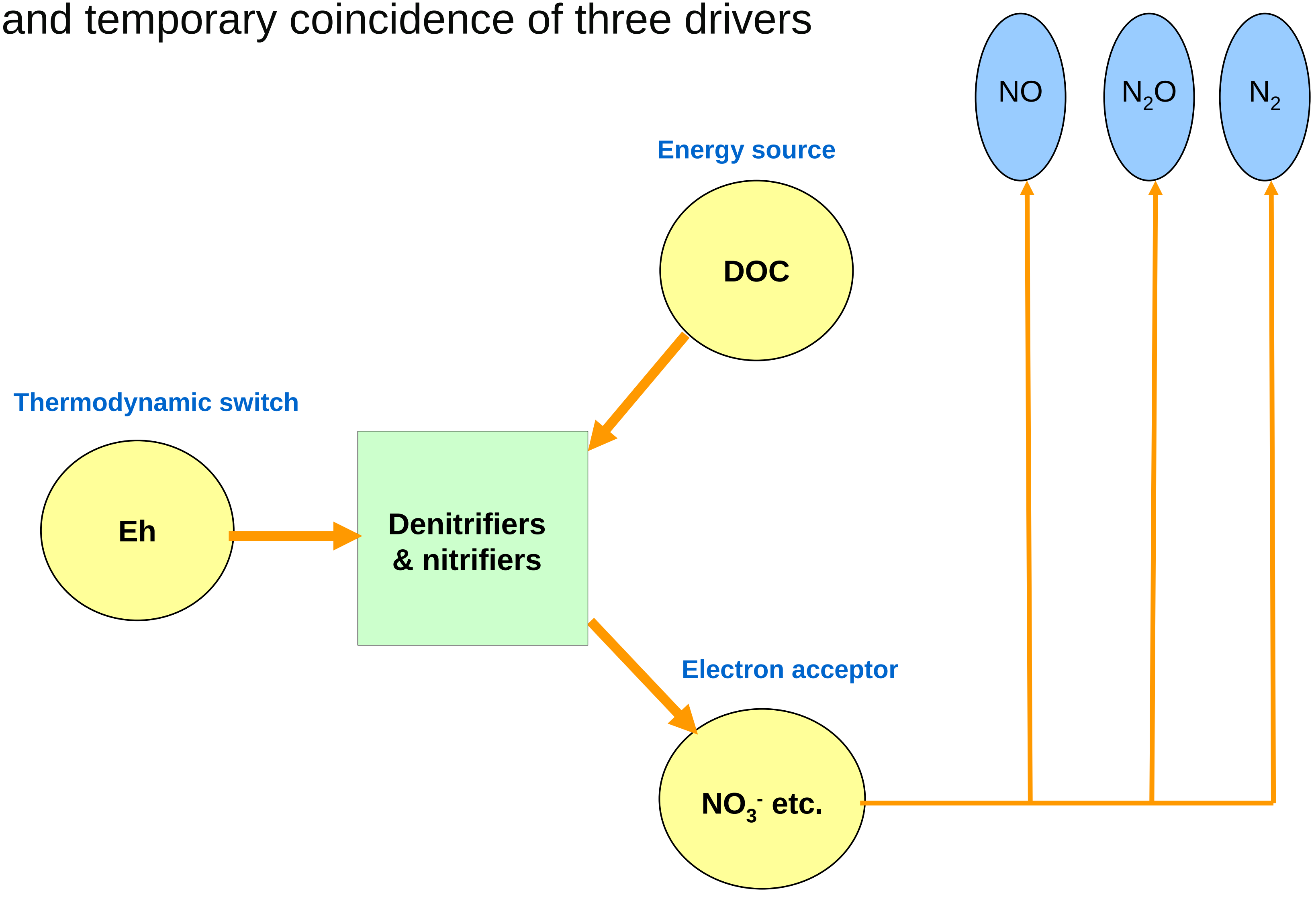
Uncertainty of Quantifying Soil N_2O Emission with Process-Based Model

Changsheng Li

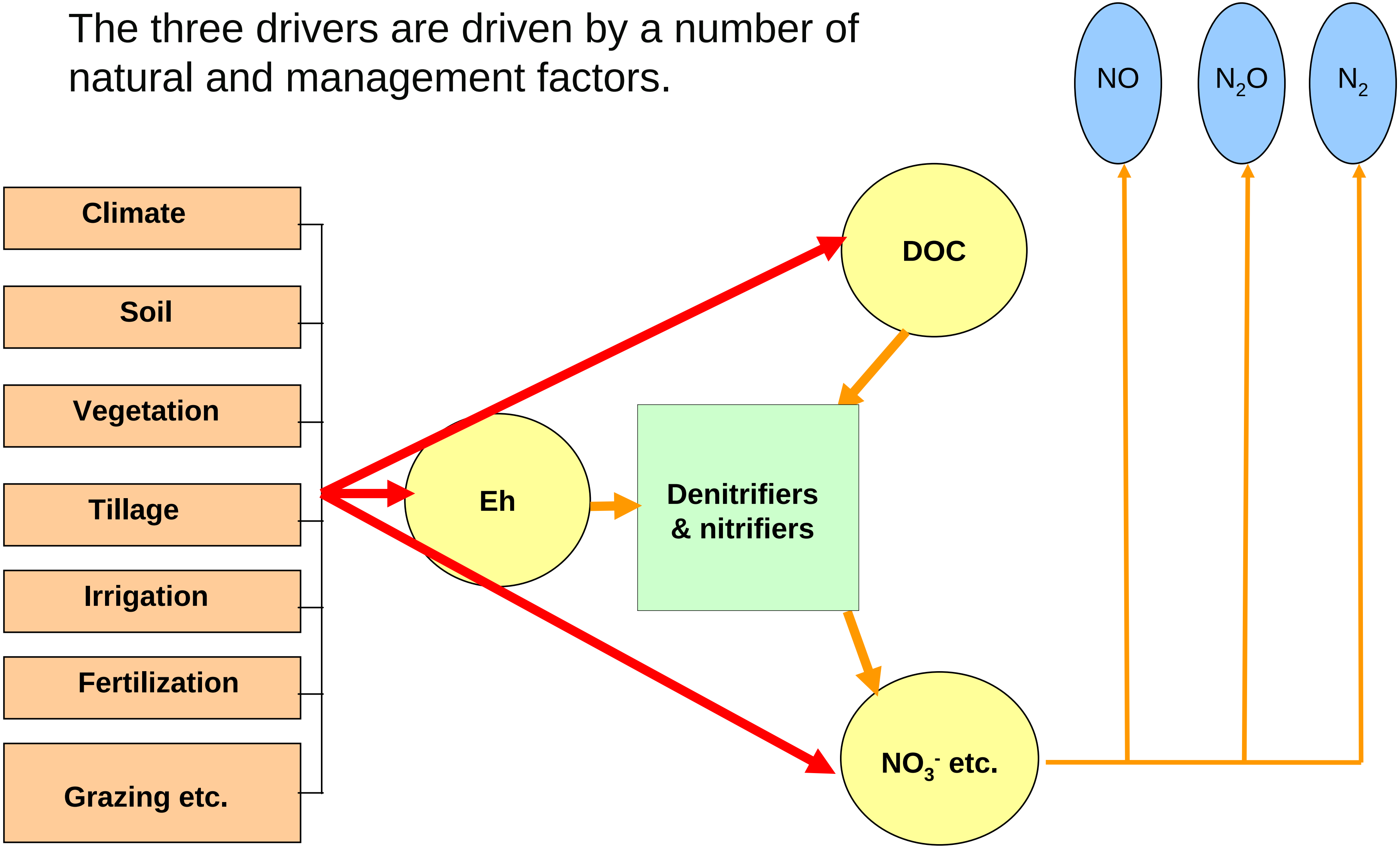
Institute for the Study of Earth, Oceans and Space
University of New Hampshire, USA

MC2 Conference, Palmerston North, NZ, 11/17-21/2009

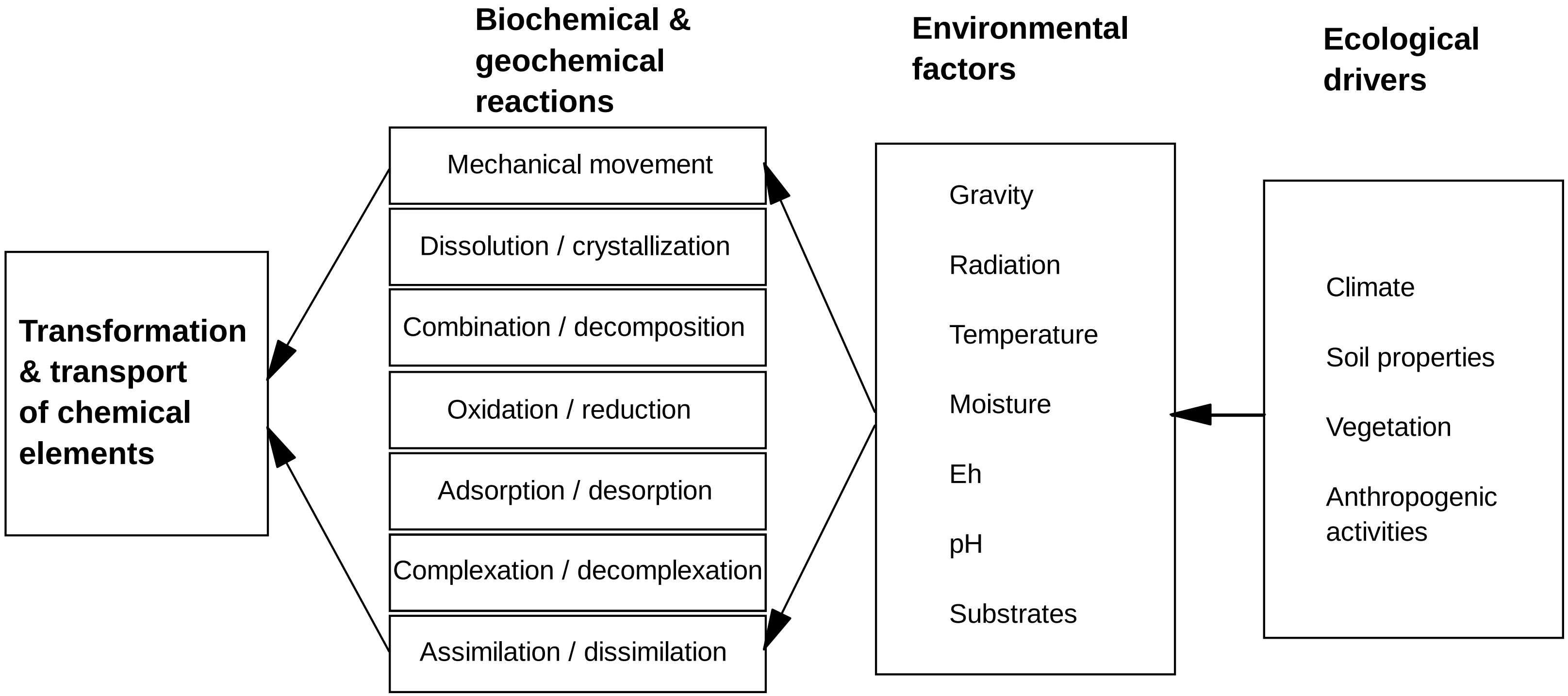
N_2O emission is highly variable due to the spatial and temporary coincidence of three drivers



