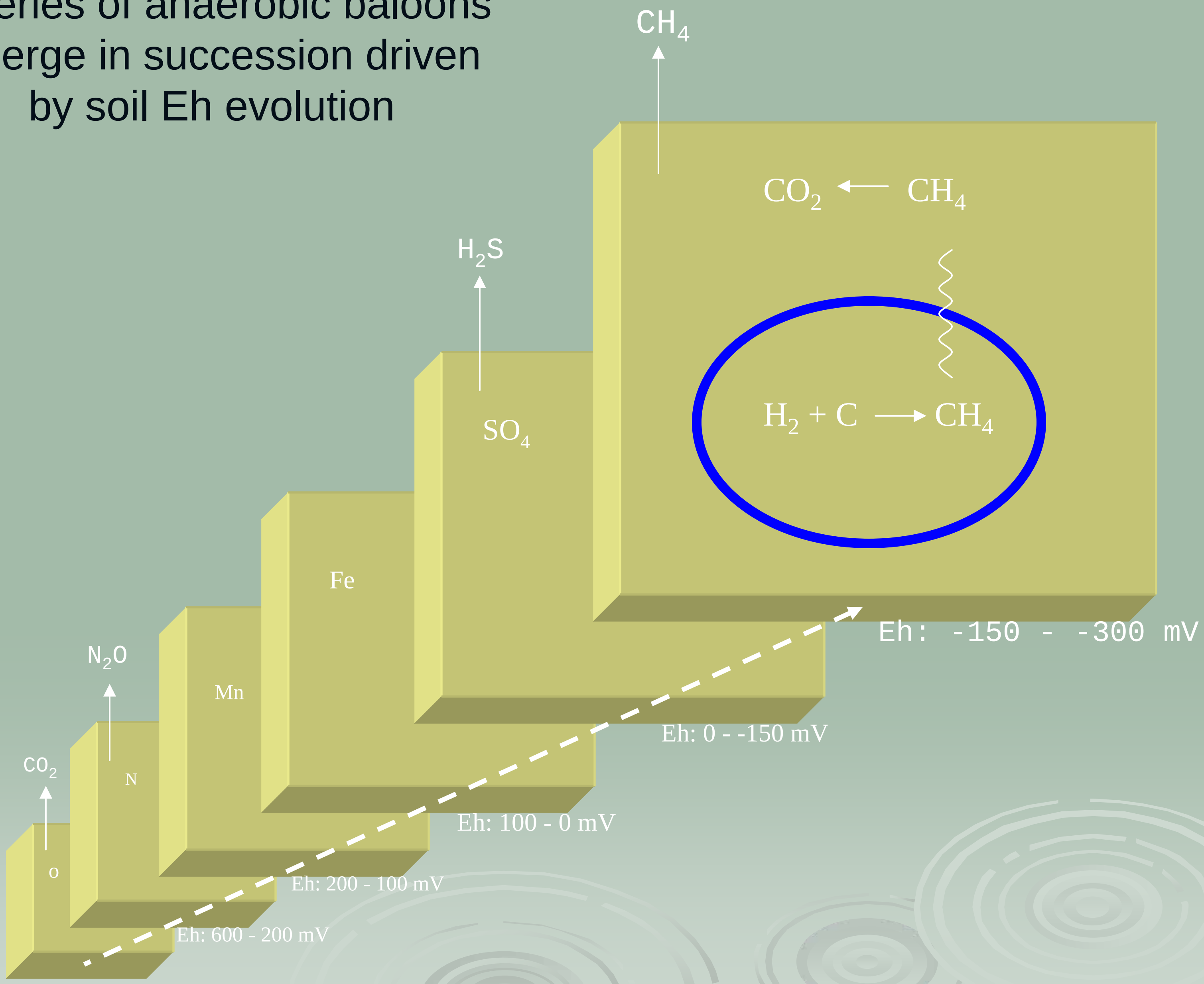
The Nernst Equation

# Denitrification and nitrification are simultanuously calculated based on the substrates allocated in and outside of the balloon



Soil Eh: 600-200 mV

# A series of anaerobic baloons emerge in succession driven by soil Eh evolution



$CH_4$

$CO_2 \leftarrow CH_4$

$H_2 + C \longrightarrow CH_4$

Eh: -150 - -300 mV

$H_2S$

$SO_4$

Eh: 0 - -150 mV

Fe

Eh: 100 - 0 mV

Mn

Eh: 200 - 100 mV

$N_2O$

N

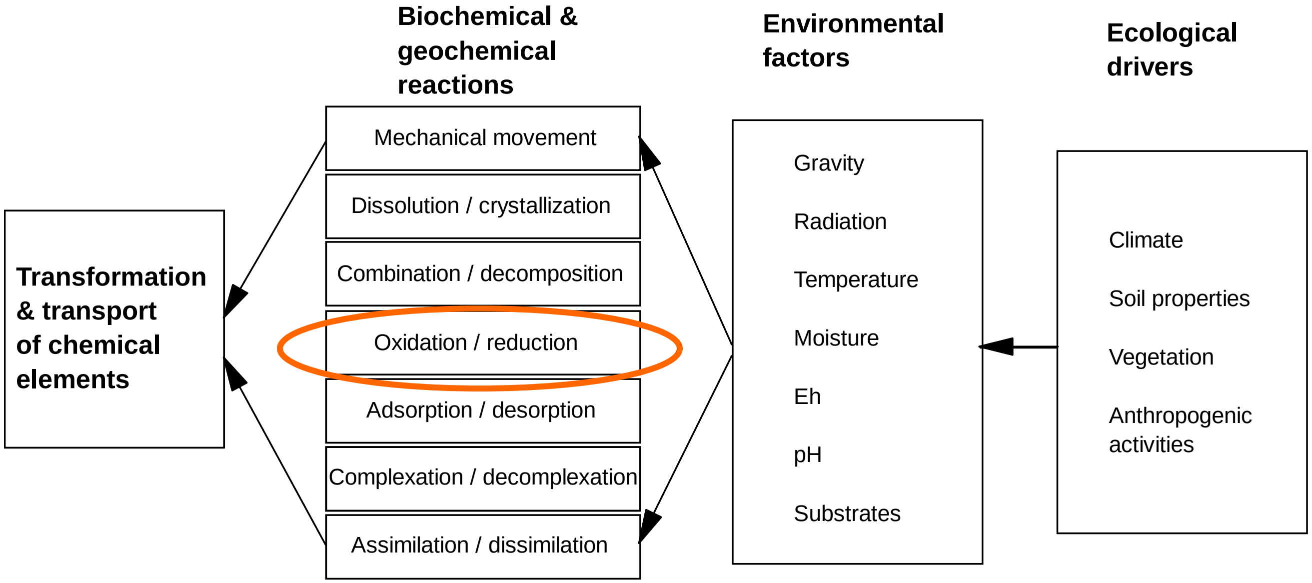
Eh: 600 - 200 mV

$CO_2$

O

# The greenhouse gas calculation has been incorporated in a model framework providing primary drivers and environmental factors

**Biogeochemical Model is a Mathematical Expression of Biogeochemical Field**



**Transformation & transport of chemical elements**

**Biochemical & geochemical reactions**

- Mechanical movement
- Dissolution / crystallization
- Combination / decomposition
- Oxidation / reduction
- Adsorption / desorption
- Complexation / decomplexation
- Assimilation / dissimilation

