Chinese Academy of Sciences

地气碳氮气体交换及面向生态系统优化管理的挑战

Land-Atmosphere Exchanges of C- and N-Gases and Challenges for Best Management of Ecosystems

郑循华

(xunhua.zheng@post.iap.ac.cn)

中国科学院大气物理研究所， 北京 200019

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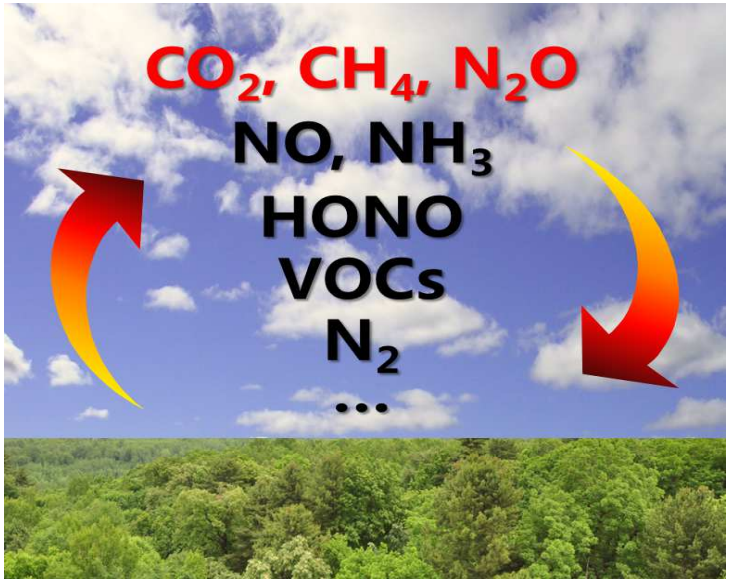
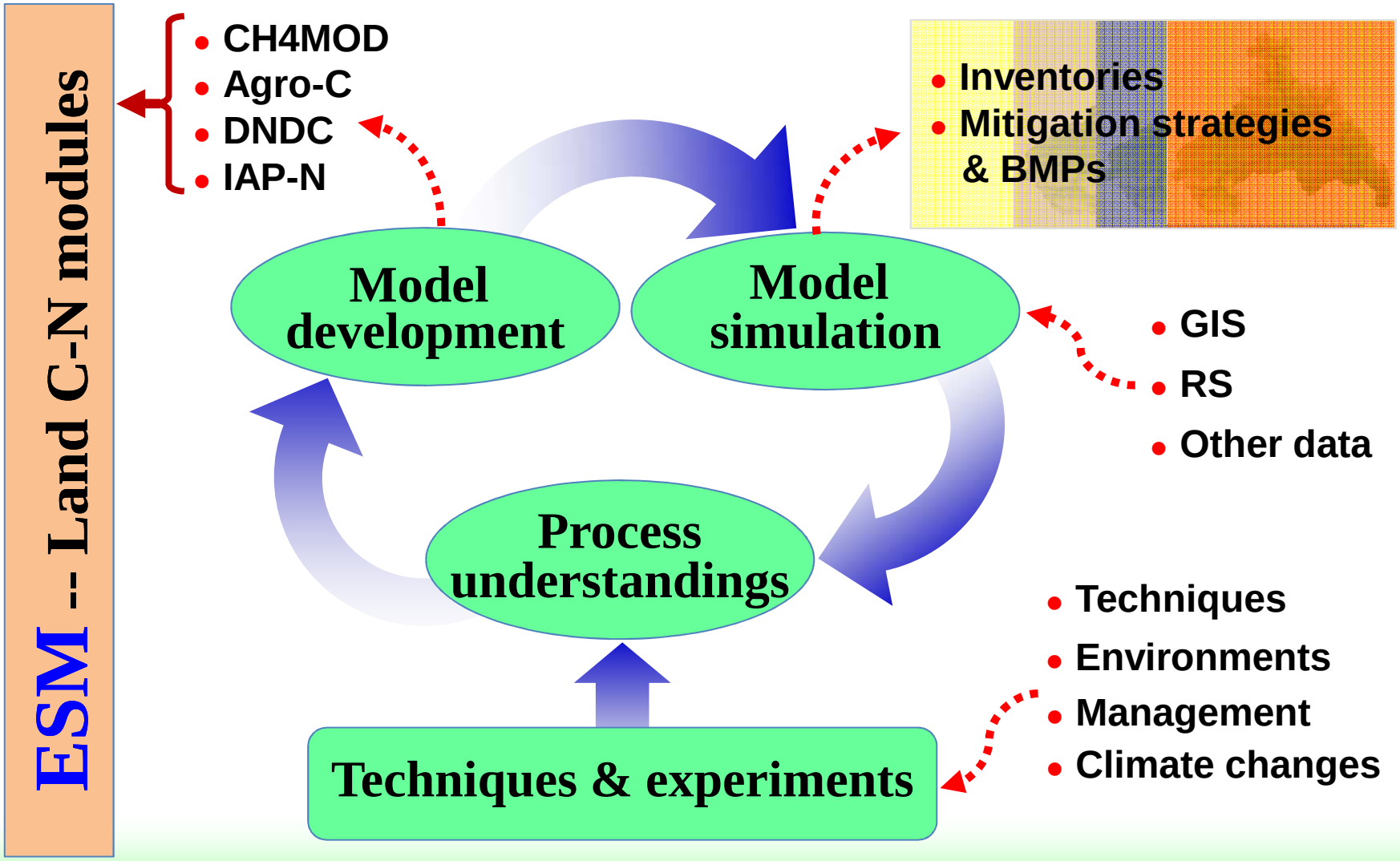
Research Focuses and Key Questions

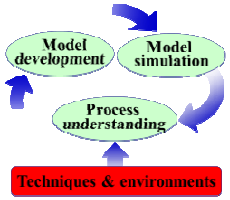
- **Focuses:**
  - **To understand the processes of terrestrial C and N cycling;**
  - **To quantify the sources and sinks of C-and N-gases.**
- **Key questions on the sources/sinks:**
  - **Where?**
  - **When?**
  - **Why?**
  - **How?**
    - **Climate change impacts**
    - **Management impacts**
    - **Mitigation of negative effects**



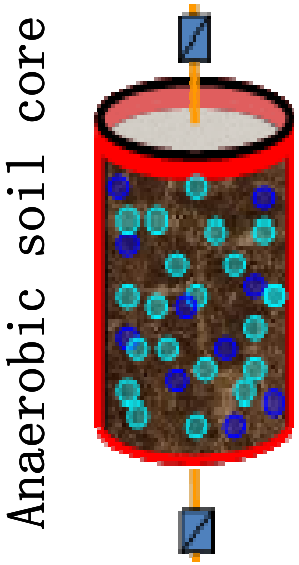
Proper answers are essential for
- understanding biogeochemical processes of C & N;
- promoting ESM development;
- making proper decisions of ecosystem management.