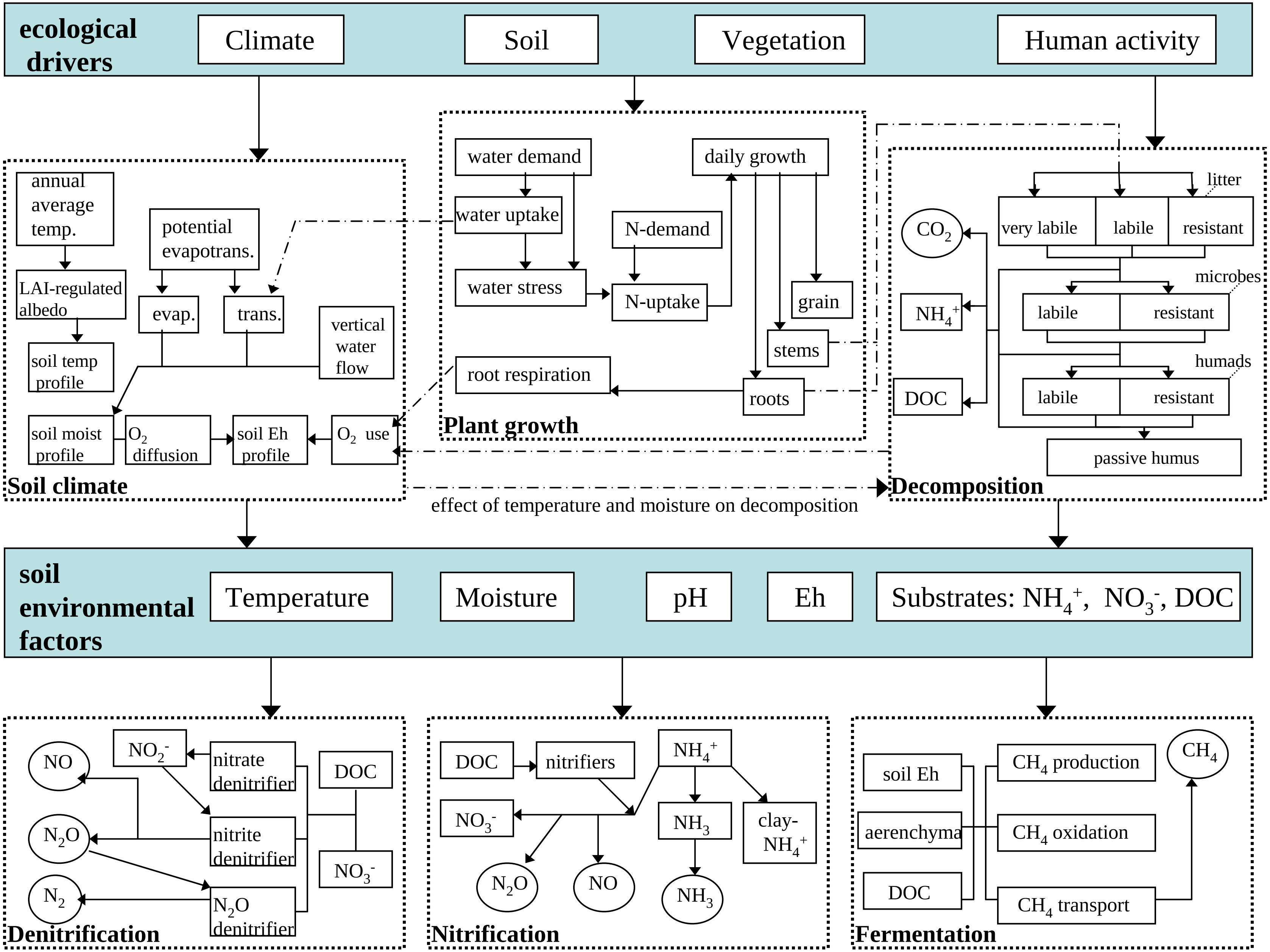
The three drivers are driven by a number of natural and management factors.



Biogeochemical concepts were utilized to build a process-based model



The DNDC Model



Uncertainty of model performance comes from two sources:

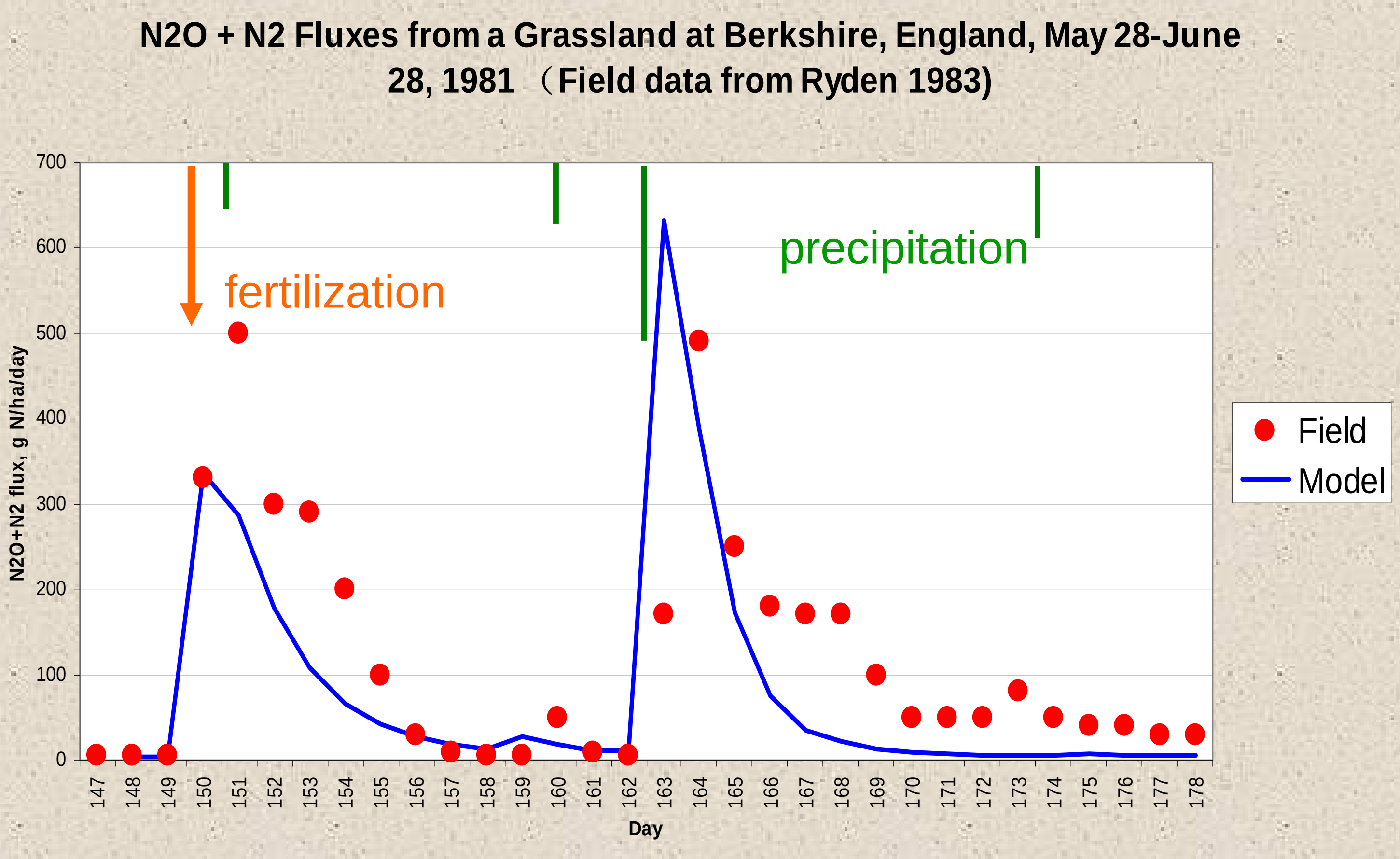
(1) **Scientific structure** (processes and parameterization);

(2) **Input data**.

Defects in scientific structure of models can be diagnosed through validation tests against observed **patterns** and **magnitudes** of N_2O fluxes.

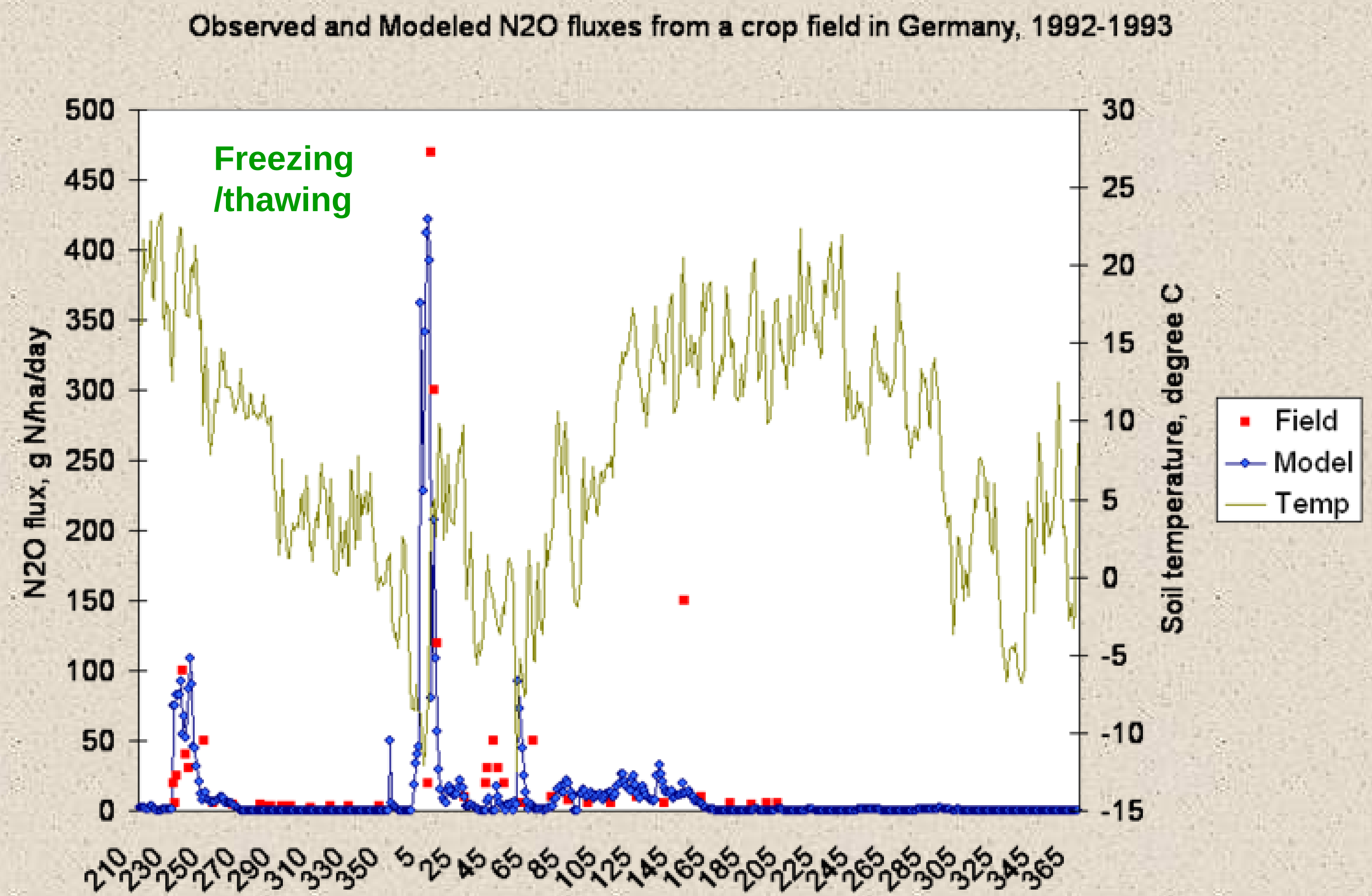
Pattern tests are usually focused on the characteristic episodes of N_2O emissions.