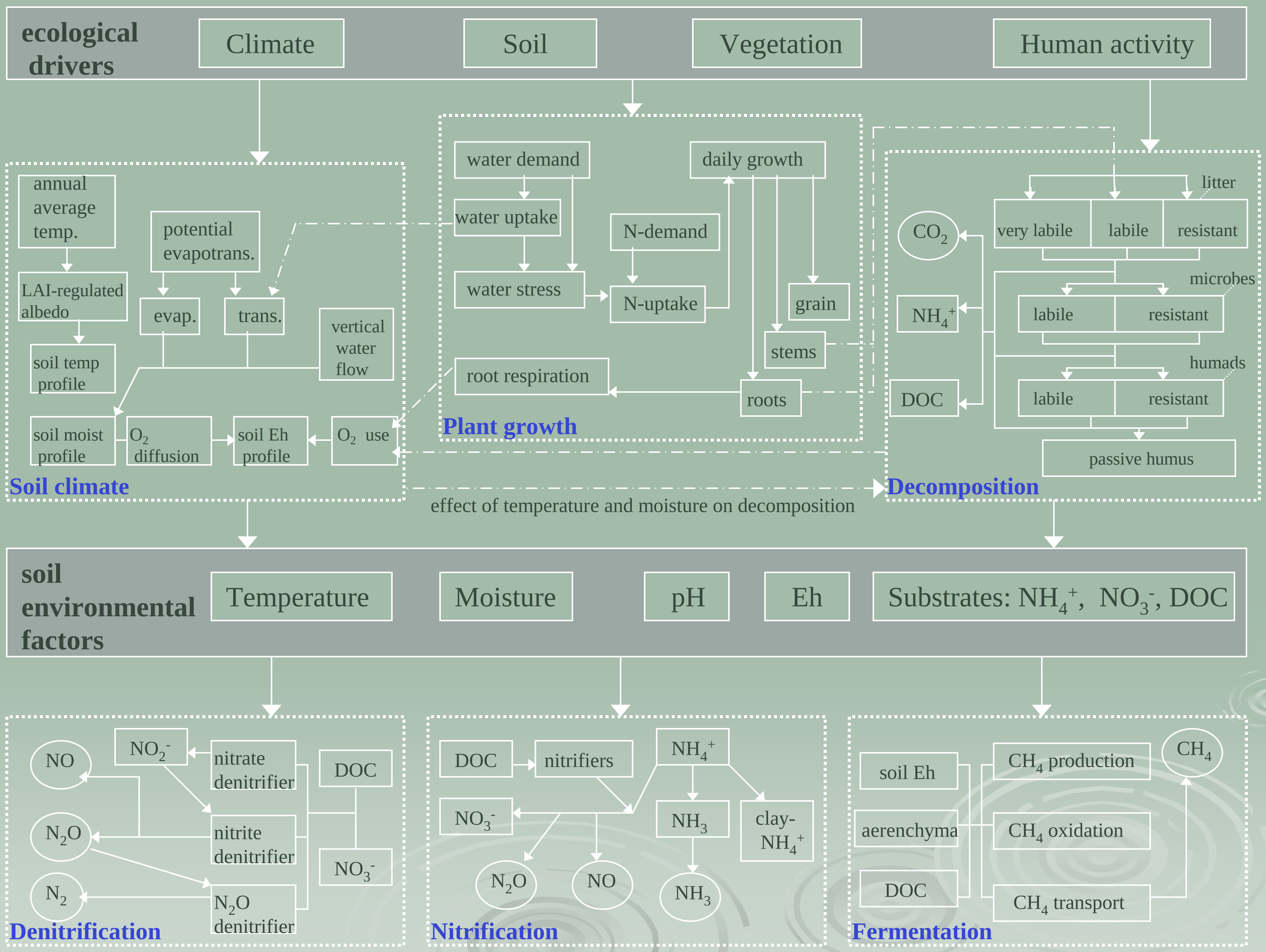
**Environmental factors**

- Gravity
- Radiation
- Temperature
- Moisture
- Eh
- pH
- Substrates

**Ecological drivers**

- Climate
- Soil properties
- Vegetation
- Anthropogenic activities

# The DNDC Model



**ecological drivers**

Climate

Soil

Vegetation

Human activity

annual average temp.

LAI-regulated albedo

soil temp profile

potential evapotrans.

evap.

trans.

vertical water flow

soil moist profile

$O_2$ diffusion

soil Eh profile

$O_2$ use

**Soil climate**

water demand

water uptake

water stress

N-demand

N-uptake

daily growth

grain

stems

roots

root respiration

**Plant growth**

litter

very labile

labile

resistant

microbes

labile

resistant

humads

labile

resistant

passive humus

$CO_2$

$NH_4^+$

DOC

**Decomposition**

effect of temperature and moisture on decomposition

**soil environmental factors**

Temperature

Moisture

pH

Eh

Substrates: $NH_4^+$, $NO_3^-$, DOC

NO

$N_2O$

$N_2$

$NO_2^-$

nitrate denitrifier

nitrite denitrifier

$N_2O$ denitrifier

DOC

$NO_3^-$

**Denitrification**

DOC

nitrifiers

$NH_4^+$

$NO_3^-$

$NH_3$

clay-$NH_4^+$

$N_2O$

NO

$NH_3$

**Nitrification**

soil Eh

aerenchyma

DOC

$CH_4$ production

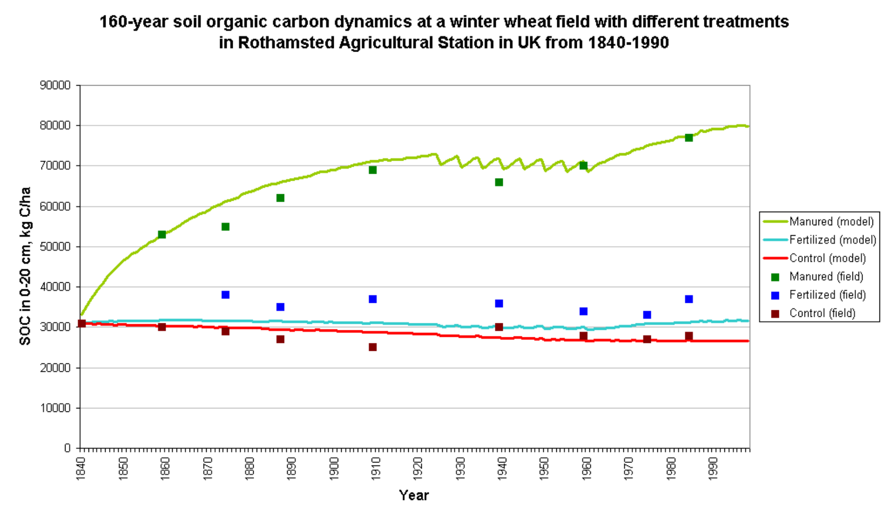
$CH_4$ oxidation

$CH_4$ transport

$CH_4$

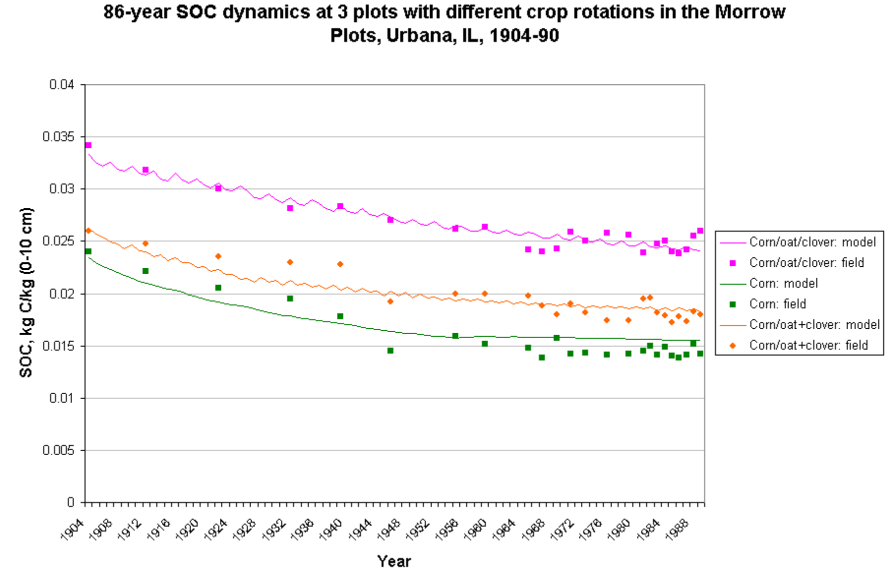
**Fermentation**

# Testing DNDC with long-term observations of SOC dynamics



Rothamsted Ag Station, UK:

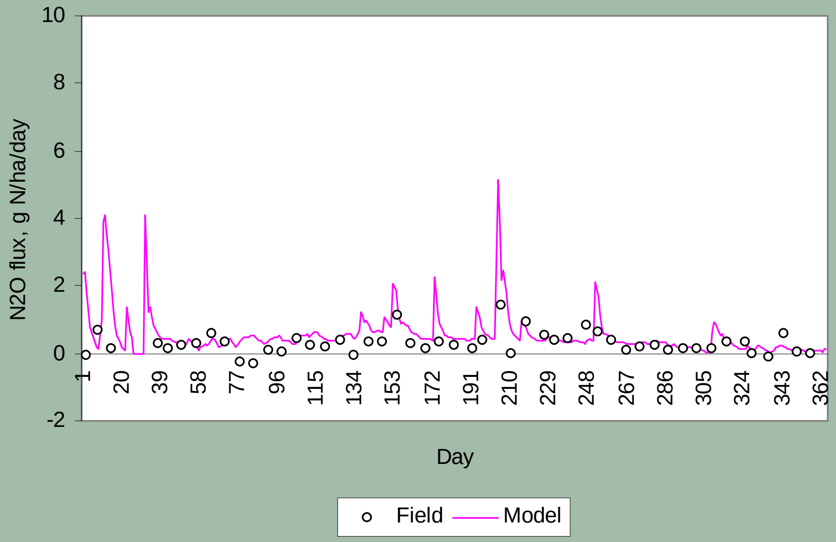
SOC in a winter wheat field with 3 treatments for 150 years (1840-1990)



Morrow Plots at Urbana, Illinois, US:

SOC in a crop field with 3 different crop-rotation systems for 86 years (1904-1990)