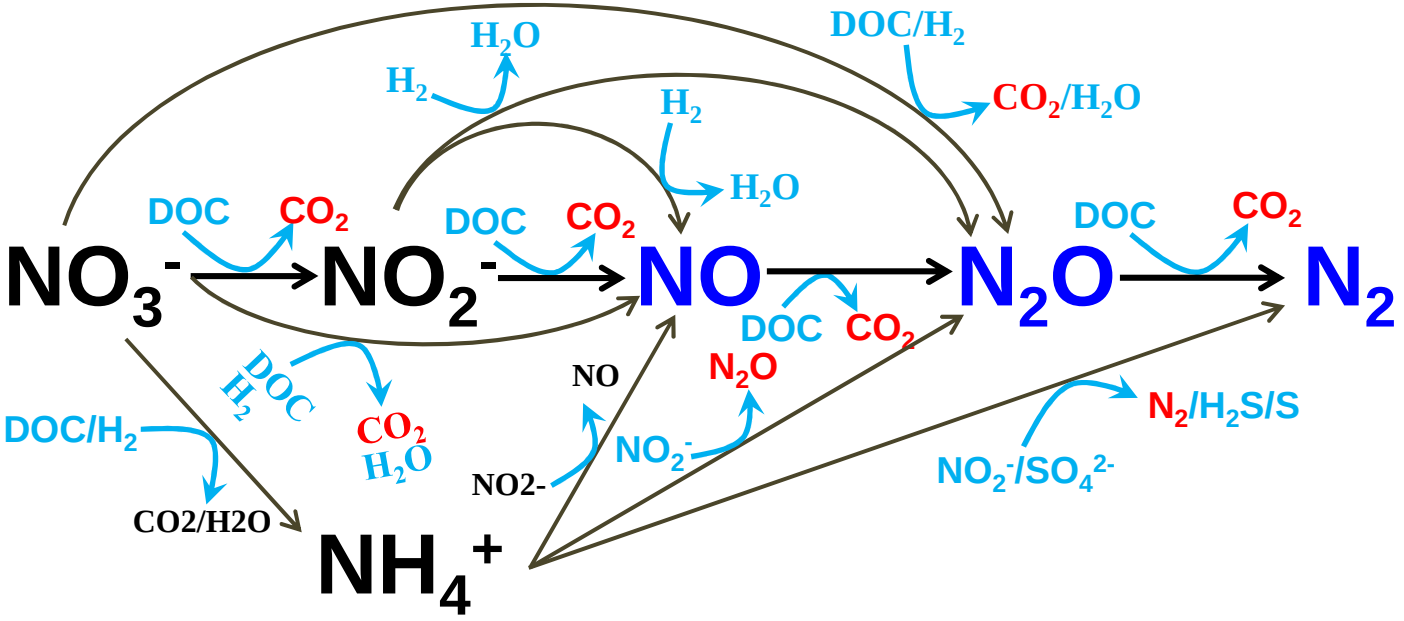
Research Approach





Technique/Method: GFSC-SMOS

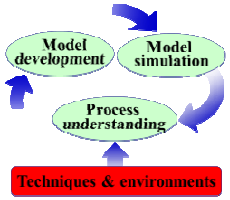




$$CO_2 + H_2 \longrightarrow CH_4 + H_2O$$

$$CH_3COO^- + H^+ \longrightarrow CH_4 + CO_2$$

$$DOC \longrightarrow H_2 + H_2O + CO_2$$



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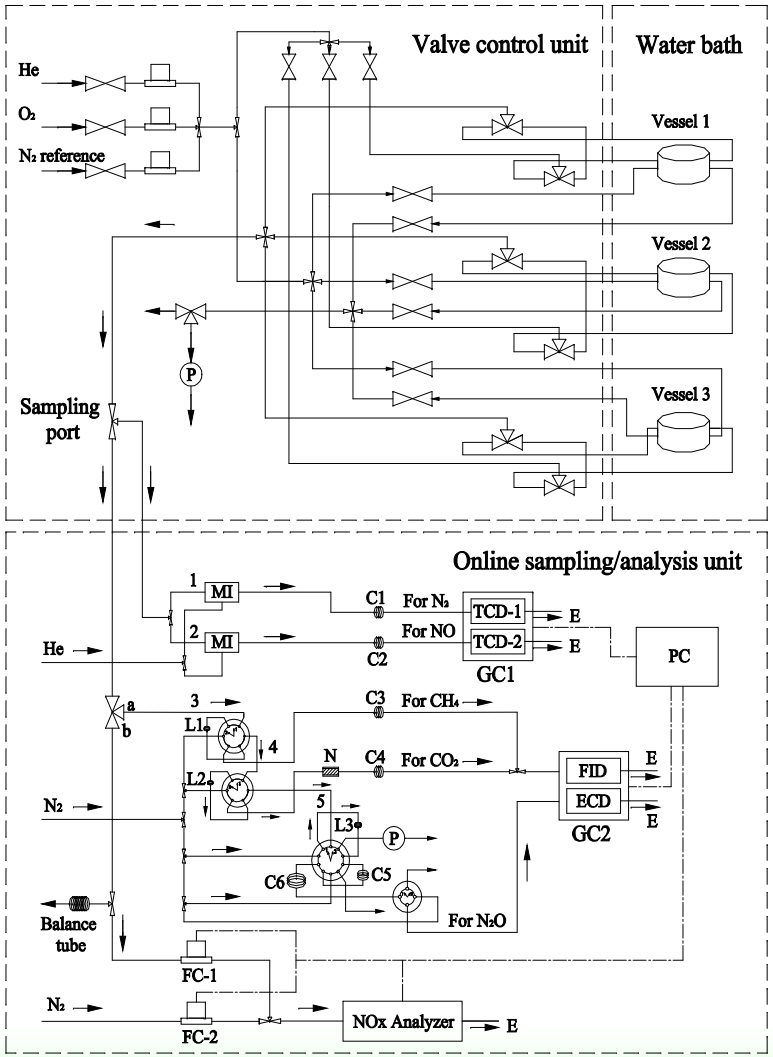
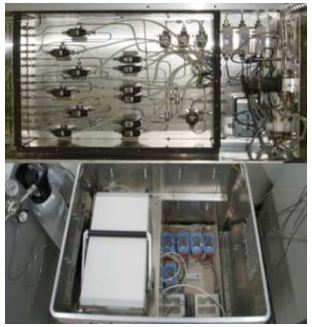
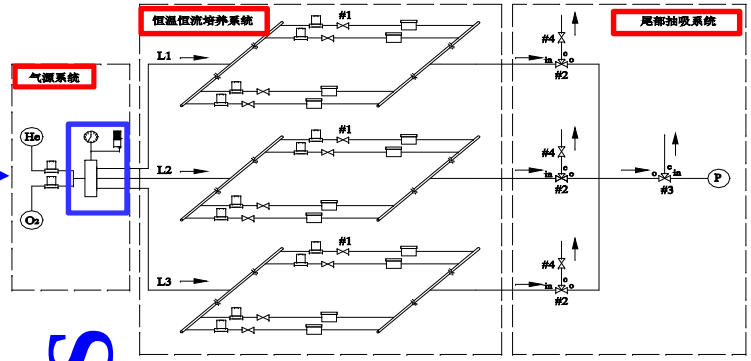