N_2O emission is stimulated by rainfall events

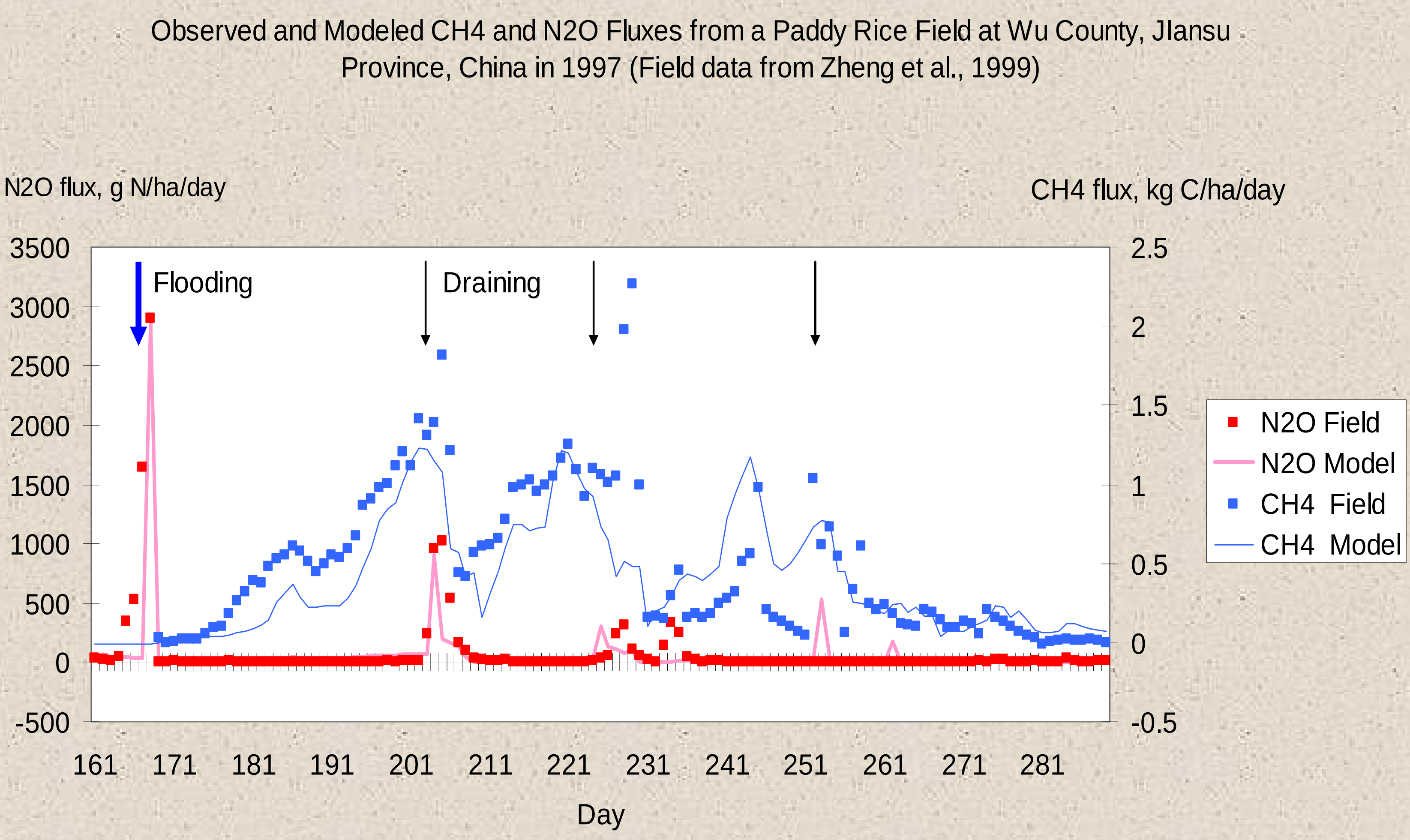


N_2O emission is stimulated by freezing/thawing events

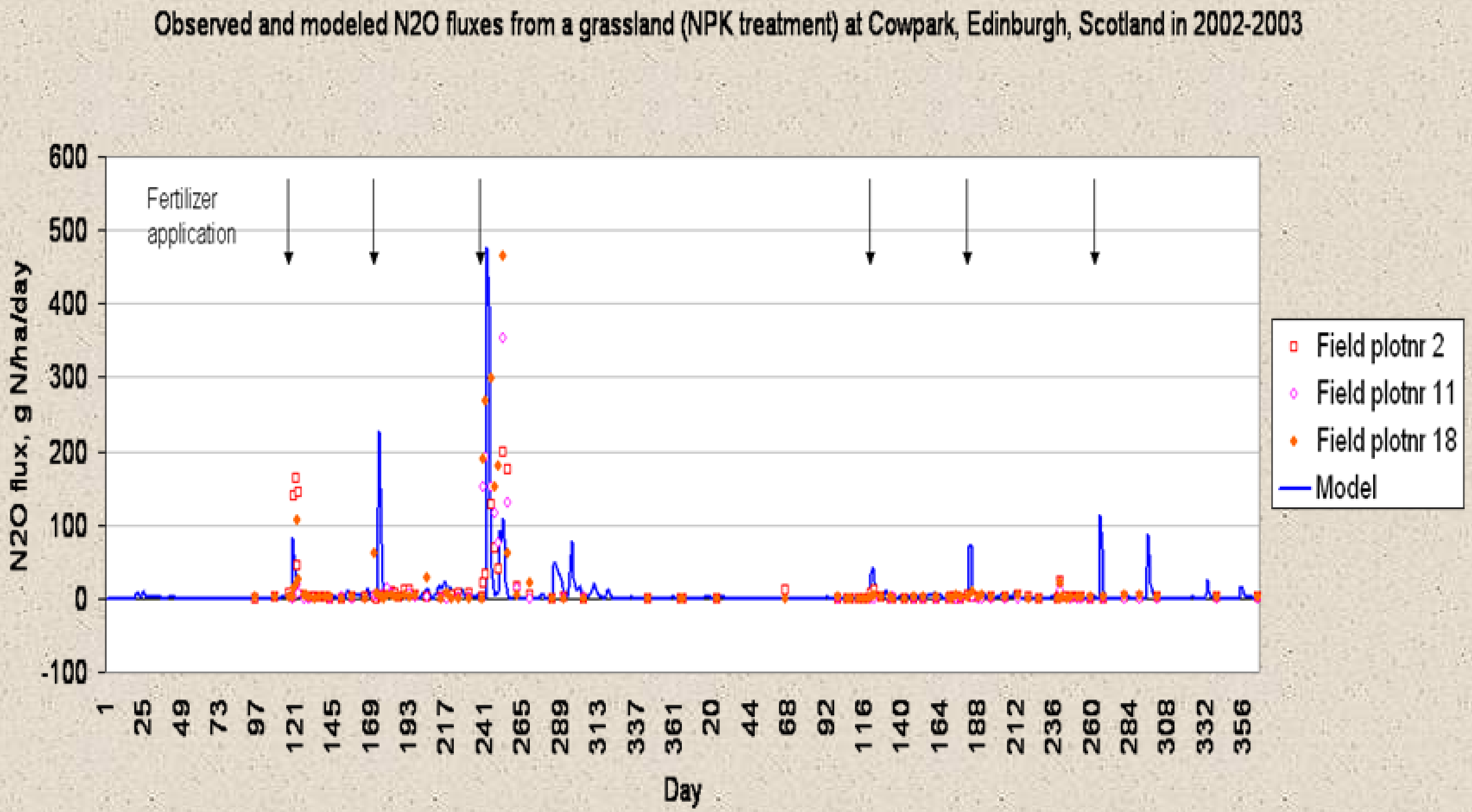
（Field data from Flessa et al. 1995)



N_2O emission is stimulated by flooding/draining events



N_2O emission is stimulated by fertilizing events



Deflection of modeled N_2O emission pattern can be located by a sequence of validation tests on