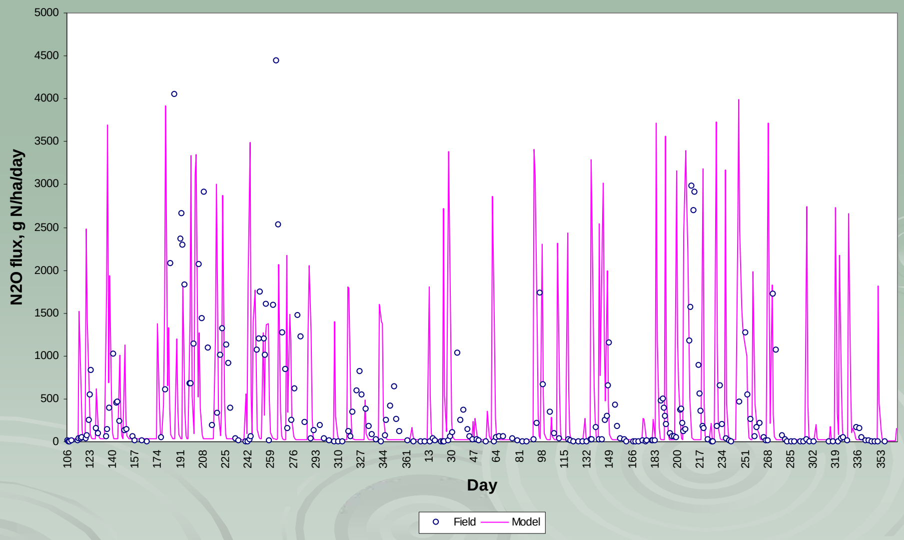
# Testing DNDC with observed background $N_2O$ emissions



Short-grass grassland, Fort Colins, CO, US:

Annual $N_2O$ flux is about 0.1 kg N/ha in 1991

**N2O Fluxes from a Organic Soil at Glades, Florida, 1979-80**

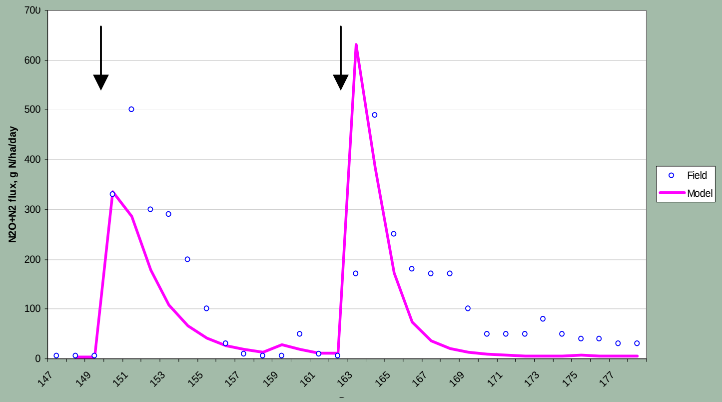


Bare organic soil, Everglades, FL, US:

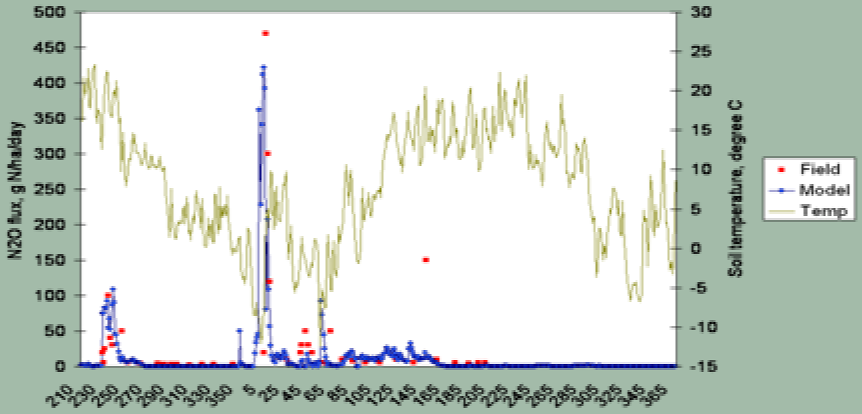
Annual $N_2O$ flux is 165 kg N/ha in 1979

# Testing DNDC with observed $N_2O$ emission epsodes induced by climate or management events

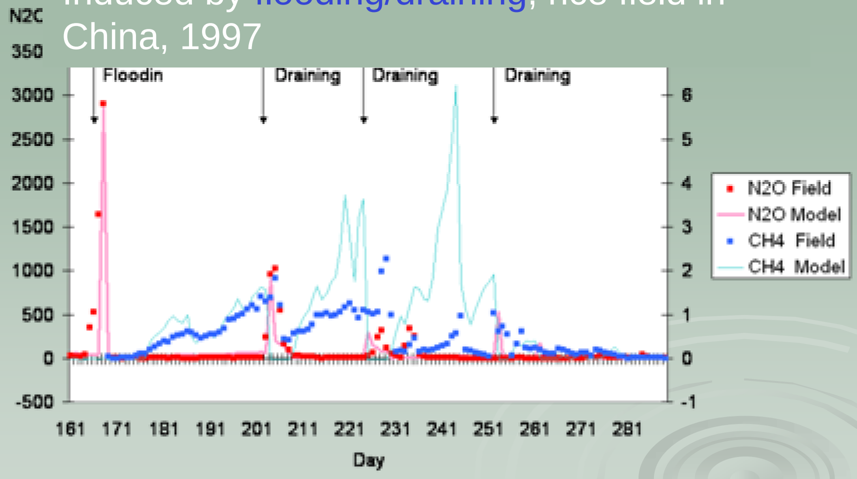
Induced by rainfalls, grassland in England, 1981



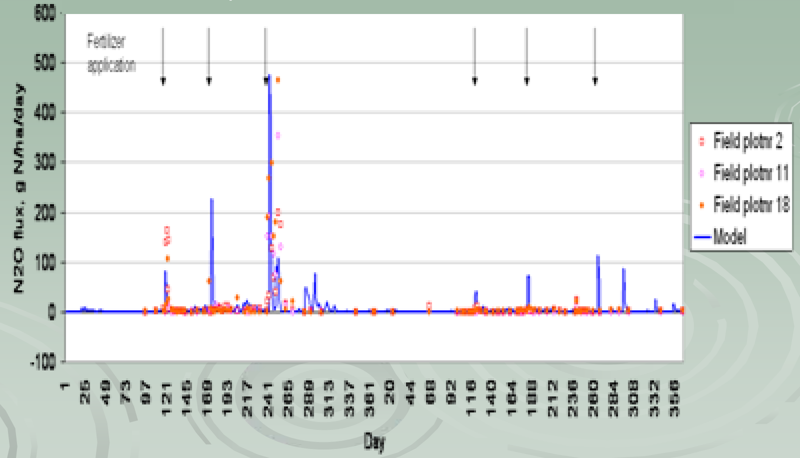
Induced by soil freezing/thawing, crop field in Germany, 1992-1993