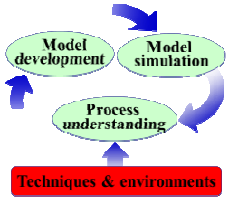
GFSC



SMOS

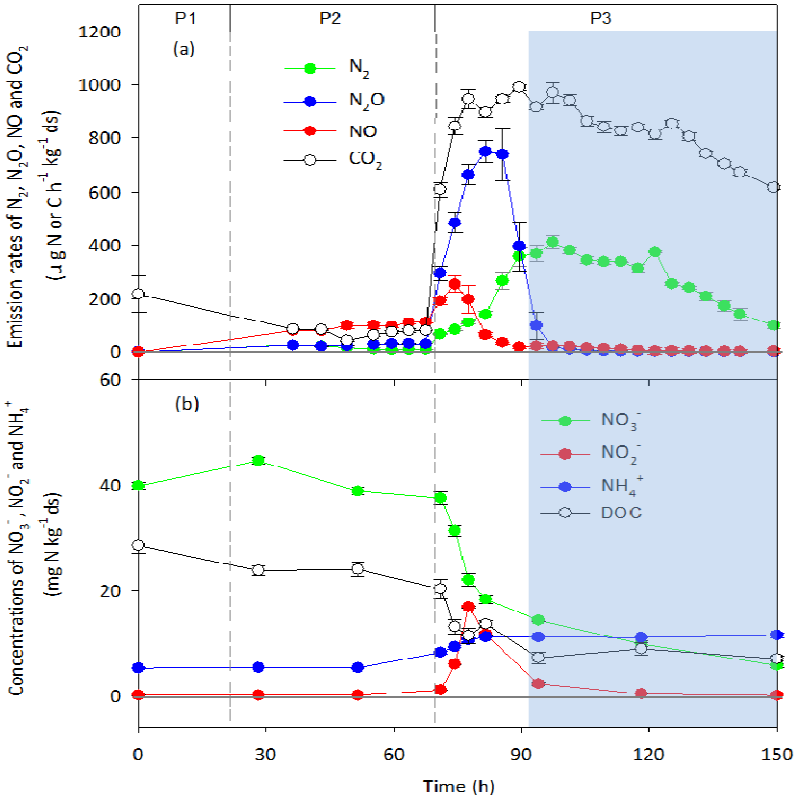


(Wang et al., 2011, EST; Liao et al., 2013, Chemosphere)



Technique/Method: GFSC-SMOS

Dynamical measurements of denitrification products and substrates using GFSC-SMOS



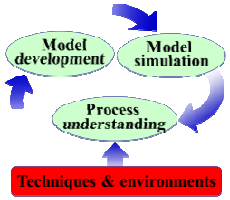
Gas emission rates:

N_2, N_2O, NO, CH_4, CO_2

Soil substrate cons.:

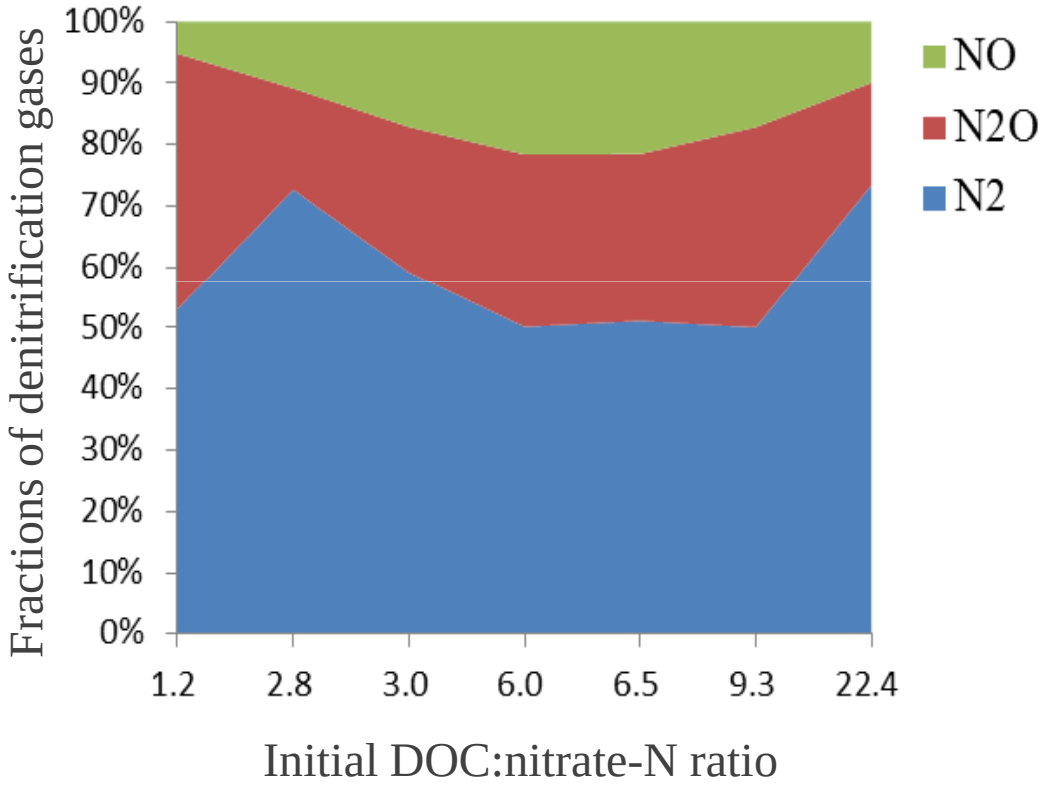
NH_4^+, NO_3^-, NO_2^-, DOC

(Liao et al., 2013, PhD thesis of IAP-CAS, UCAS)



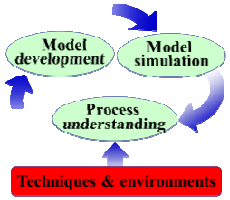
Technique/Method: GFSC-SMOS

GFSC-SMOS measurements



- To promote deep insights into nitrogen and/or carbon transformation processes;
- To provide key parameters for process models.

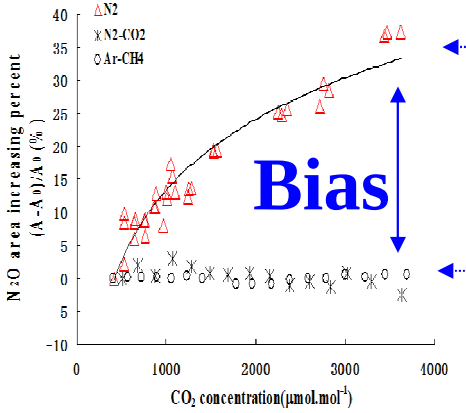
（Wang et al., 2013, Plant Soil）



Technique/Method: N_2-CO_2 for GC

- **Identified the problem of the N_2 method for analyzing N_2O by GCs**
- **Invented its alternative N_2-CO_2 method**
- **Extended application of the N_2-CO_2 method (> 80% GCs in China or > 50 lab/stations)**

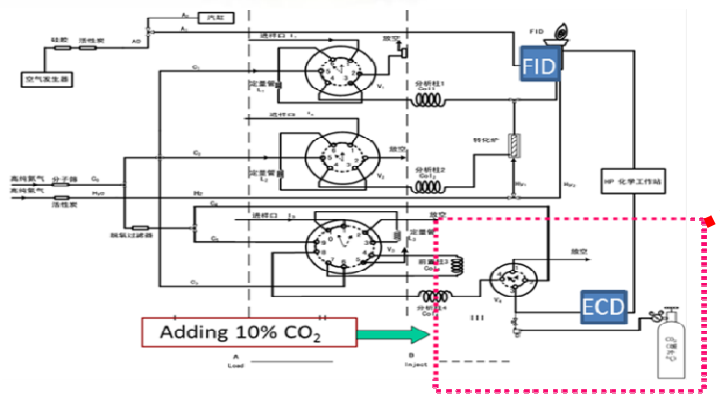
Problem



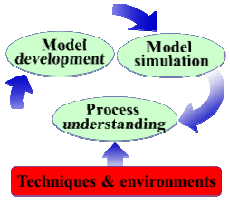
Bias

- N_2
- Ar-CH_4
- N_2-CO_2

Technical solution

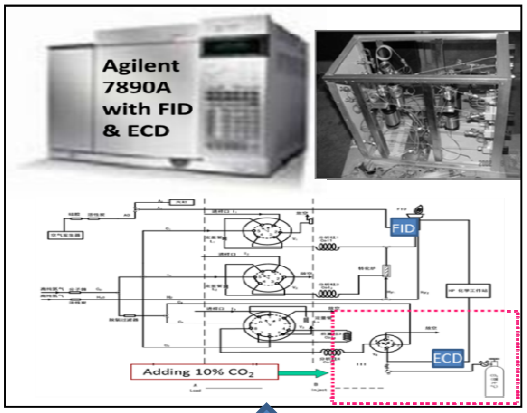


(Zheng et al., 2008, Plant Soil; Wang et al., 2010, AAS)