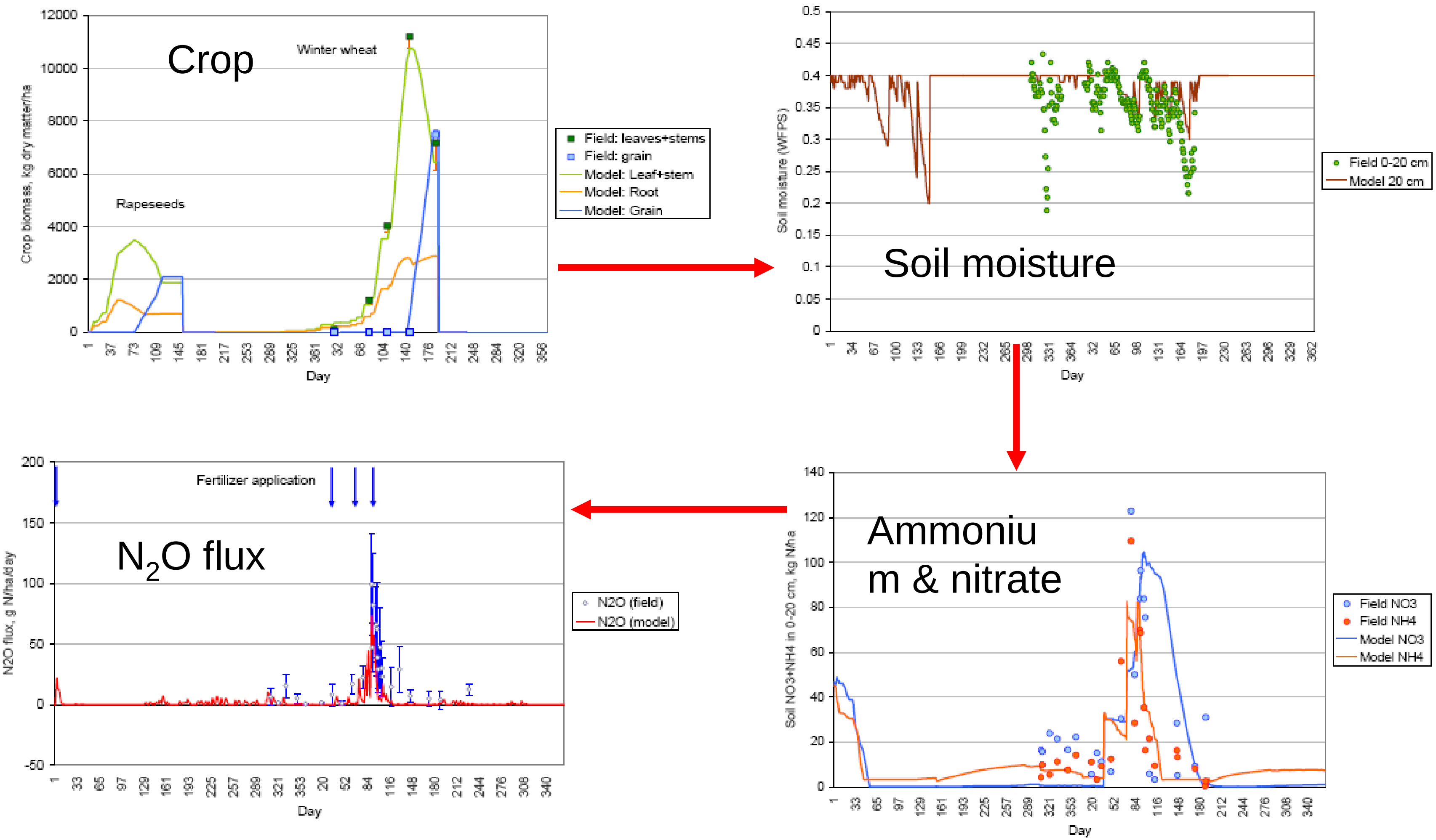
- crop growth/yield,

- soil climate,

- soil C dynamics, and

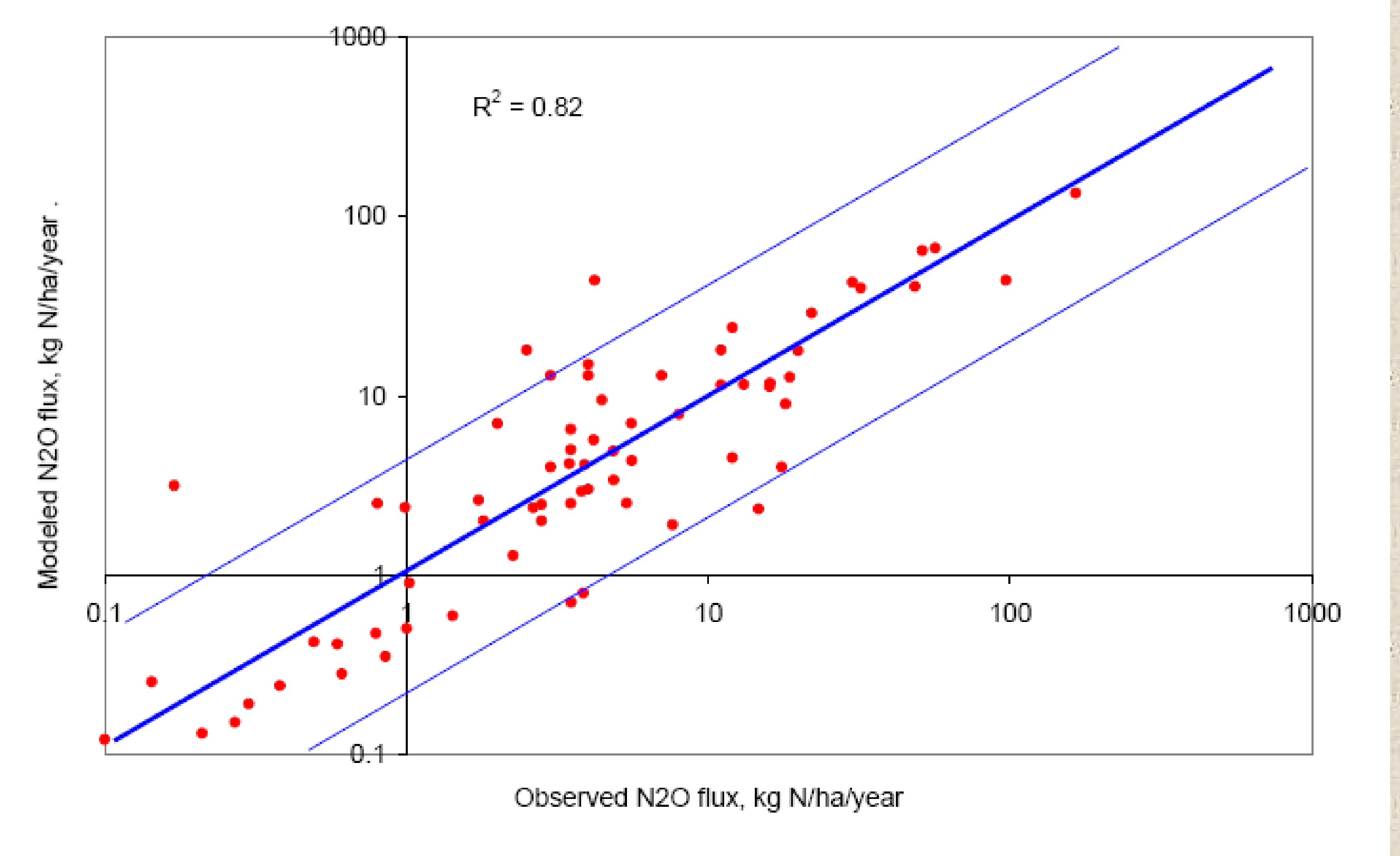
- N fluxes.

Measured and modeled crop biomass, soil moisture, soil ammonium and nitrate, and N_2O emissions in a farmland at Arrou, France in 1998 and 1999 (Field data from Hénault et al. 2005)



Magnitude tests are usually based on large samples of comparisons between modeled and measured results.

Observed and DNDC-Modeled Annual N_2O Fluxes for 69 Agricultural Sites in U.S., Canada, U.K., Germany, Belgium, France, Swiss, New Zealand, China, Japan, and Costa Rica



A summarized version of DNDC with no processes requiring only 9 input parameters

$$F = \prod_{i=0}^{4} A_i + \prod_{j=0}^{2} B_j \frac{R_f}{\prod_{k=0}^{7} K_k + R_f}$$

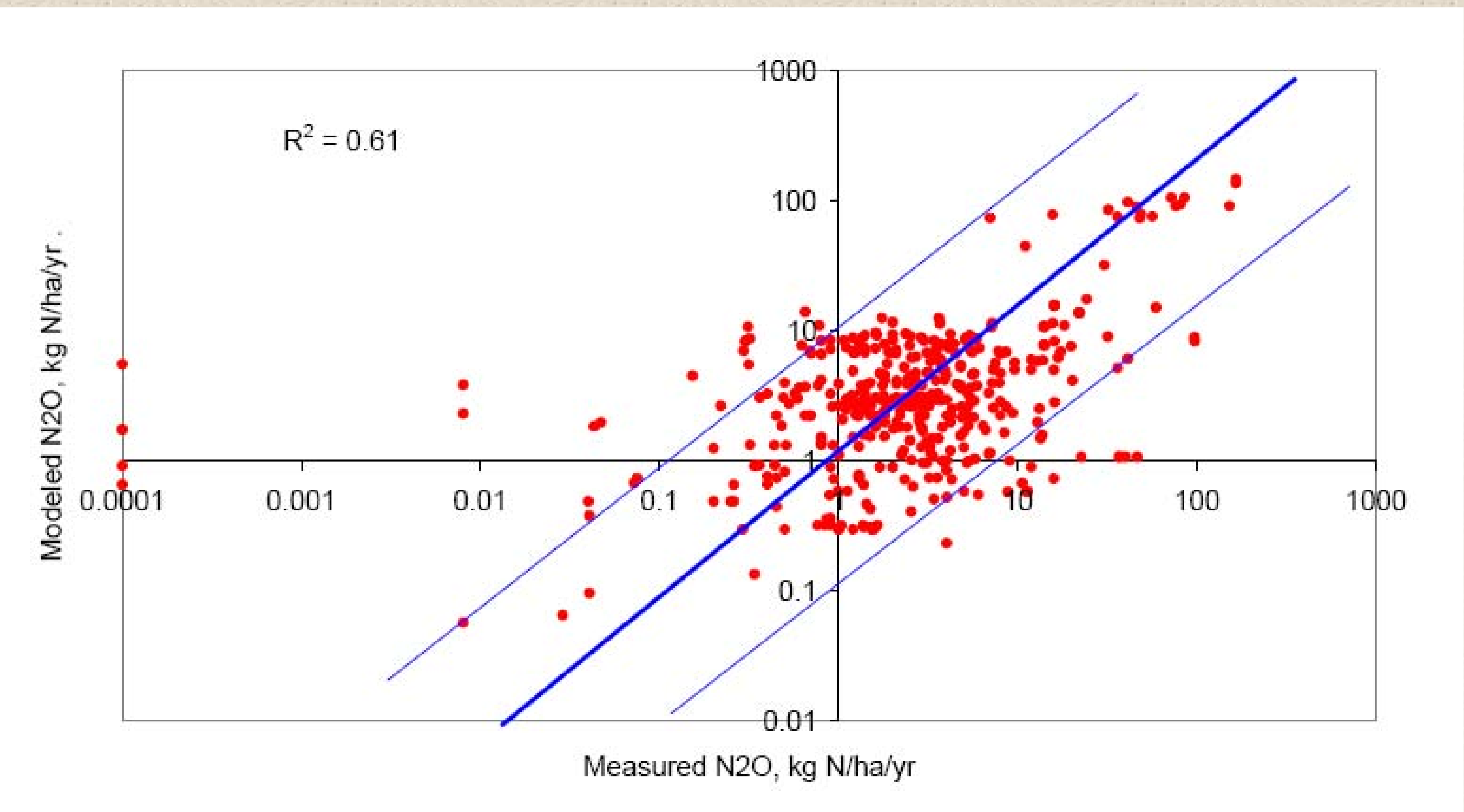
Coefficient equations	$A_0 = 2.13$; $A_1 = 245C - 1.4385$ $A_2 = 1E\text{-}05(CN)^2 - 0.0053(CN) + 1.5254$ $A_3 = 0.9259e^{0.0005(M)}$ $A_4 = 1/LU^2$ $B_0 = 35$; $B_1 = 0.2207e^{0.1858(T)}$ $B_2 = 21.704*\ln C + 122.51$ $K_0 = 300$ $K_1 = 0.2356e^{0.1694(T)}$ $K_2 = 2E\text{-}05(P)^2 - 0.0361\ (P)\ + 15.433$ $K_3 = 1.0339e^{3.9509(CLAY)}$ $K_4 = 0.2029(PH)^2 - 2.7911(PH) + 10.568$ $K_5 = 0.0745e^{0.0166(CN)}$ $K_6 =$ 2.14 (for anhydrous ammonia or ammonium bicarbonate) or 1 (for other fertilizers) $K_7 = -9E\text{-}05(M) + 0.9808$
Definitions	F: annual soil N2O flux, kg N/ha/yr; R_f : fertilizer application rate, kg N/ha/yr; $A_{0\text{-}3}$: background N2O flux coefficients, kg N/ha/yr; $B_{0\text{-}2}$: saturated N2O flux coefficients, kg N/ha/yr; $K_{0\text{-}7}$: rate coefficients; C: SOC content in top soil, kg C/kg soil; CN: crop demand for N, kg N/ha; LU: land-use (upland crop 1; paddy rice 2; grassland/pasture 3) M: manure application rate, kg C/ha; T: mean annual air temperature, °C; P: total annual precipitation, mm; CLAY: soil clay fraction; PH: soil pH

A global dataset of measured N_2O fluxes from 434 agricultural fields provided by Lex Bouwman

Available input information for the 434 cases:

- Annual mean temperature;
- Annual precipitation;
- Location;
- Soil texture;
- SOC content;
- Soil pH;
- Crop type;
- Synthetic fertilizer application rate;
- Manure application rate.