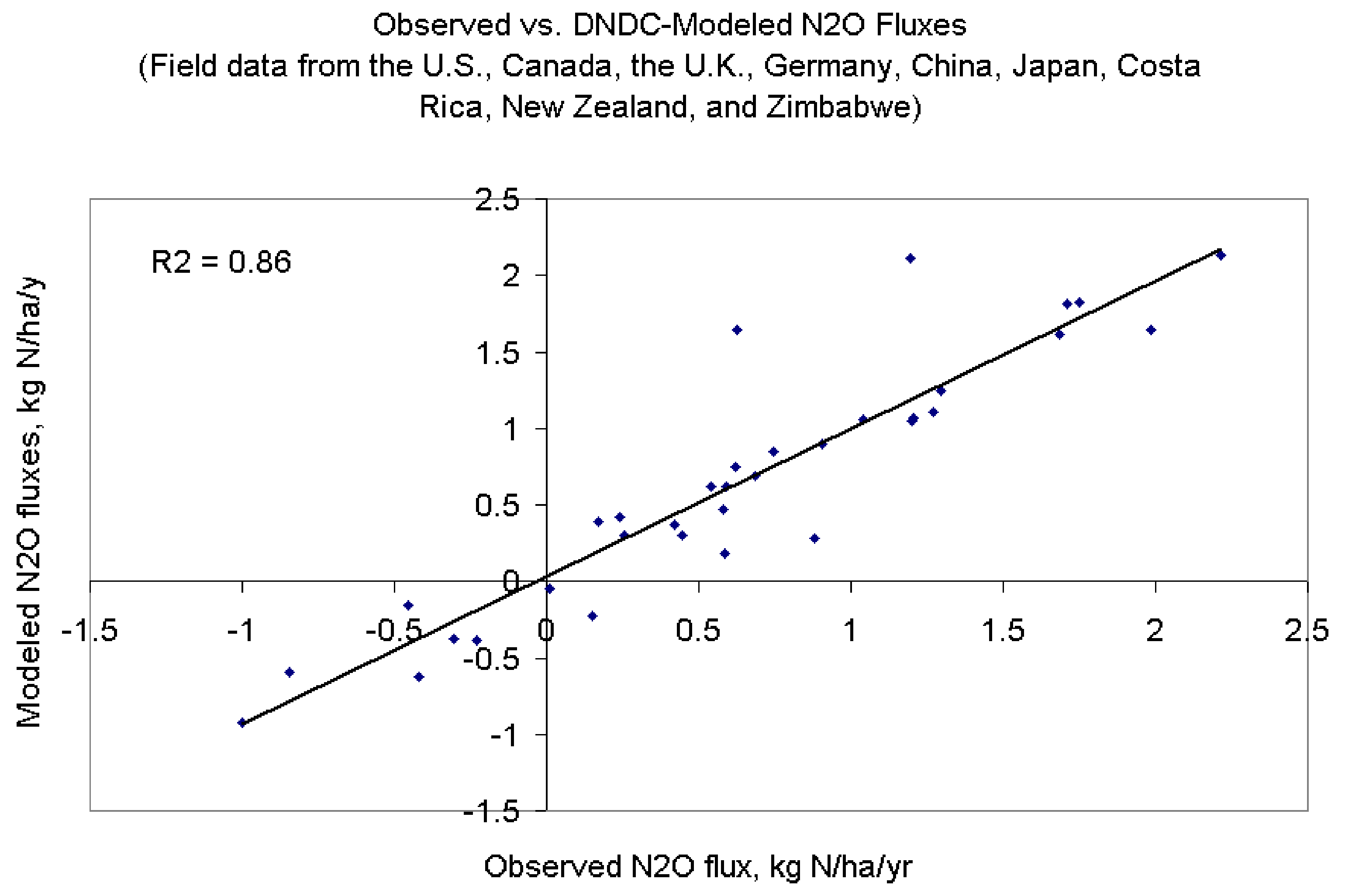
Induced by flooding/draining, rice field in China, 1997



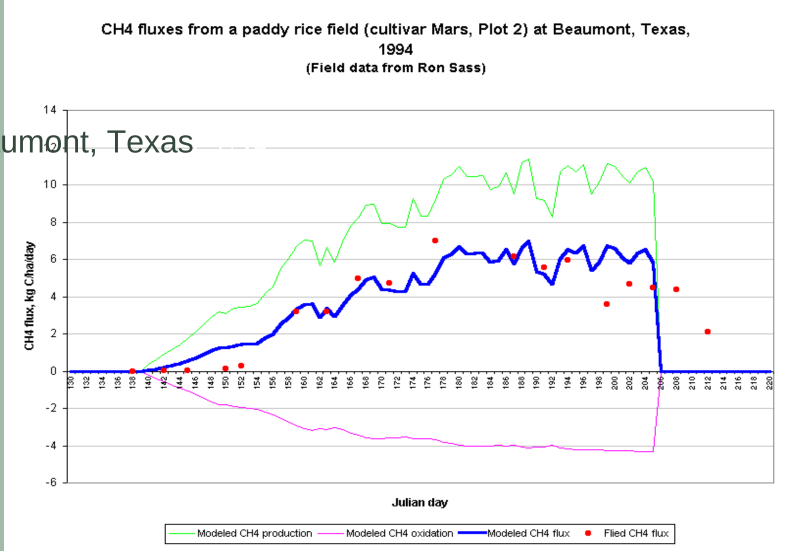
Induced by fertilization. pasture in Scotland, 2002-2003



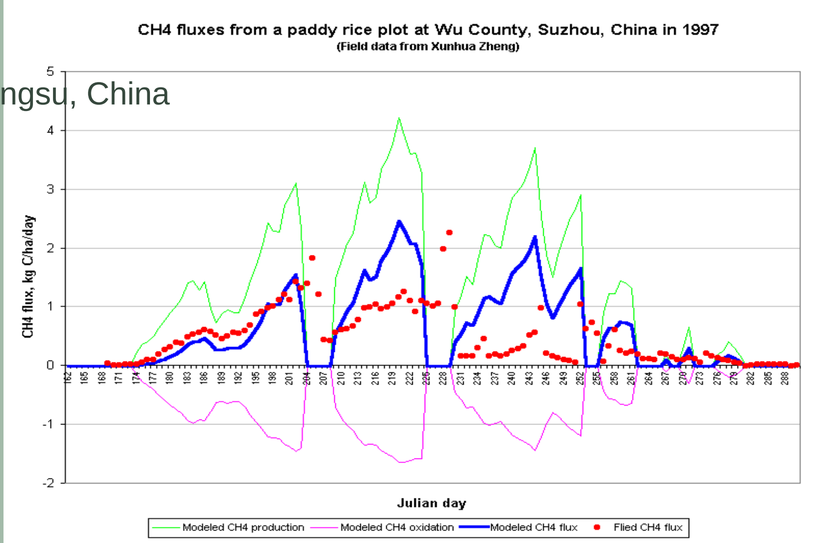
# Comparison between observed and DNDC-modeled $N_2O$ fluxes from 34 agricultural soils worldwide



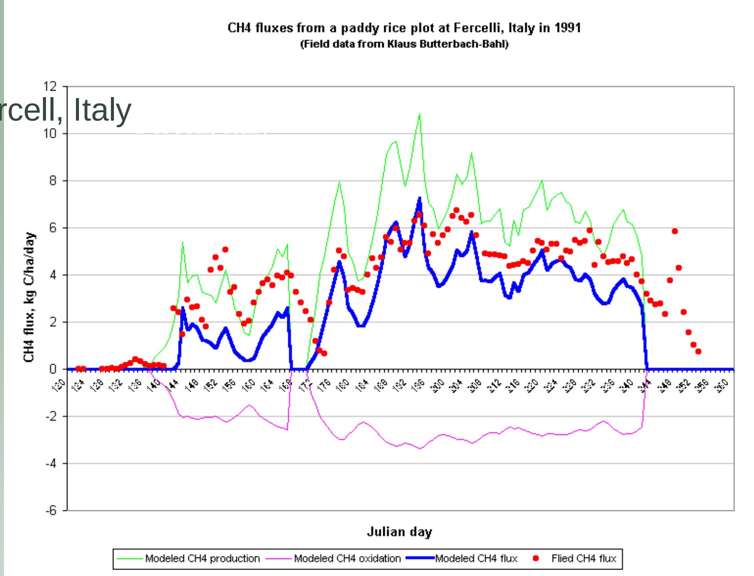
# Measured and Modeled $CH_4$ Fluxes from rice paddies


CH4 fluxes from a paddy rice field (cultivar Mars, Plot 2) at Beaumont, Texas, 1994
(Field data from Ron Sass)

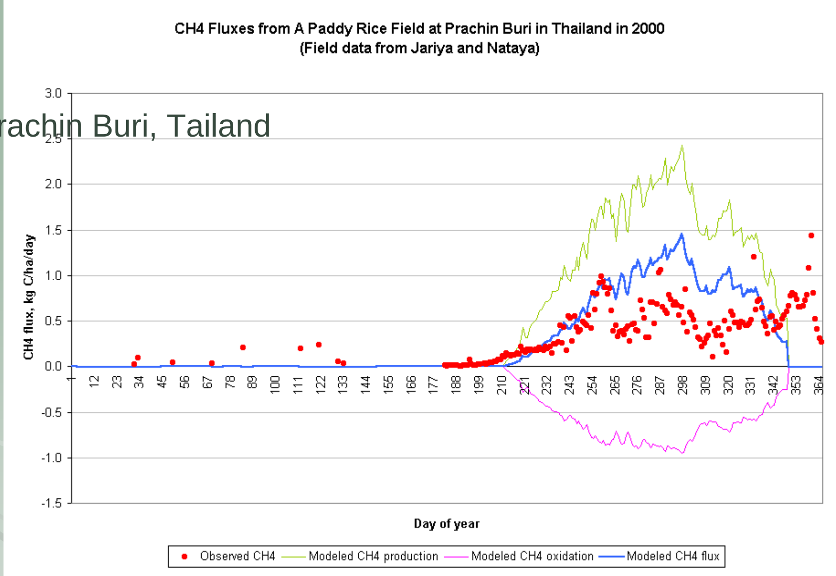
Beaumont, Texas


CH4 fluxes from a paddy rice plot at Wu County, Suzhou, China in 1997
(Field data from Xunhua Zheng)