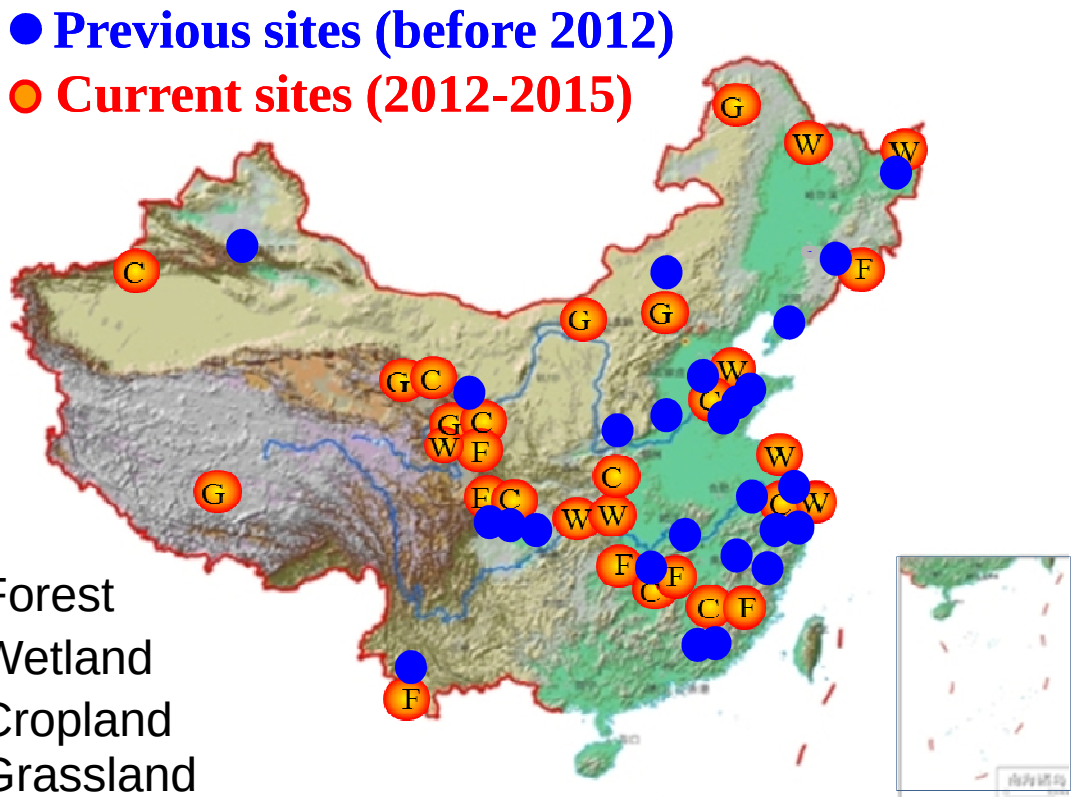


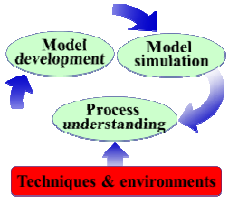
Experiments: Field Network Studies

Measurements of terrestrial gases exchanges



GC-ECD method for N_2O at the current sites (N_2-CO_2)

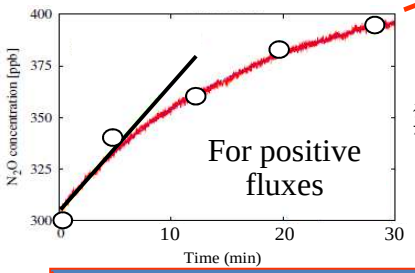


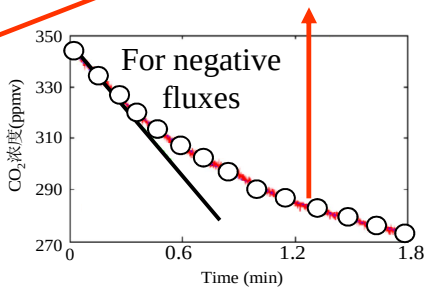


Technique/Method: AMEG

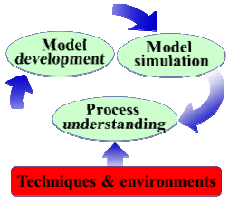
Automatic monitor for exchanges of trace gases (CH_4, N_2O, NO, NEE-CO_2) between an ecosystem and the atmosphere (AMEG)

$$F = H \cdot \rho_0 \cdot T_0 / T) \cdot P/P_0 \cdot dC_t/dt$$



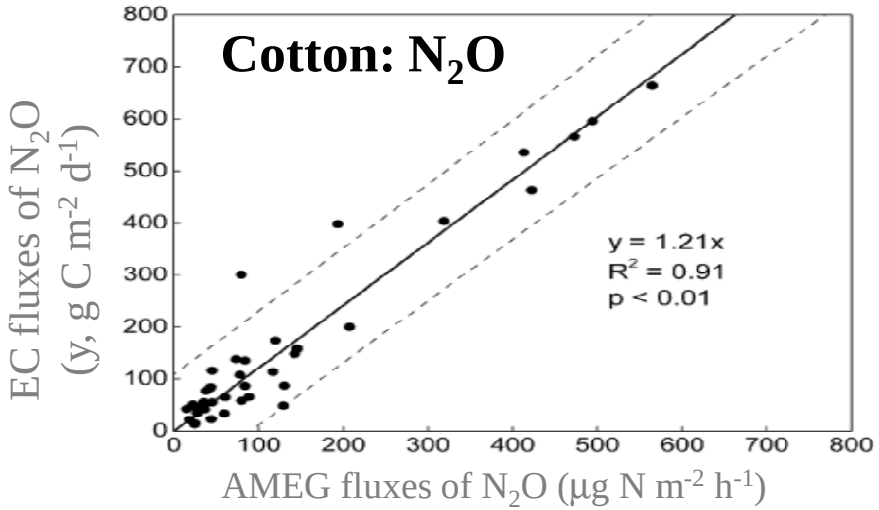


(Wang et al., 2012, AFM; Wang et al., 2013, BG)