Observed and Summarized DNDC-Modeled N2O Fluxes for 434 Agricultural Sites Worldwide (Field datasets from Lex Bouwman)



Statistical tools serve comparison between measured and modeled N_2O fluxes

Modeling efficiency (E) **A measure of the degree to which modeled values matches with measured values (-8 – 1)**	$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q_o}\right)^2}$
Theil's Inequality (U) **A measure of the degree to which modeled values differs from measured values (0 – 1)**	$U = \frac{\sqrt{\frac{1}{n}\sum(X_i - Y_i)^2}}{\sqrt{\frac{1}{n}\sum X_i^2} + \sqrt{\frac{1}{n}\sum Y_i^2}}$
Correlation coefficient (R) **A measure of how well future outcomes are likely to be predicted by the model (0 – 1)**	$SS_{\text{tot}} = \sum_i (y_i - \bar{y})^2,$ $SS_{\text{reg}} = \sum_i (f_i - \bar{f})^2,$ $SS_{\text{err}} = \sum_i (y_i - f_i)^2$ $R^2 \equiv 1 - \frac{SS_{\text{err}}}{SS_{\text{tot}}}.$
Root mean square error (RMSE) **A measure of the differences between measured and modeled values (0 – 1)**	$\sqrt{\frac{\sum_{i=1}^{n} (x_{1,i} - x_{2,i})^2}{n}}$

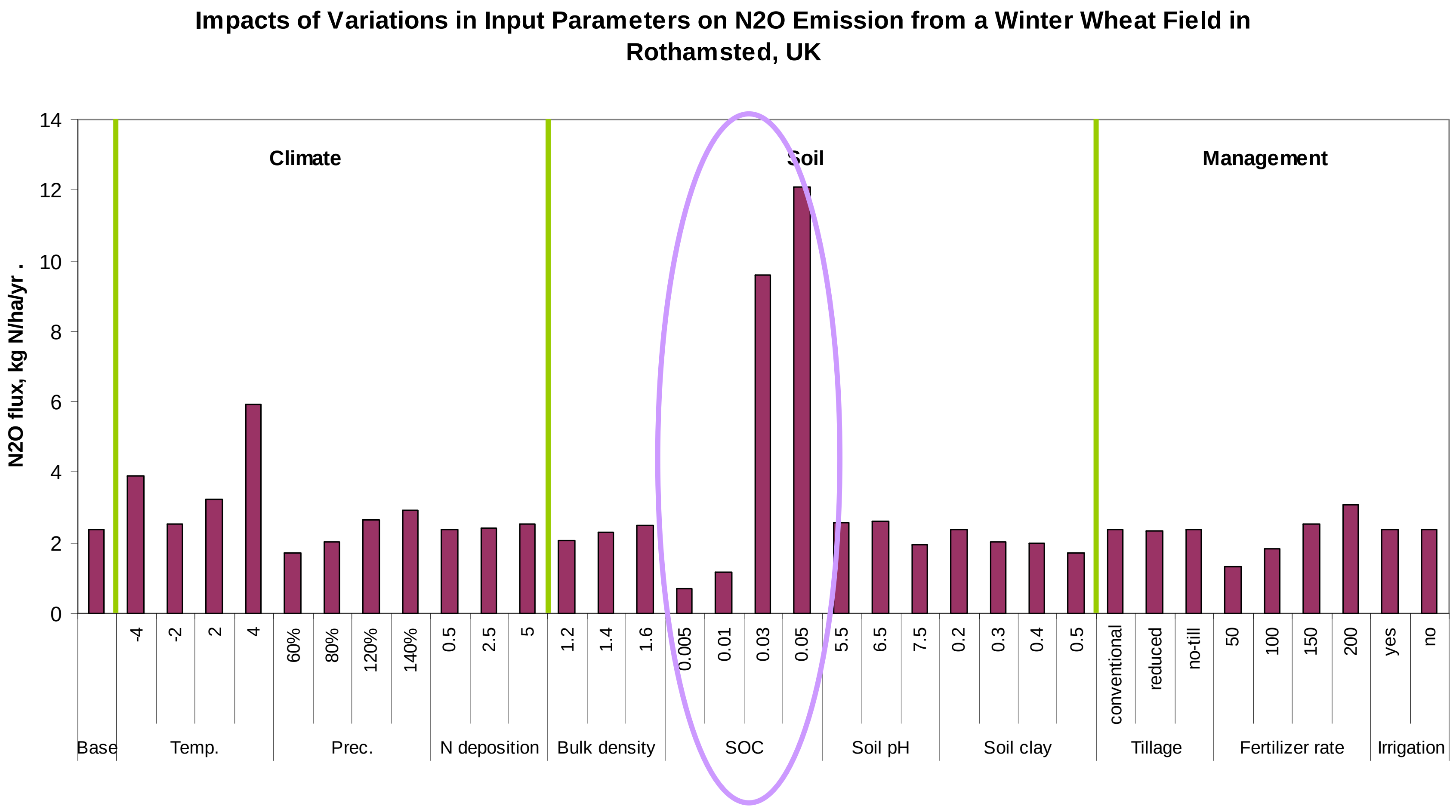
Comparison between measured and modeled N_2O emissions with a matrix of statistical tools

	69 cases (modeled with DNDC)		**434 cases** (modeled with summarized DNDC)	
Statistic measure	Measured N_2O fluxes	Modeled N_2O fluxes	Measured N_2O fluxes	Modeled N_2O fluxes
Root mean square error (RSQE), kg N/ha/yr	**10**		**30**	
Modeling efficiency (E)	**0.82**		**0.56**	
Theil's inequality (U)	**0.20**		**0.31**	
Correlation coefficient (R^2)	**0.82**		**0.61**	
Average, kg N/ha/yr	**11.86**	**12.06**	**7.51**	**7.40**

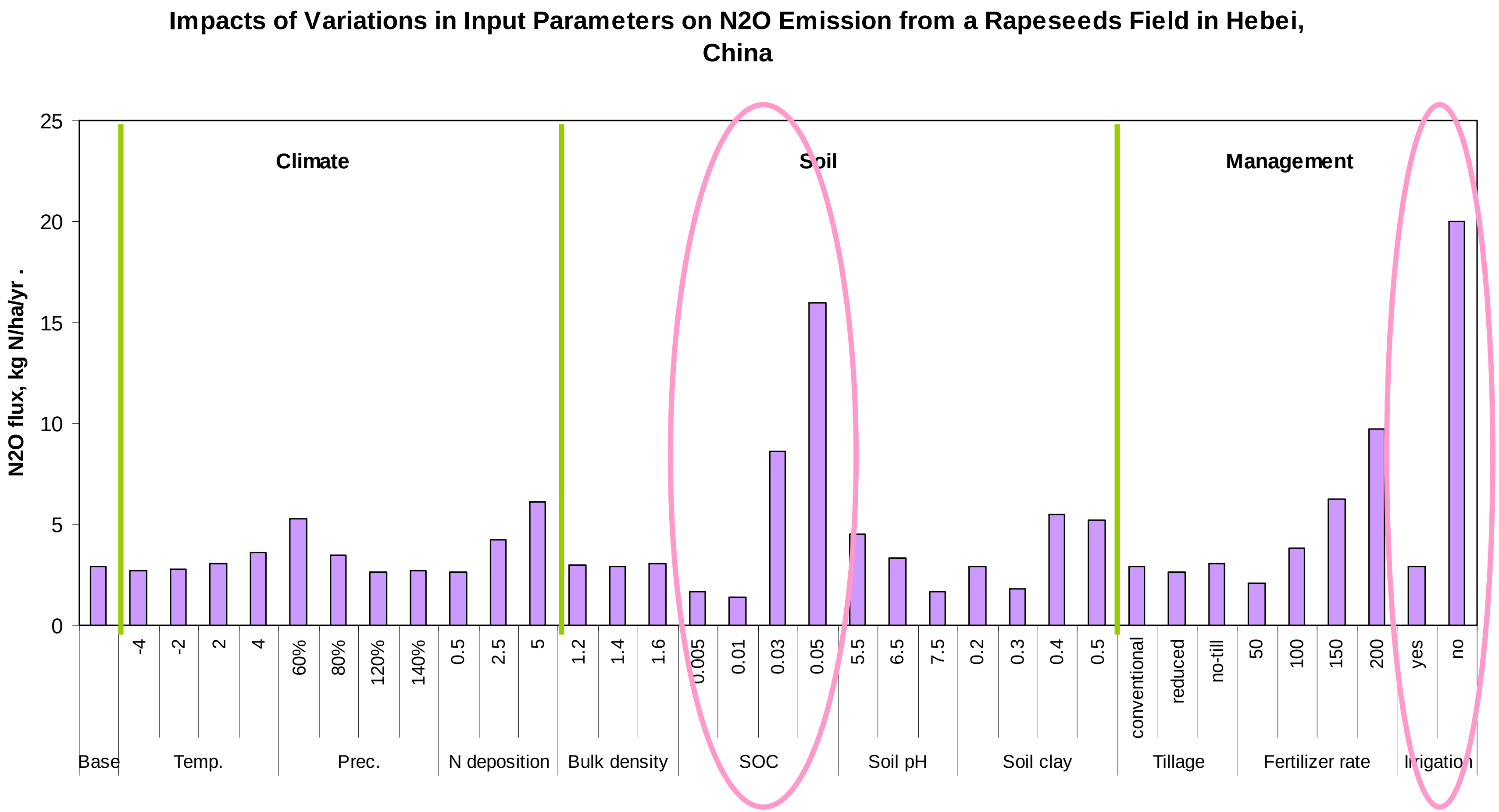
Input data for DNDC simulation

1. Climate: - Daily max and min air temperature;
   - Precipitation;
   - Atmospheric N deposition;
2. Soil: - Bulk density;
   - Texture (clay fraction);
   - Total organic C content;
   - pH;
3. Management: - Crop type and rotation;
   - Tillage;
   - Irrigation;
   - Fertilization;
   - Manure amendment;
   - Grazing etc.