Jiangsu, China

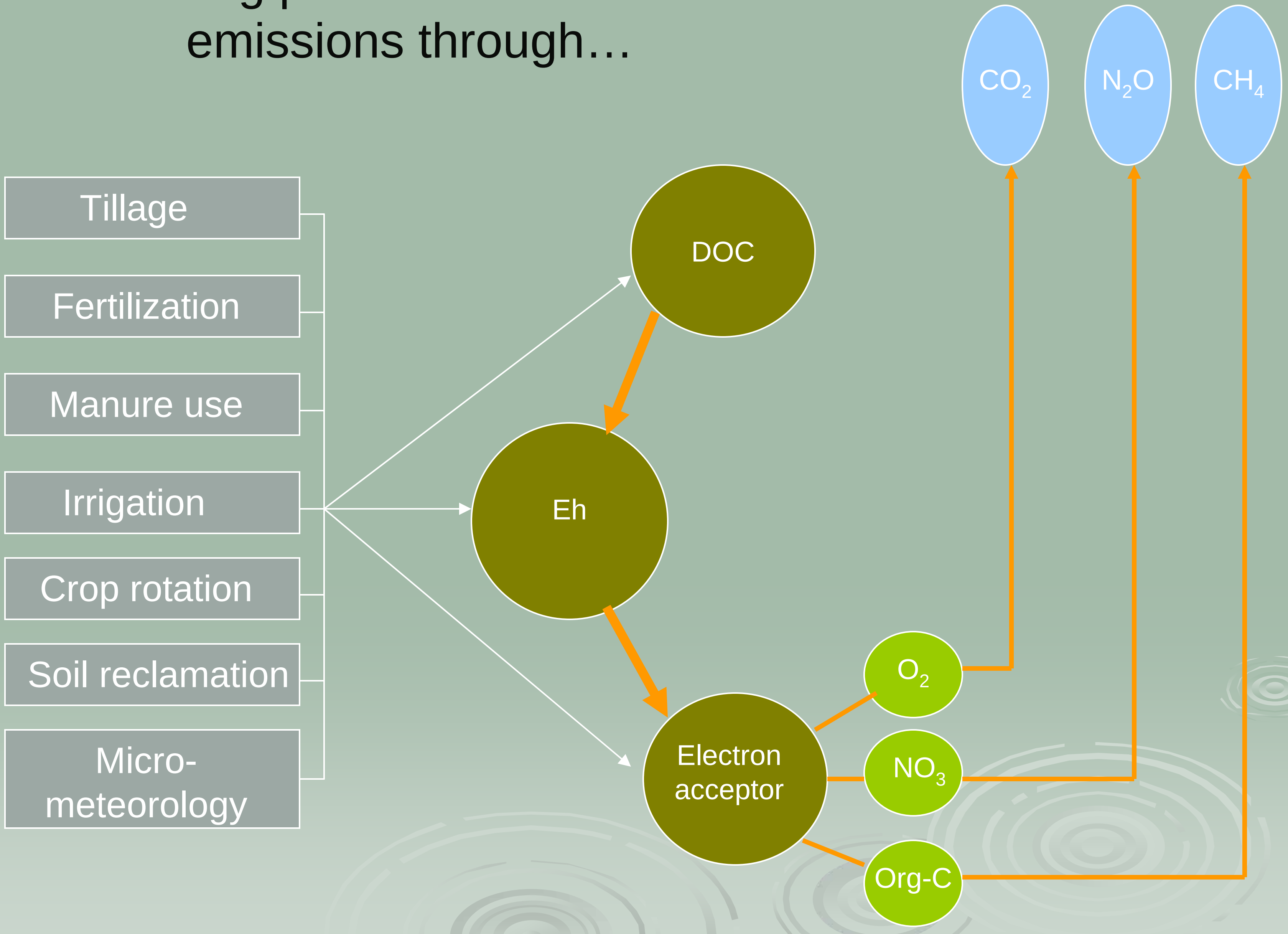

CH4 fluxes from a paddy rice plot at Fercelli, Italy in 1991
(Field data from Klaus Butterbach-Bahl)

Fercell, Italy


CH4 Fluxes from A Paddy Rice Field at Prachin Buri in Thailand in 2000
(Field data from Jariya and Nataya)