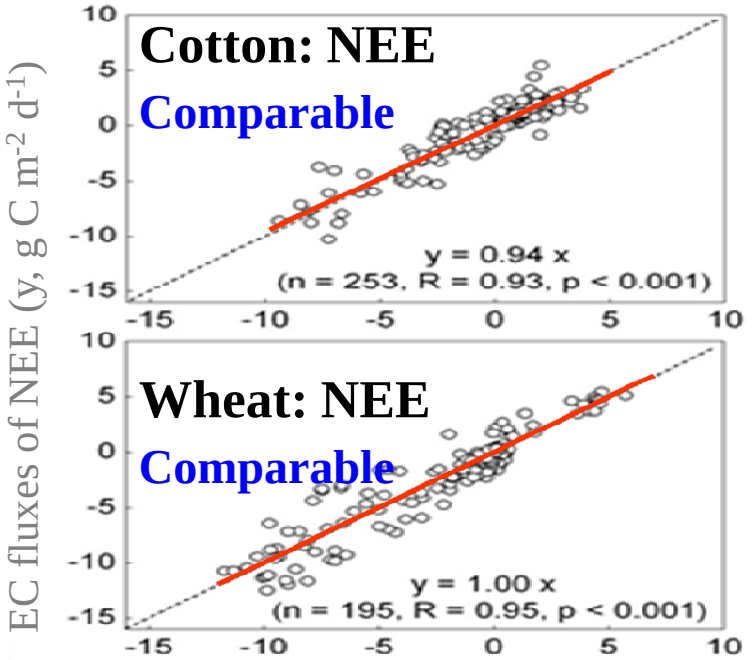


Technique/Method: AMEG

AMEG (chamber) fluxes versus eddy covariance fluxes



AMEG fluxes of N_2O: 17-20 % lower



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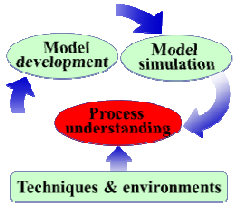
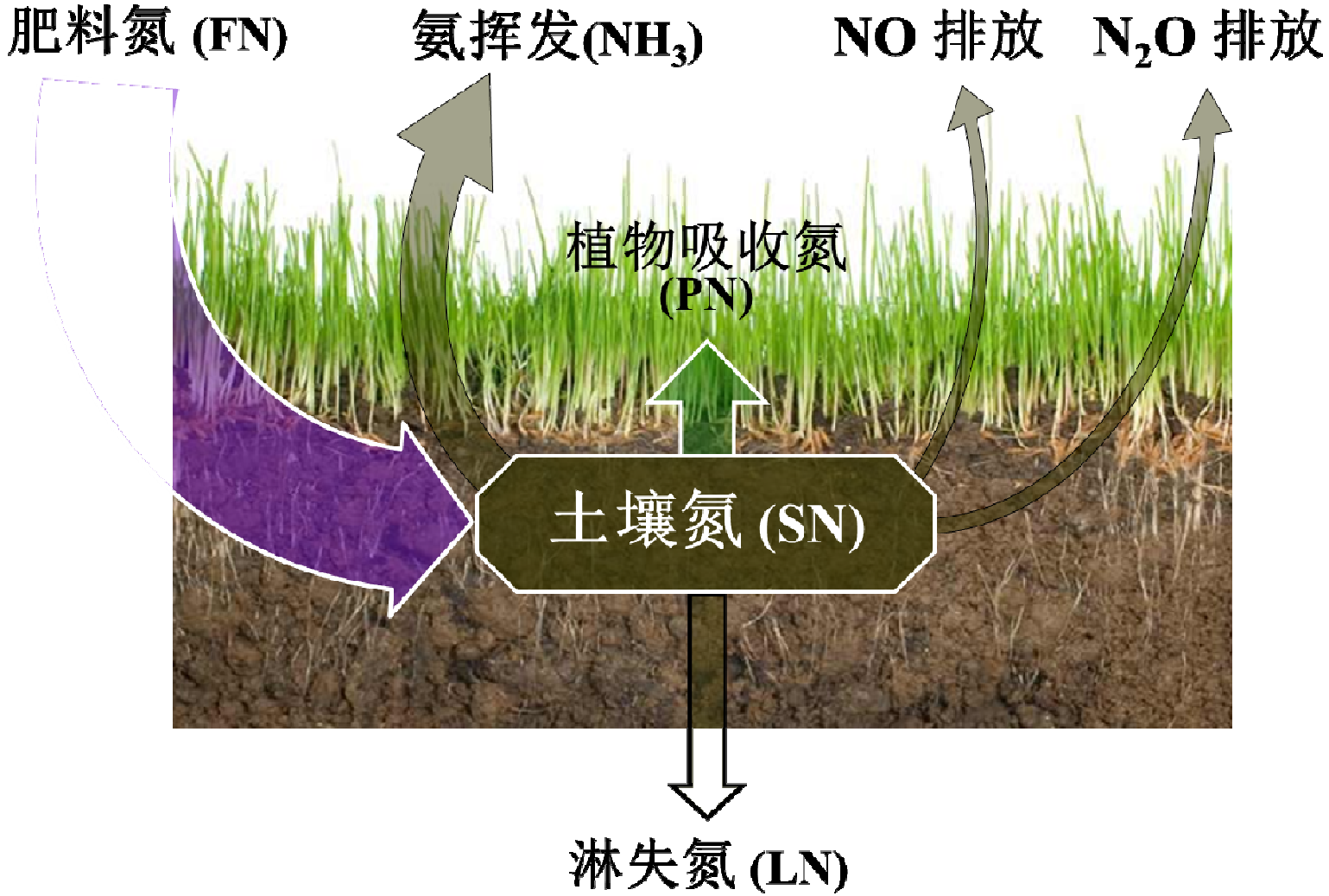
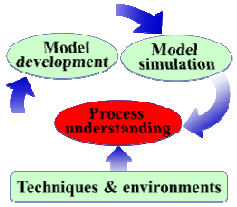