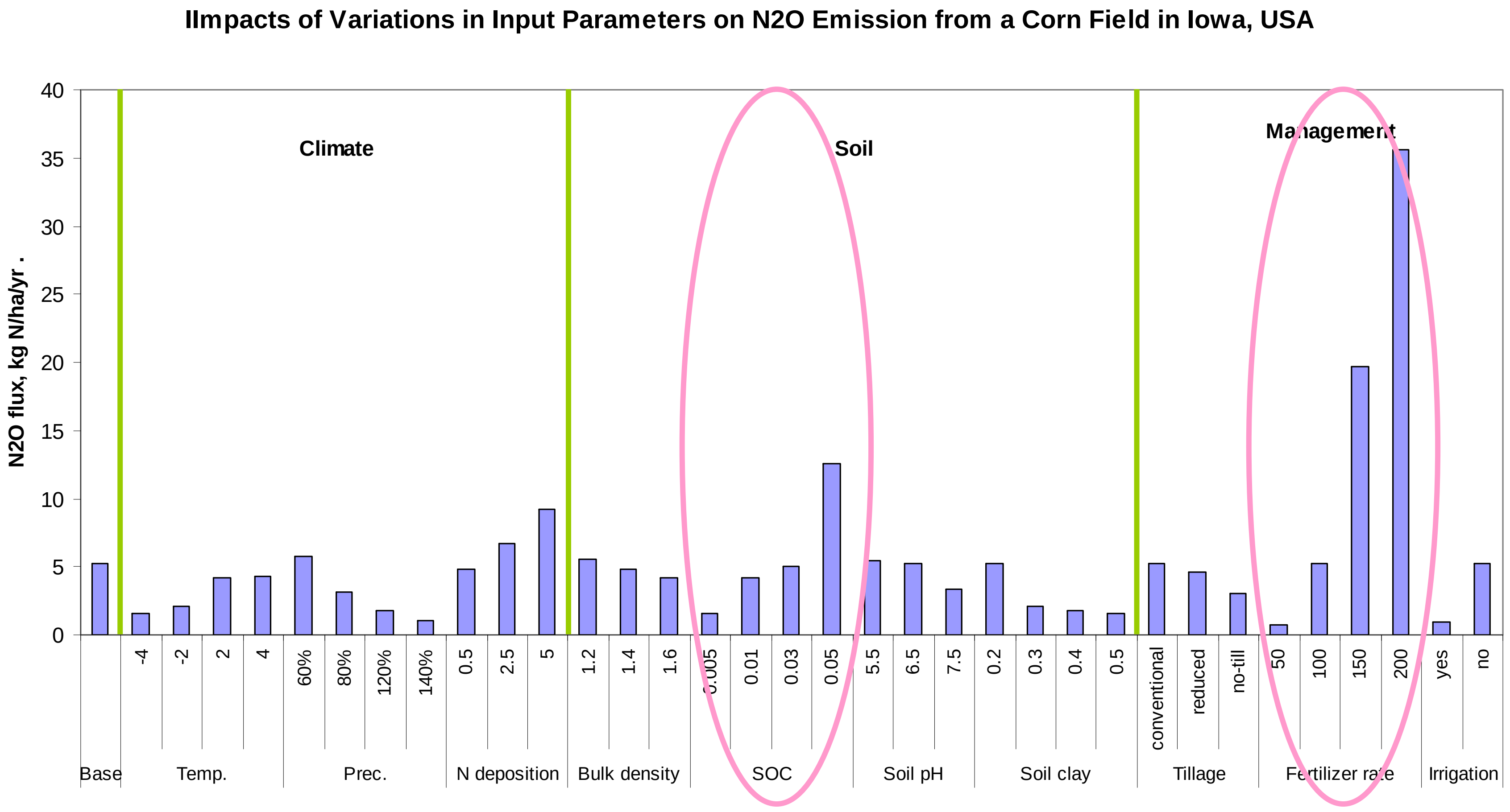
Sensitivity Tests for Identifying the Most Sensitive Factors Affecting N2O Emissions from a Winter Wheat Field in Rothamsted, the U.K.



Sensitivity Tests for Identifying the Most Sensitive Factors Affecting N2O Emissions from a Rapeseeds Field in Hebei, China



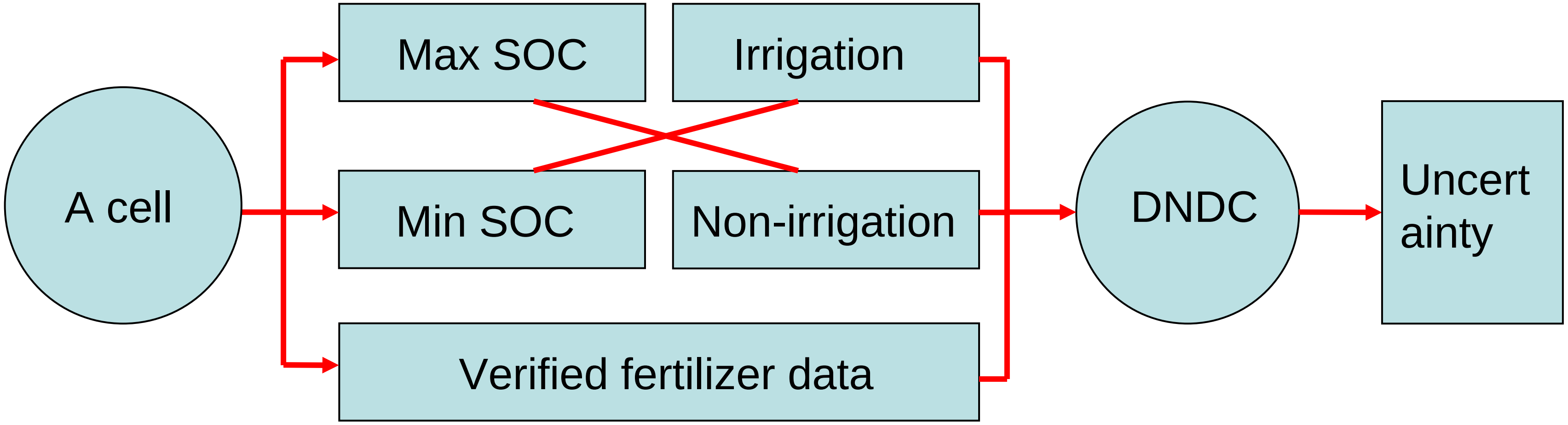
Sensitivity Tests for Identifying the Most Sensitive Factors Affecting N2O Emissions from a Corn Field in Iowa, the U.S.



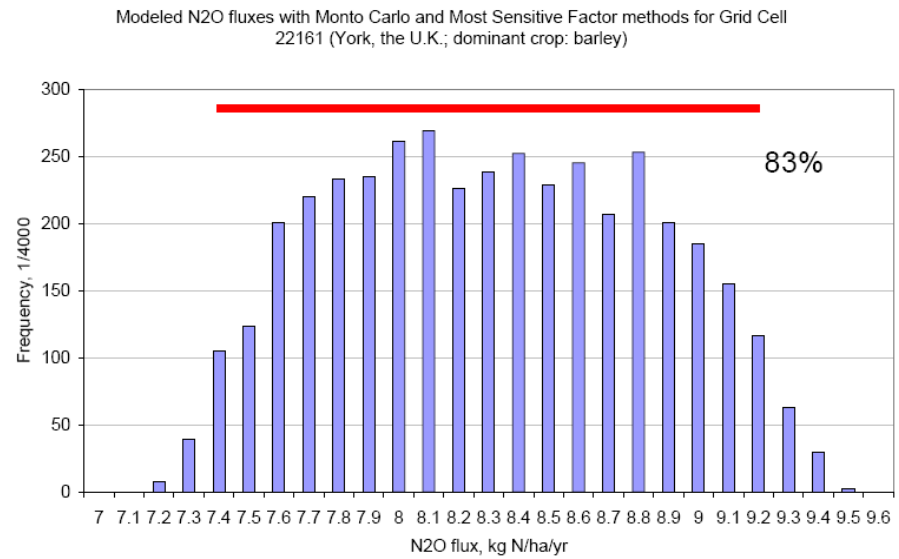
Most Sensitive Factors for N_2O Prediction

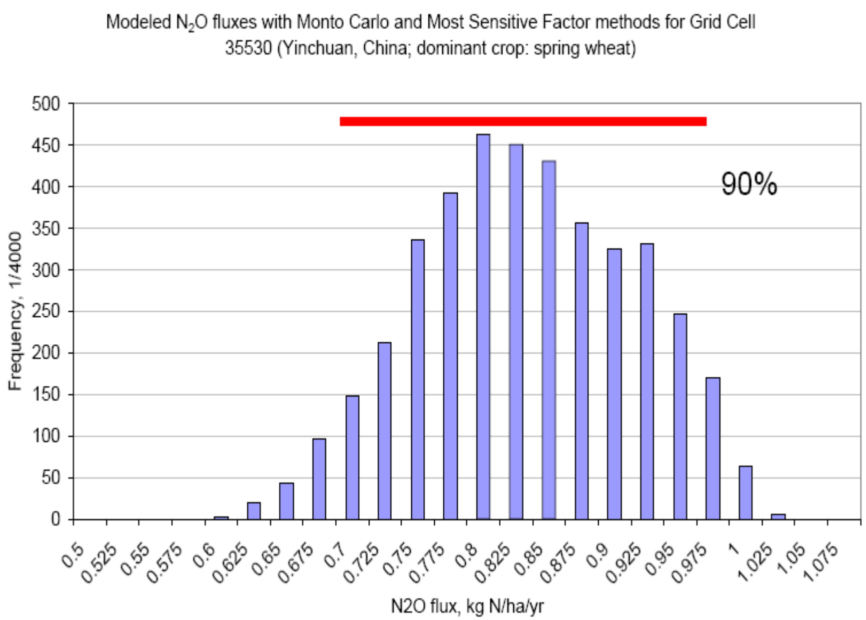
- Soil organic carbon (SOC) content;
- Fertilizer application rate;
- Irrigation

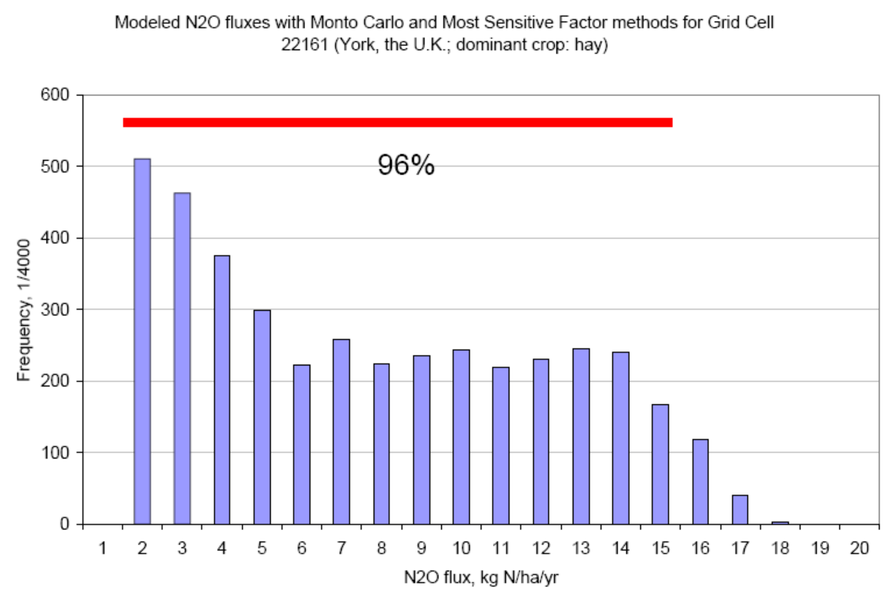
Enhanced database for quantifying uncertainty at regional scale:



More than 80% of Monte Carlo method-produced N_2O fluxes are located within the ranges produced with the MSF method.