Prachin Buri, Tailand

# Farming practices affect GHG emissions through…



Tillage

Fertilization

Manure use

Irrigation

Crop rotation

Soil reclamation

Micro-meteorology

DOC

Eh

Electron acceptor

$O_2$

$NO_3$

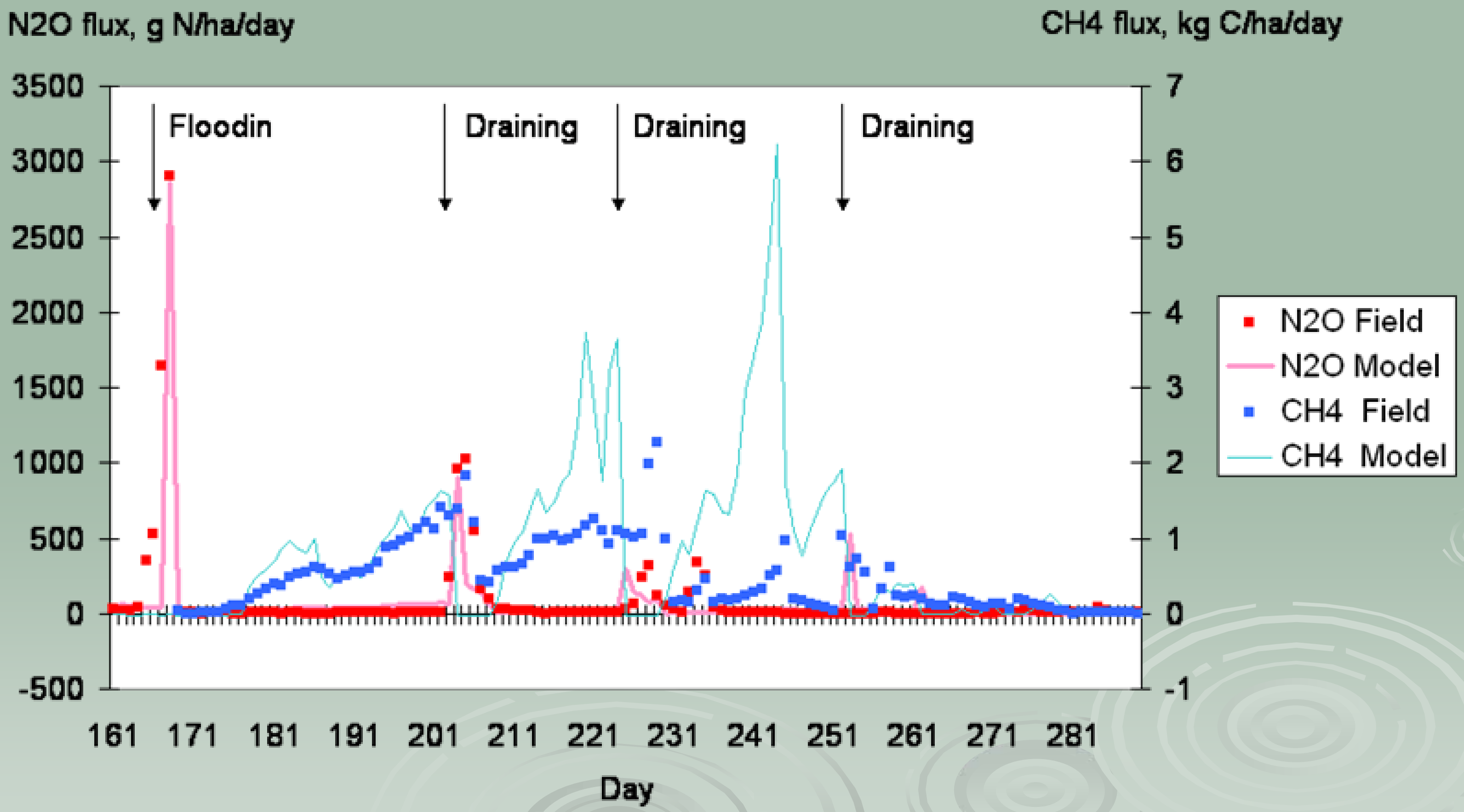
Org-C

$CO_2$

$N_2O$

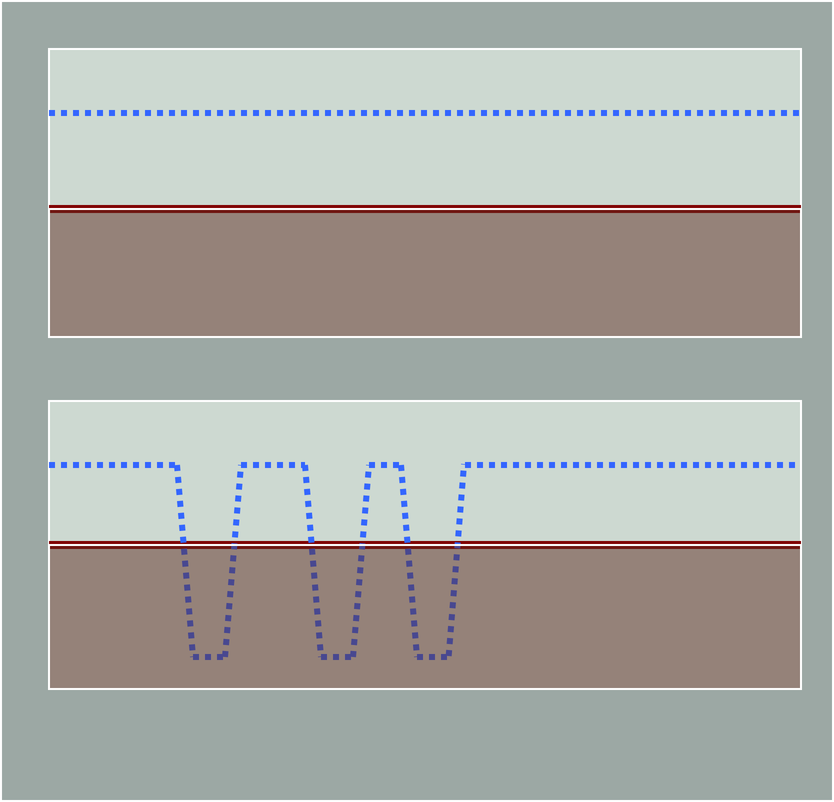
$CH_4$

# Impact of water management on $CH_4$ and $N_2O$ fluxes from a rice field in China



Observed and Modeled CH4 and N2O Fluxes from a Paddy Rice Field at Wu County, JIansu Province, China in 1997 (Field data from Zheng et al., 1999)

# Major water management practices for rice fields in China from 1950-2000



1950-1980: Continuous flooding

1980-2000: Midseason drainage

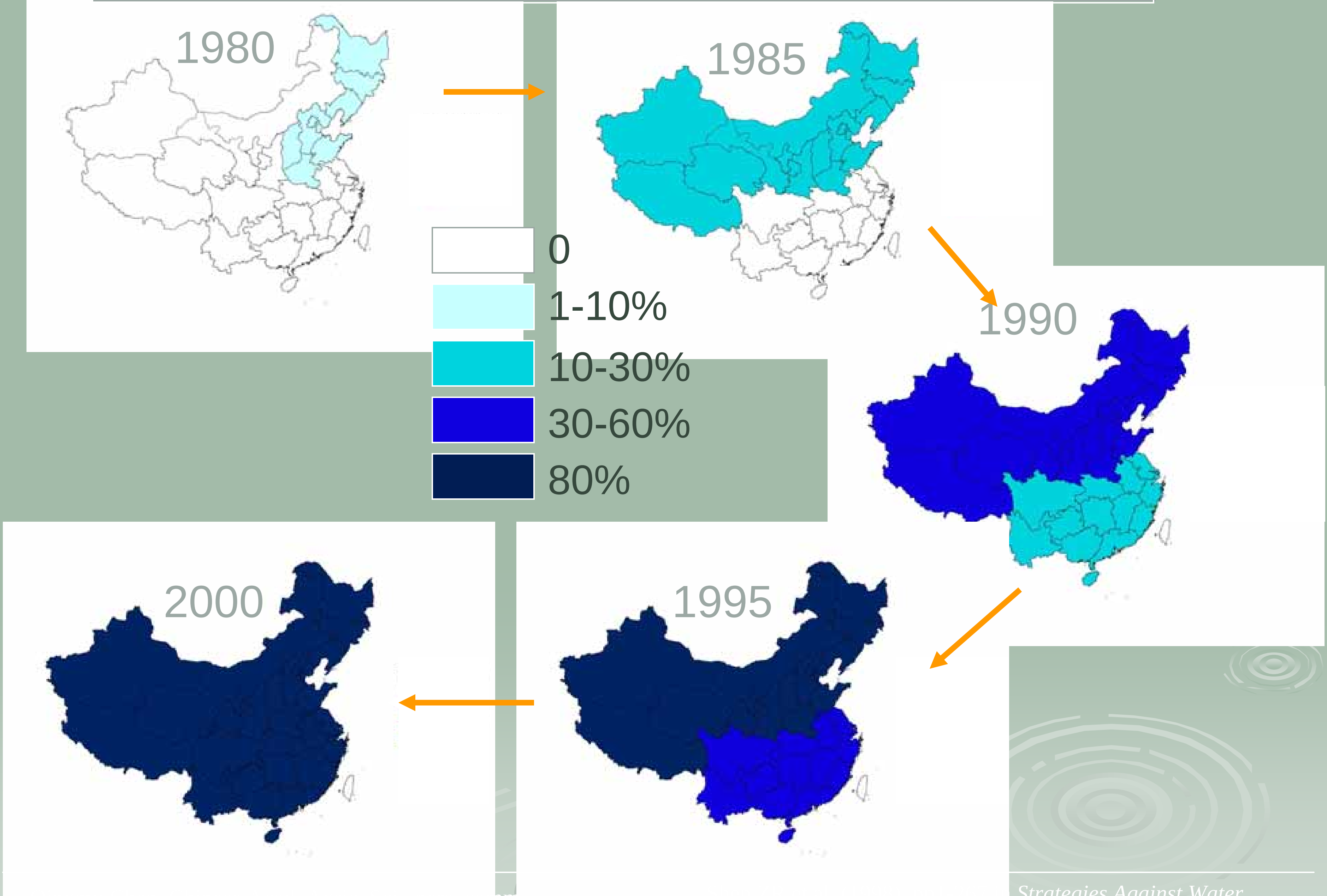
***Biogeochemical Implications:***

- Improve soil aeration;
- Stimulate root/shoot development;
- Increase soil mineralization.

***Consequences:***

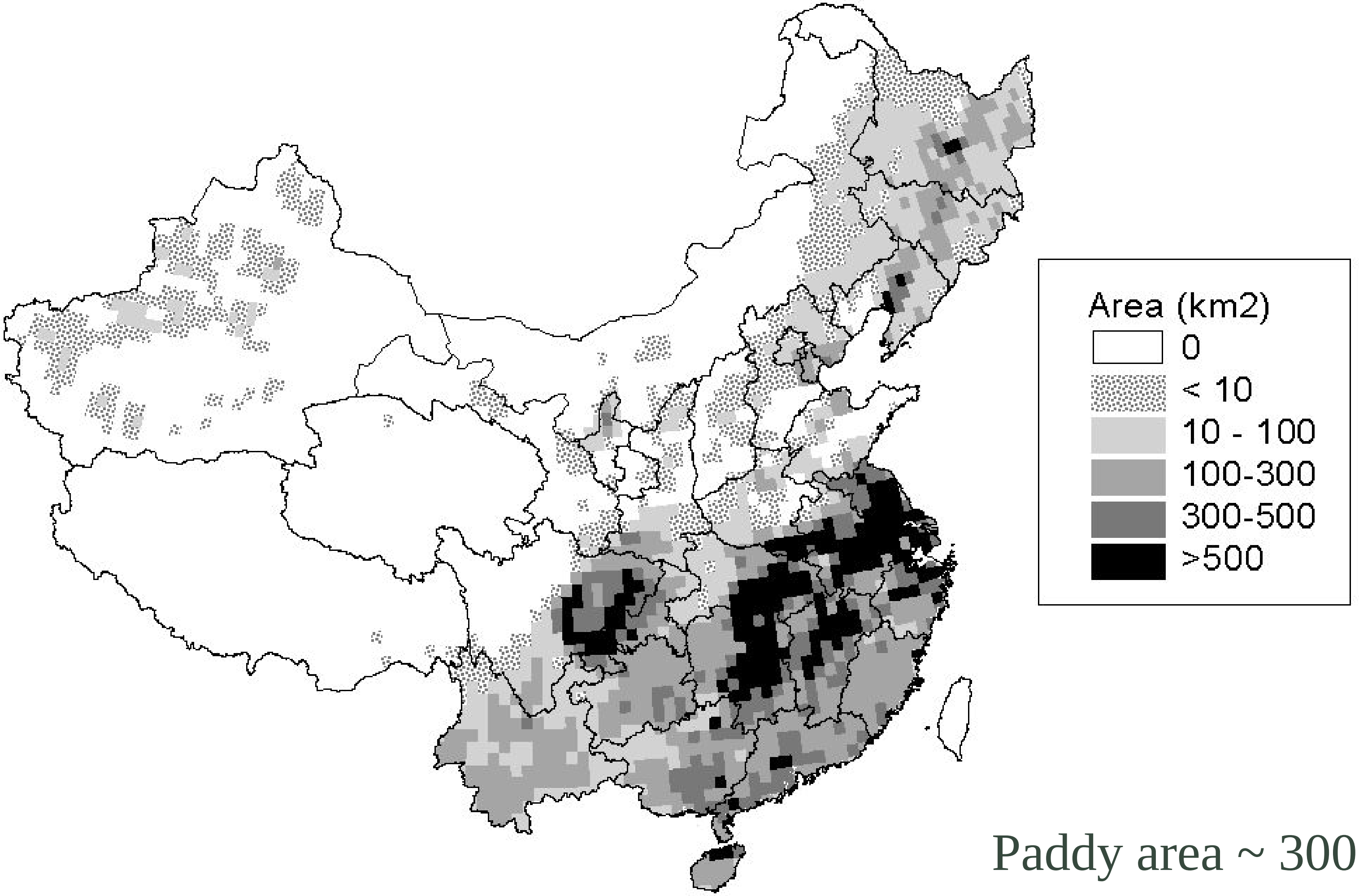
- Increase crop yield;
- Decrease water consumption;
- Alter GHG emissions.