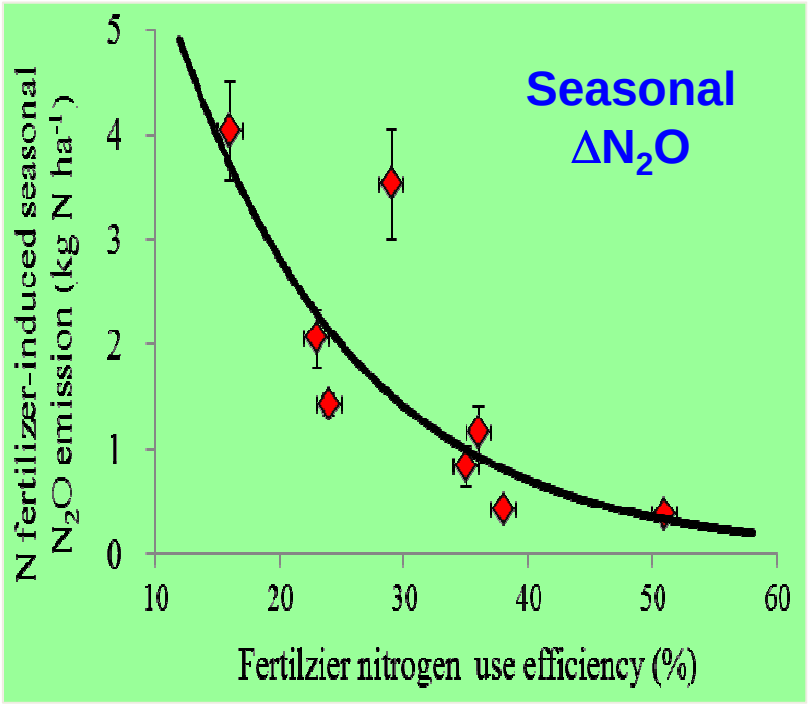
Process Understandings: N_2O, NO

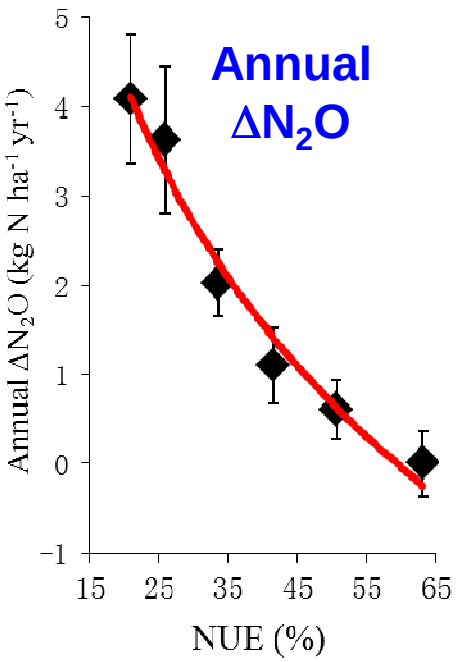


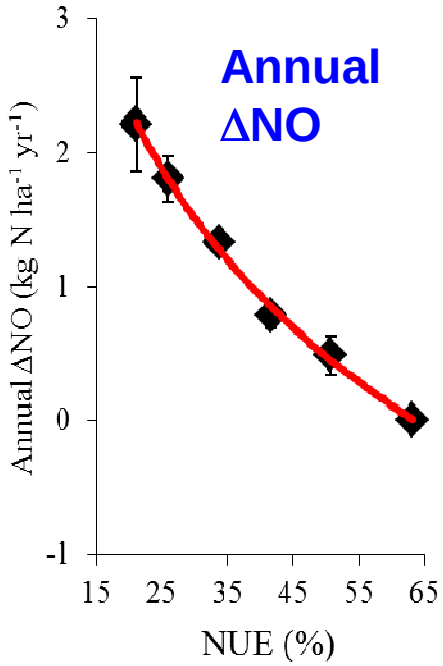


Process Understandings: N_2O, NO

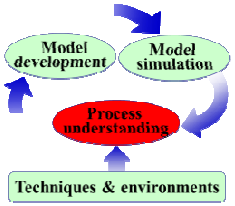
Site-scale trade-off effects between N-derived gas emissions (ΔN_2O or ΔNO) and NUE







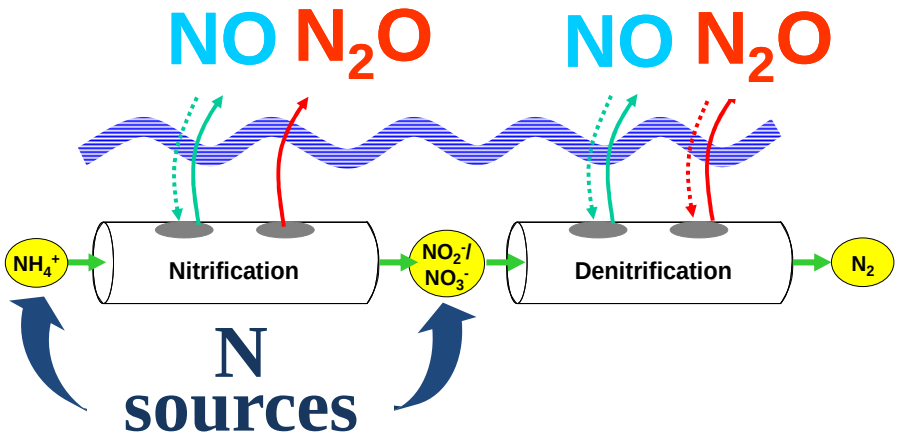
(Yan et al., 2013, AGEE; adapted from Liu et al., 2012, BG)



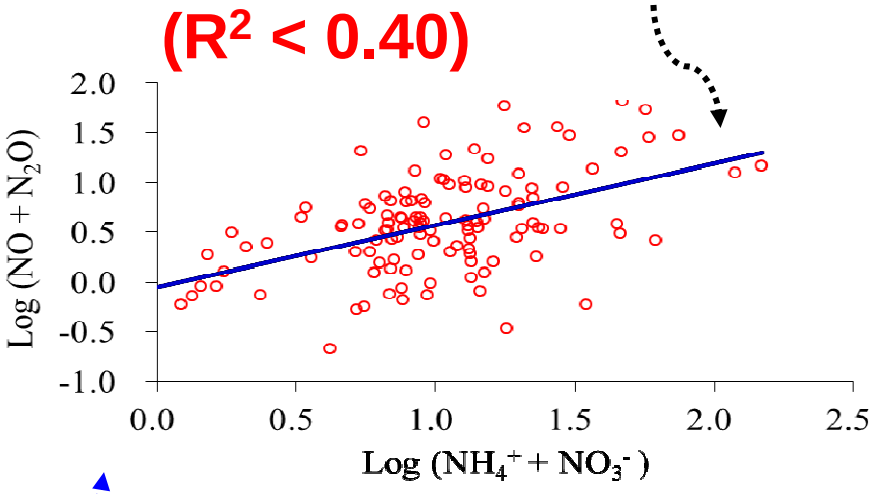
Process Understandings: N_2O, NO

"Holes-in-the-pipe" model ⇨ $\text{Log}(N_2O+NO) = \alpha\ \text{Log}(NH_4^+ + NO_3^-) + \beta$

(Firestone & Davidson, 1989)



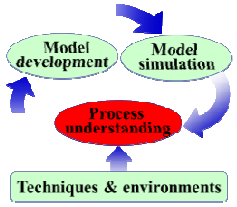
(Davidson & Verchot, 2000)