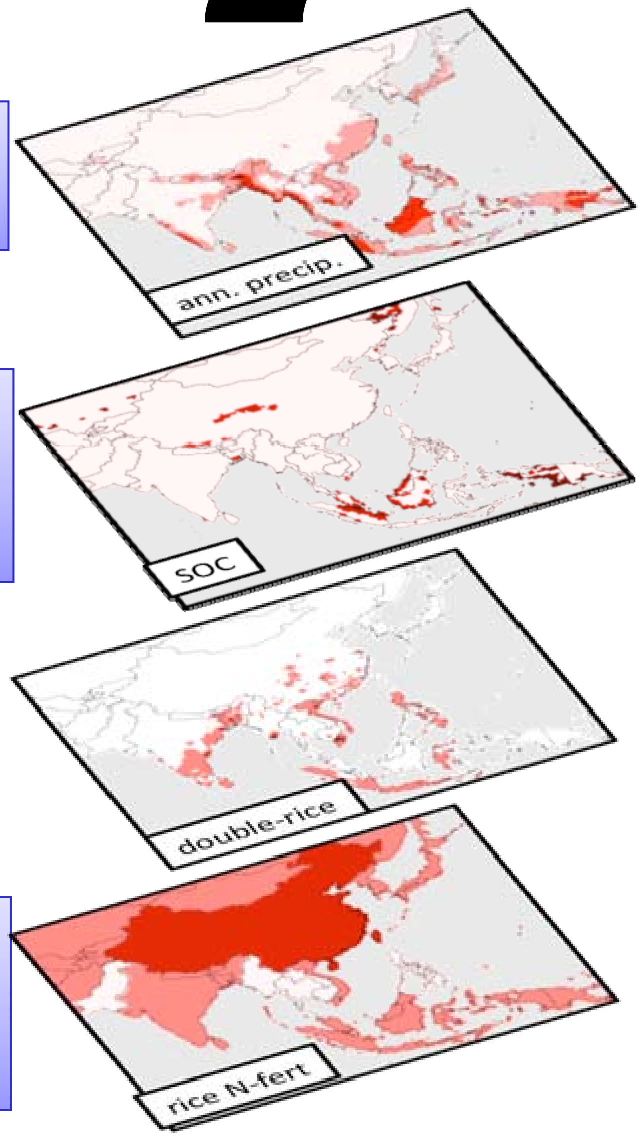
With the enhanced database, DNDC calculates uncertainty during regional simulations

meteorological data (daily temp, precip.)

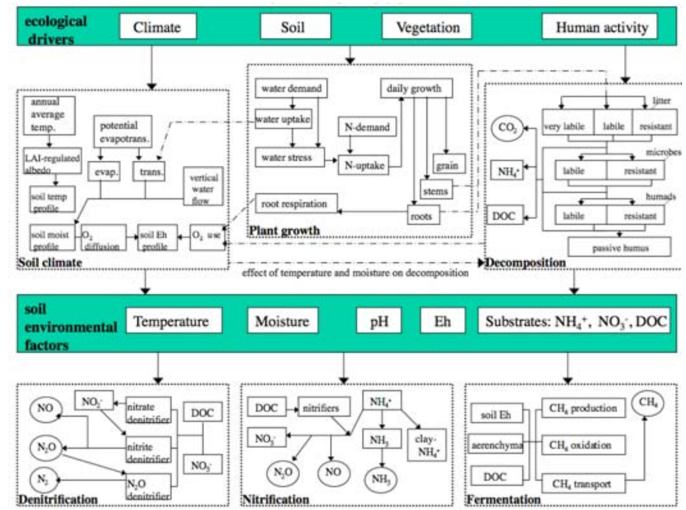
soil properties (max. and min. SOC, pH, texture, bulk den.)

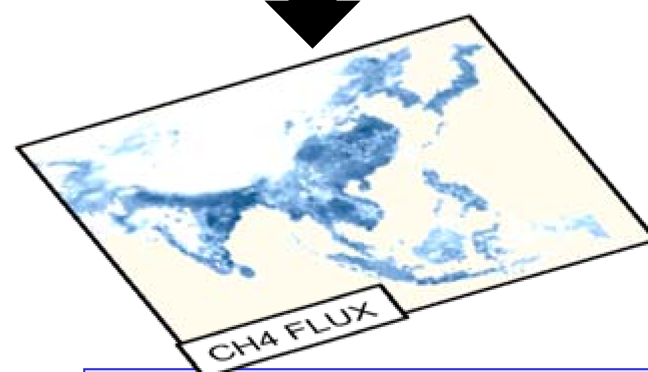
crop types & rotations

farm management (fert., irrig., manure, crop residue, …)



DNDC Model

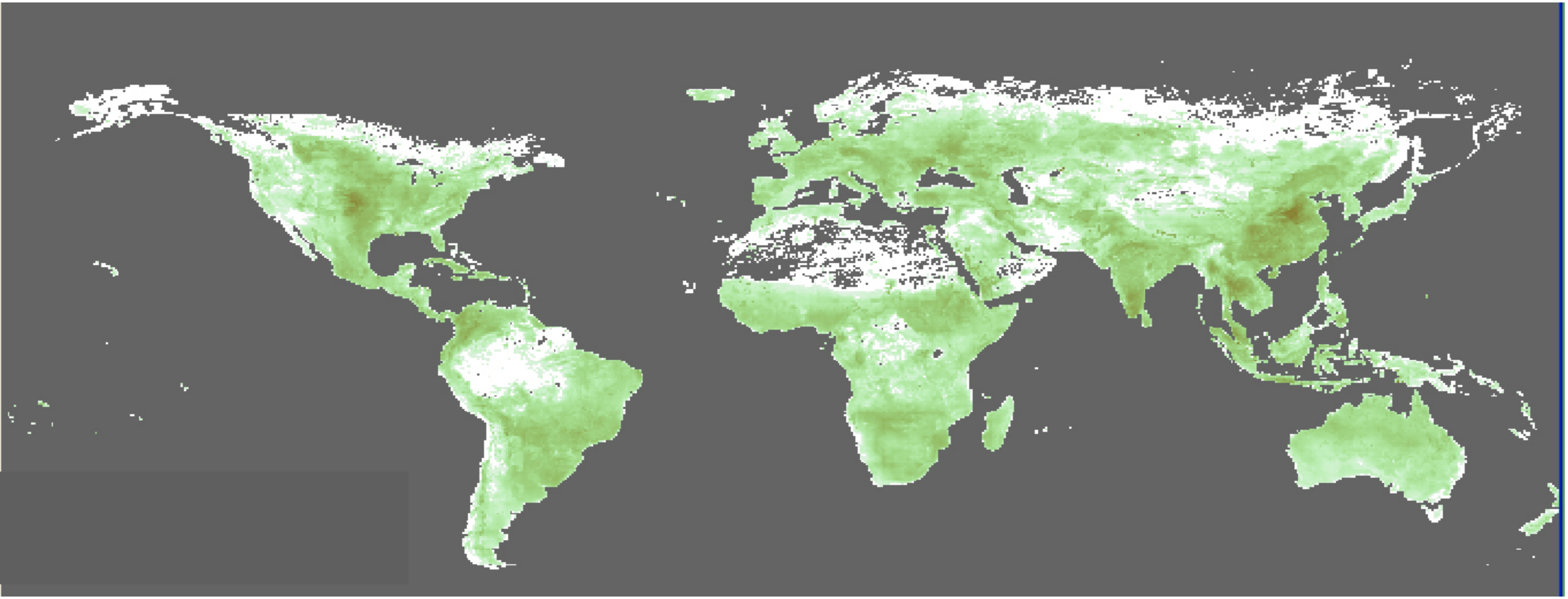




CO_2, CH_4, N_2O emissions in ranges

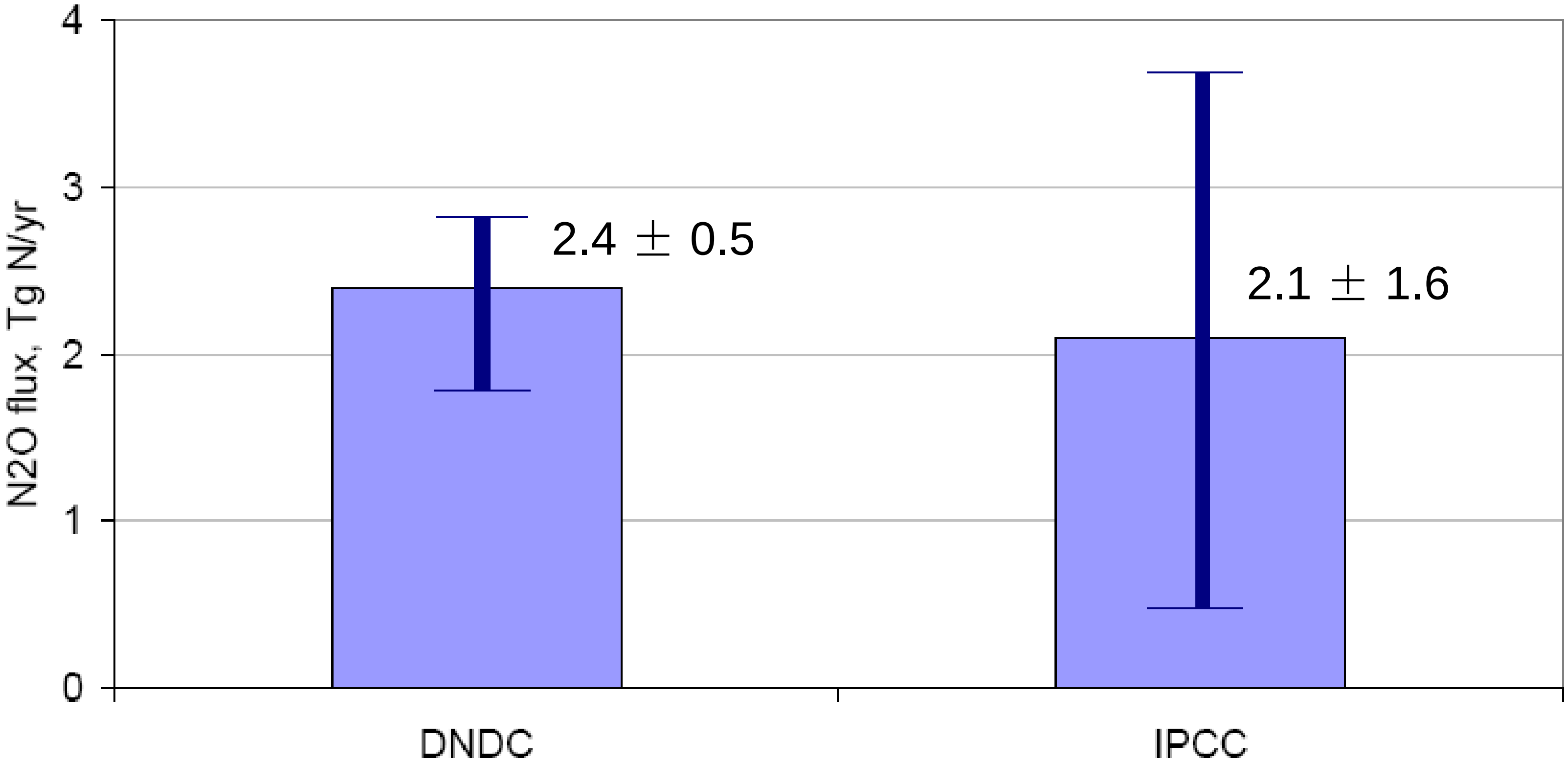
DNDC-Modeled Global N_2O Emissions from Agricultural Soils