# Rice Paddies with mid-season drainage (estimated)



Qinghu Chen, Chinese Acad. Agric. Sci., pers. comm.

*Strategies Against Water Crisis in Chinese Agriculture*, Ag. Sci. & Tech. Press, Beijing.

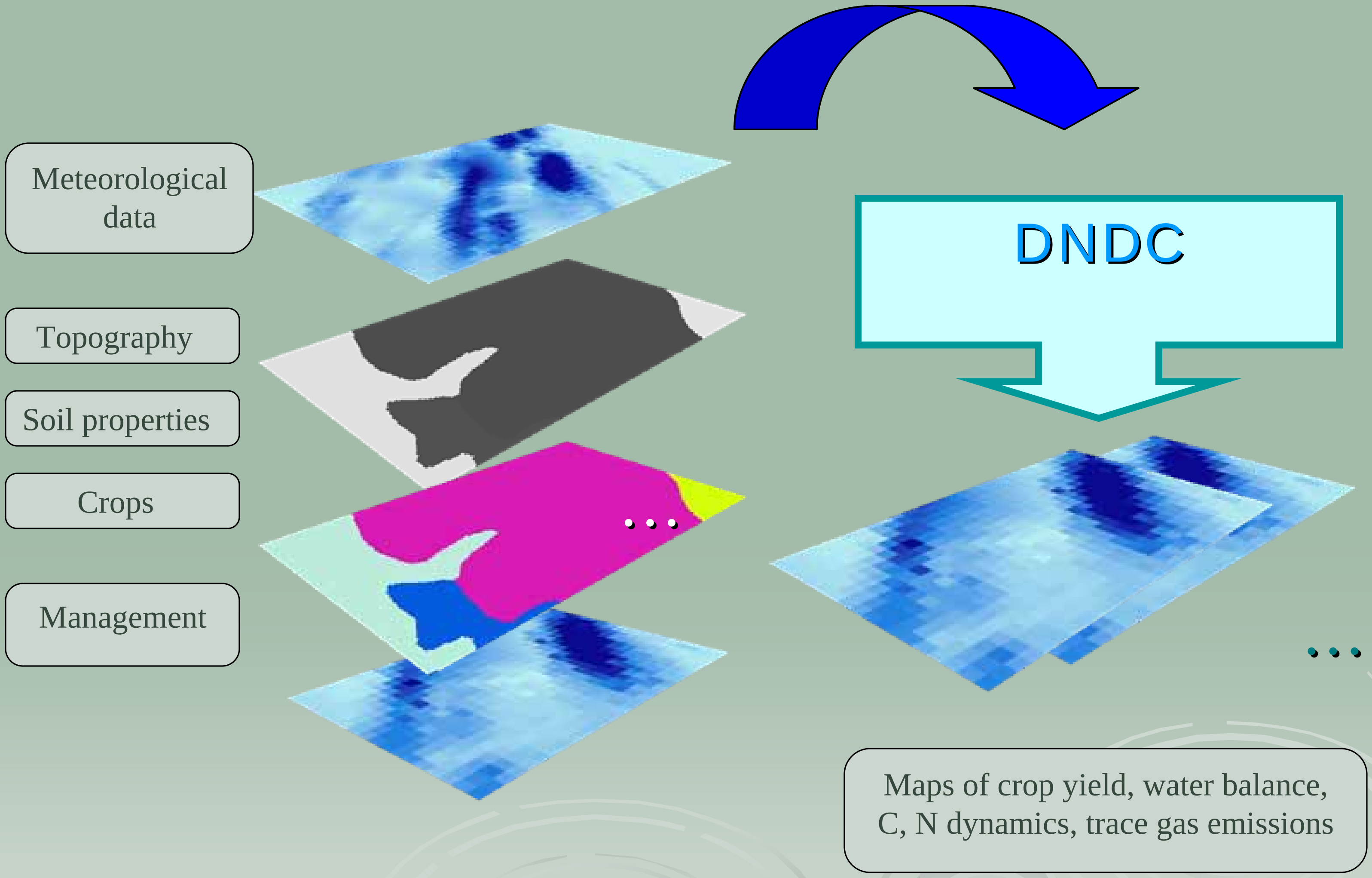


All rice -- pure and mixed (per 0.5 degree grid cell)

Paddy area ~ 300,000 km$^2$

Rice sown area ~ 470,000 km$^2$

# Linking DNDC with GIS database for upscaling



Meteorological data

Topography

Soil properties

Crops

Management

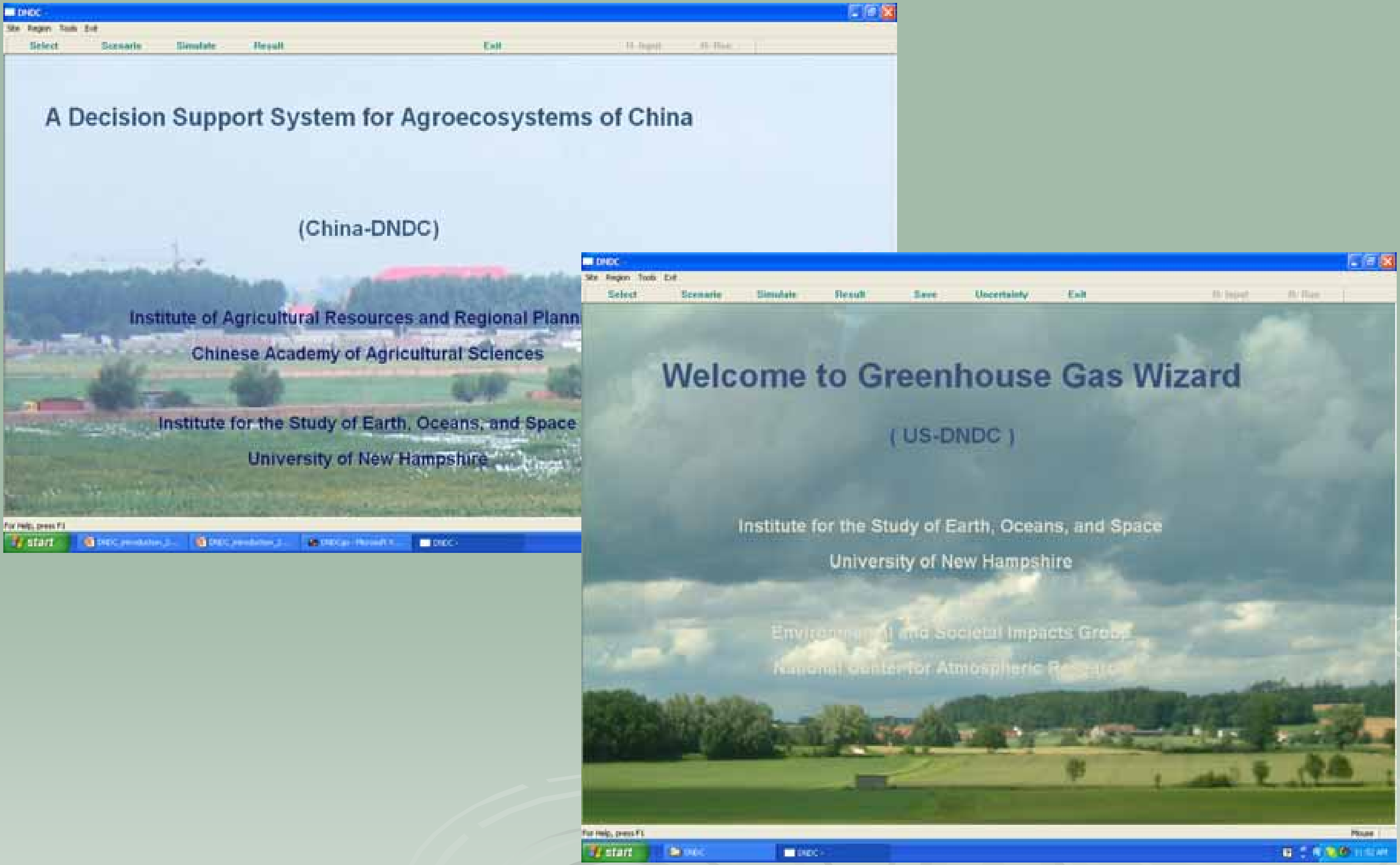
…

DNDC

…

Maps of crop yield, water balance, C, N dynamics, trace gas emissions

# Convert DNDC into decision support systems by linking it with spatial databases for regions



A Decision Support System for Agroecosystems of China

(China-DNDC)