2.4 ± 0.5 Tg N



IPCC and DNDC Estimated Global N2O Emissions from Agricultural Soils

（IPCC data from Mosier et al. 1998 ）

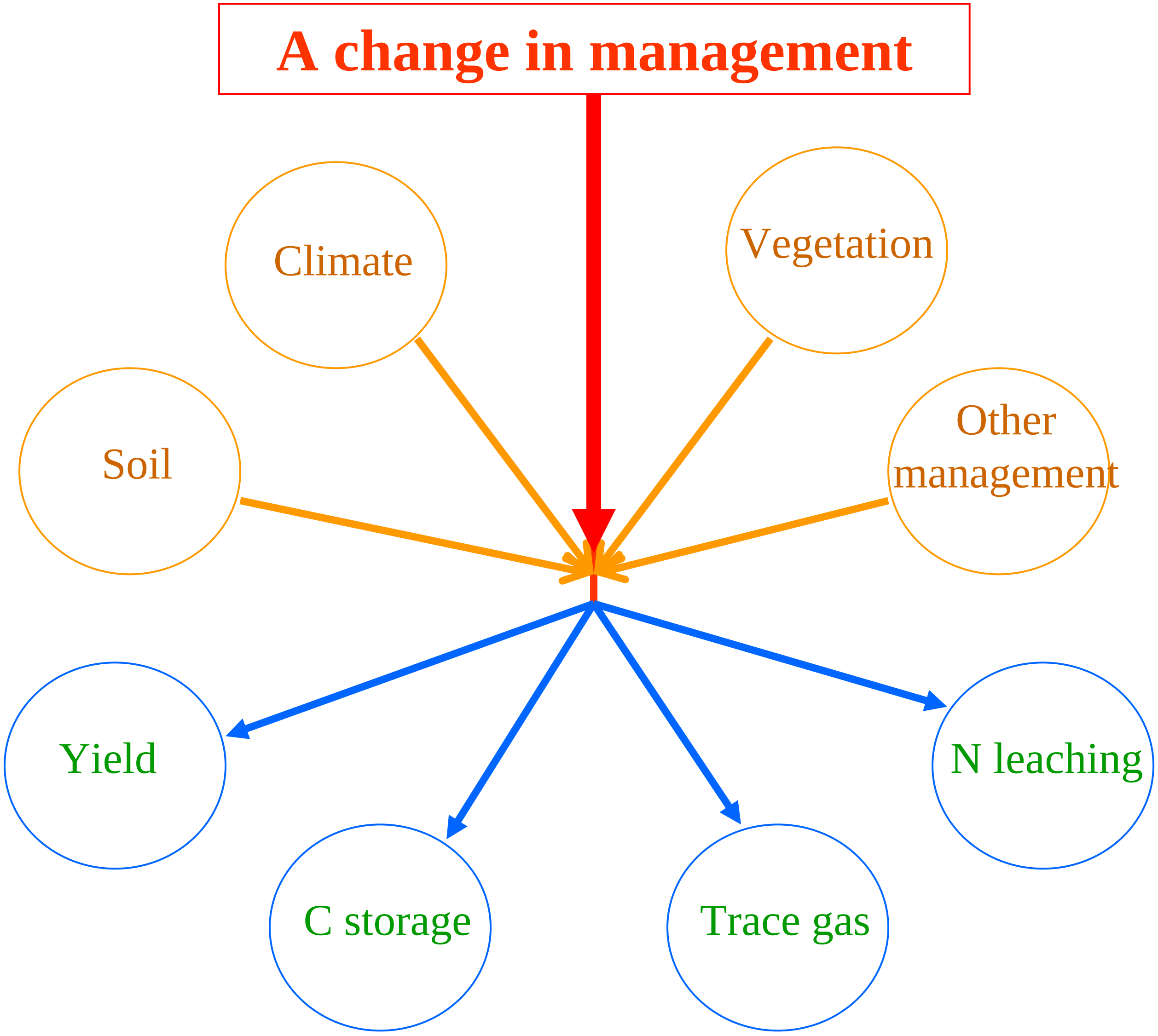


Top Ten World N_2O Emitters

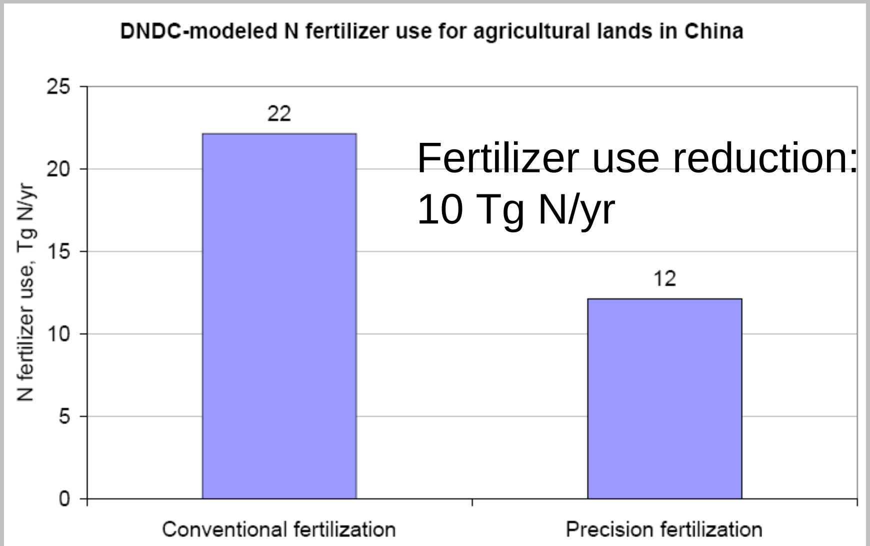
(Accounting for 79% of world total)

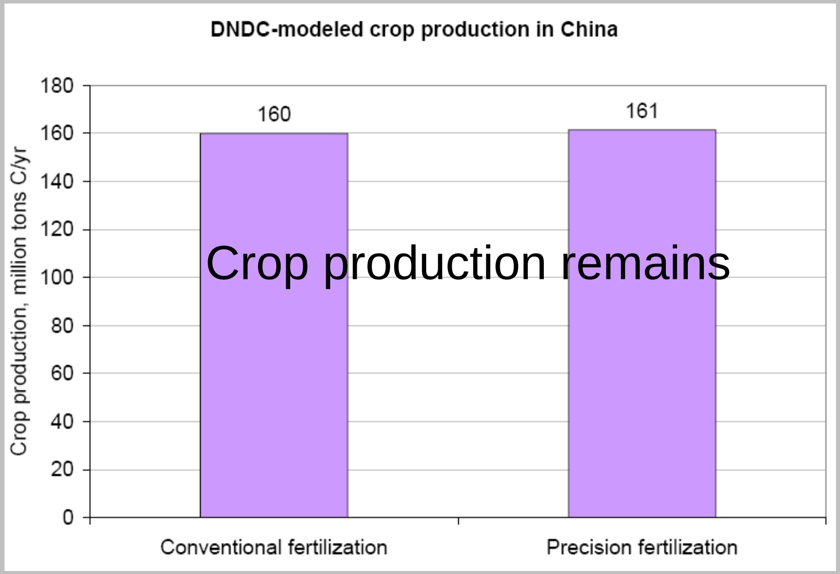
Country	Direct N_2O emission from agricultural soils (tons N/yr)
China	0.65 ± 0.17
United States	0.46 ± 0.07
India	0.38 ± 0.05
Russia	0.11 ± 0.03
Argentina	0.09 ± 0.008
Mexico	0.07 ± 0.02
Canada	0.045 ± 0.01
France	0.037 ± 0.01
Brazil	0.036 ± 0.004
Ukraine	0.035 ± 0.006

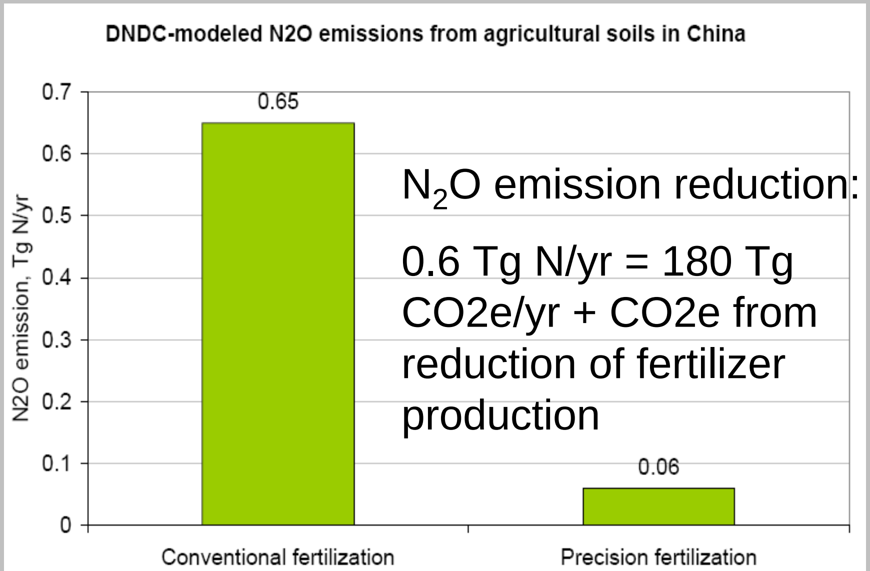
Test Alternative Management Practices for Mitigation at Regional/Global Scale



DNDC estimated impacts of precision fertilization at national scale for China (Li & Salas, 2009)







Conclusions

- Uncertainty produced from process-based model applications can be brought under control through validation, sensitivity test and database enhancement;

- With quantified uncertainty, process-based models will be a powerful tool for both inventory and mitigation.