Institute of Agricultural Resources and Regional Plann

Chinese Academy of Agricultural Sciences

Institute for the Study of Earth, Oceans, and Space

University of New Hampshire

Welcome to Greenhouse Gas Wizard

( US-DNDC )

Institute for the Study of Earth, Oceans, and Space

University of New Hampshire

Environmental and Societal Impacts Group

National Center for Atmospheric Research

# Modeled $CH_4$ and $N_2O$ emissions from all the rice fields in China

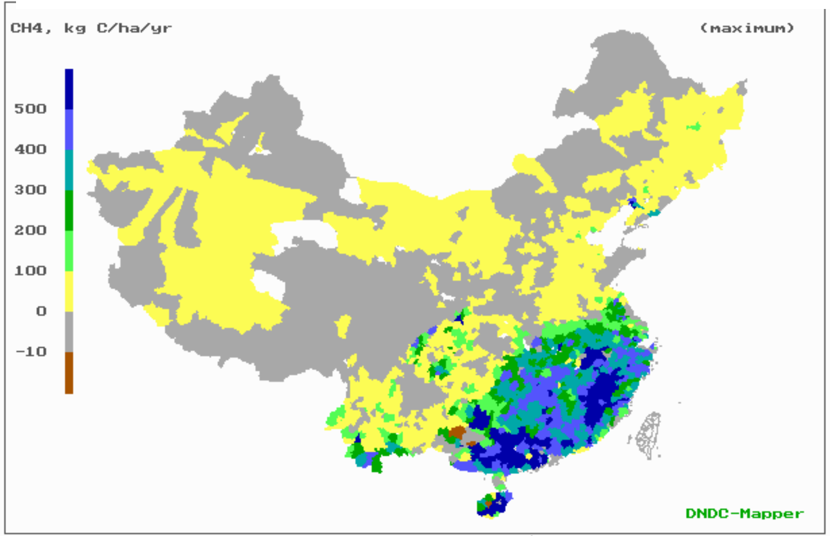
Conversion from continuous flooding to midseason drainage reduced $CH_4$ emission by 4.4 Tg $CH_4$-C but increased $N_2O$ emission by 0.17 Tg $N_2O$-N per year.

The increase in $N_2O$ offset about 65% of the benefit gained by the decrease in $CH_4$ emissions.

The net benefit is 43 Tg $CO_2$-equivalent per year.

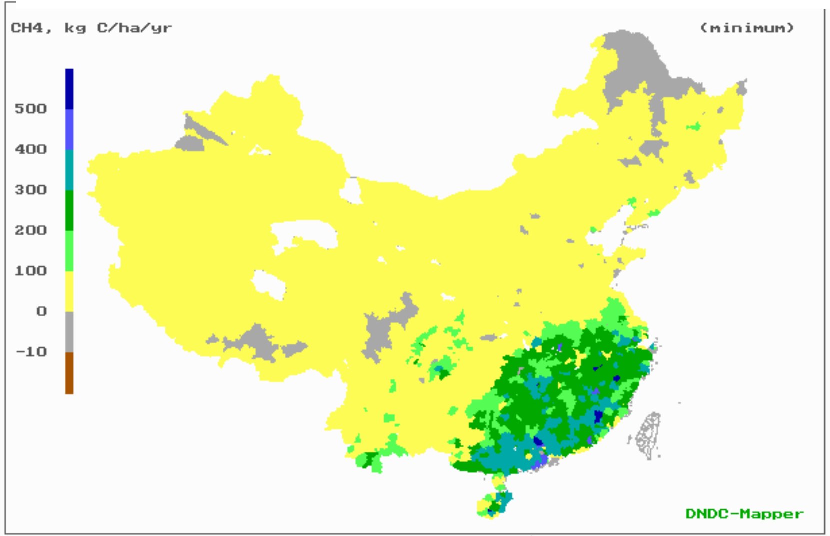
Continuous flooding:

9.2±2.8 Tg $CH_4$-C; 0.35±0.06 Tg $N_2O$-N

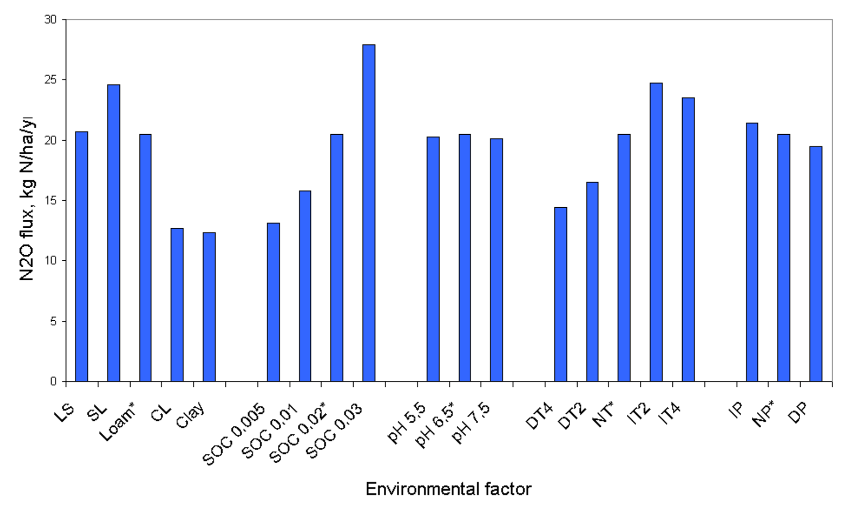


Midseason drainage:

4.8±3.1 Tg $CH_4$-C; 0.52±0.09 Tg $N_2O$-N

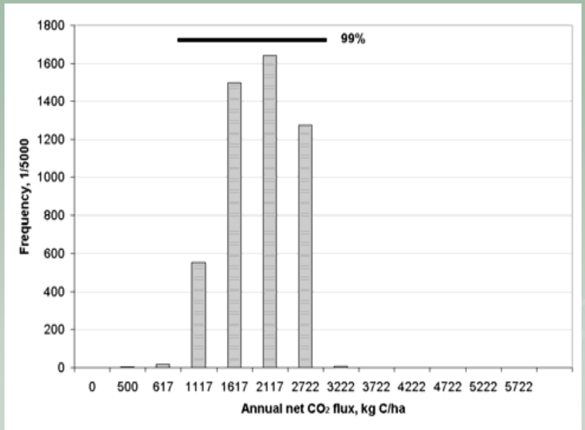


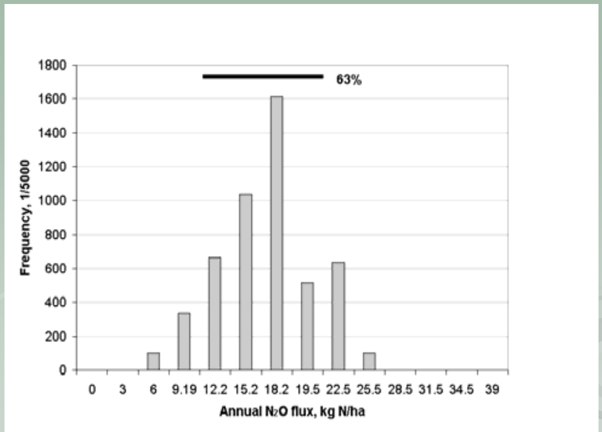
# Most Sensitive Factor (MSF) method is used for DNDC to quantify the uncertainty produced from upsacling

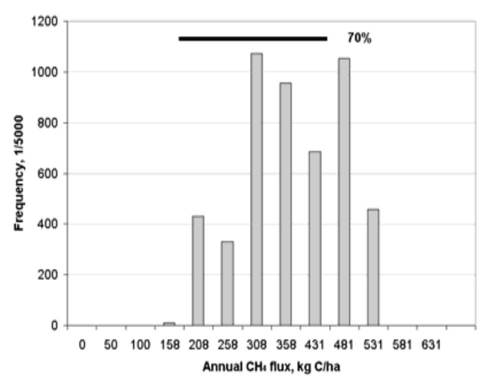


Sensitivity tests indicate that SOC and soil texture are most sensitive factors for $N_2O$ and $CH_4$.

60-90% of Monte Carlo method-produced GHG fluxes are located within the ranges produced with the MSF method for a rice field in Colusa County, California, USA







# Discussions

- Biogeochemical model is a powerful tool for quantifying agricultural greenhouse gas emissions by precisely tracking their impacts of farming management practices;
- After model verification, spatial database will become crucial for correctly producing regional estimates;
- Bias in database is unavoidable. Uncertainty must be quantified to back the modeled results.

Thanks