(R^2 doubled)

$$\text{Log}(N_2O+NO) = A\ \text{Log}(NH_4^+ + NO_3^-) + B\ \text{Log}(M) - E_a / (R\,T)$$

（Yan et al., 2013, AGEE）



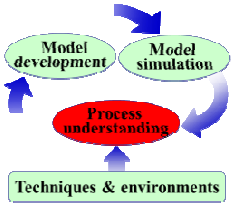
Process Understandings: N_2O, NO

Dual Michaelis-Menten and Arrhenius kinetics well account for the trade-off effects

$$F = \alpha \cdot M \frac{NH_4^+}{k_1 + NH_4^+} \cdot \frac{NO_3^-}{k_2 + NO_3^-} \cdot \frac{DOC}{k_3 + DOC} \cdot e^{-\frac{Ea}{RT}}$$

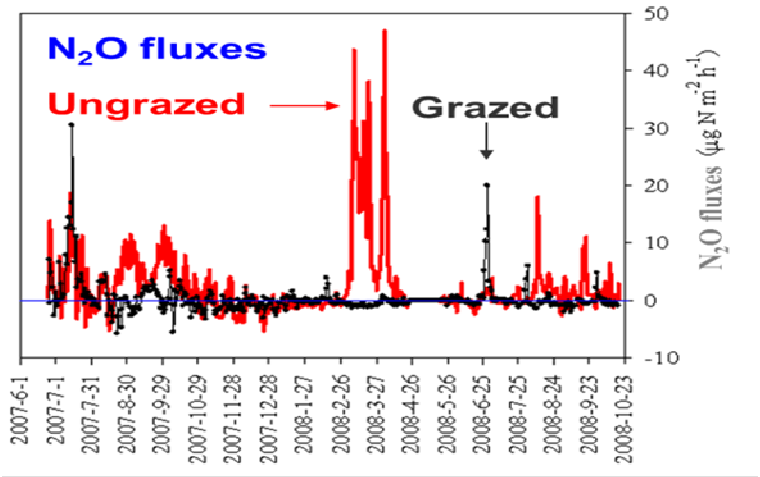
	α	k_1	k_2	k_3	E_a
F_{N2O}	7.8×10^4	3.2	7.5	7.1	40
(n = 104, R^2 = 0.60, P < 0.01)					
F_{NO}	3.8×10^8	0.3	362	0	59
(n = 104, R^2 = 0.54, P < 0.01)					

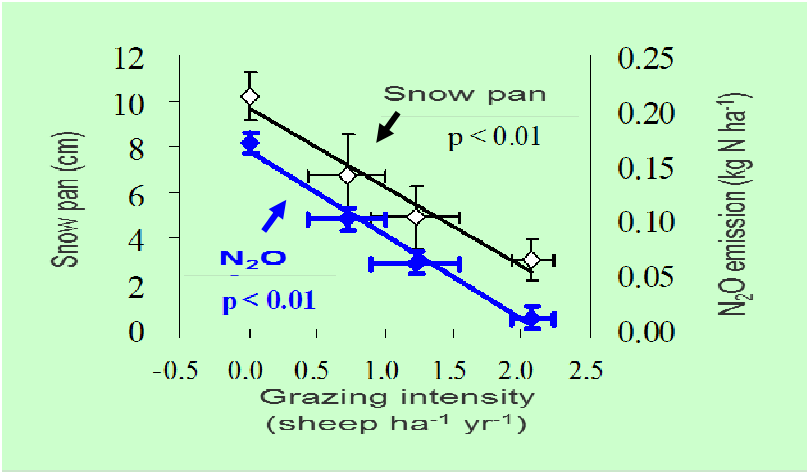
(Yan et al., 2013, AGEE)

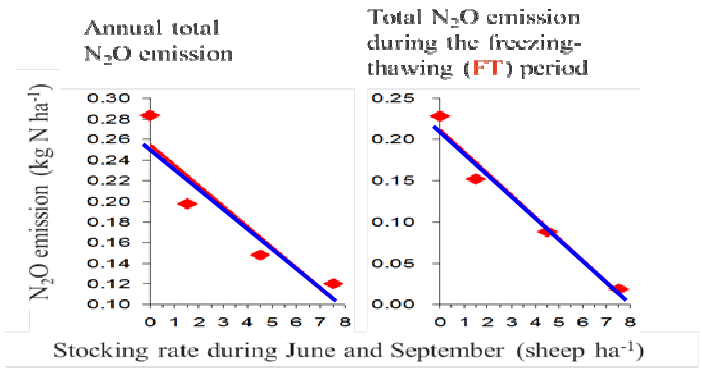


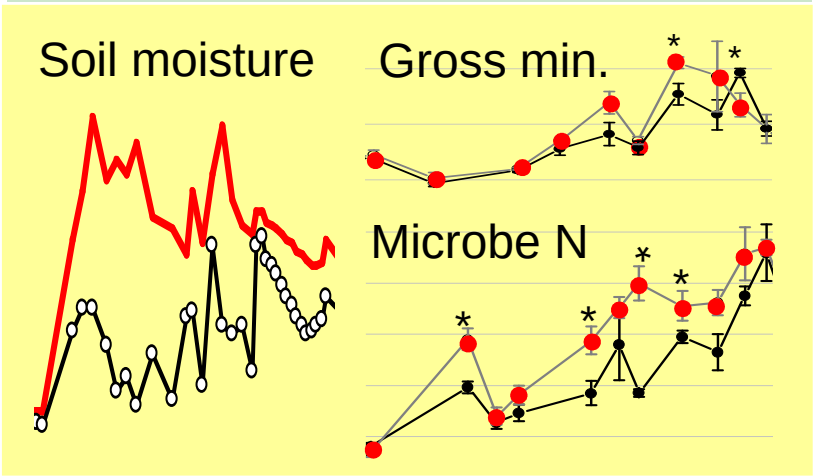
Process Understandings: N_2O

Effects of grazing in temperate semi-arid steppe

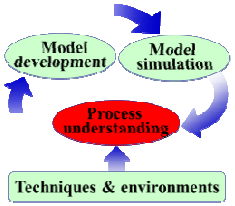






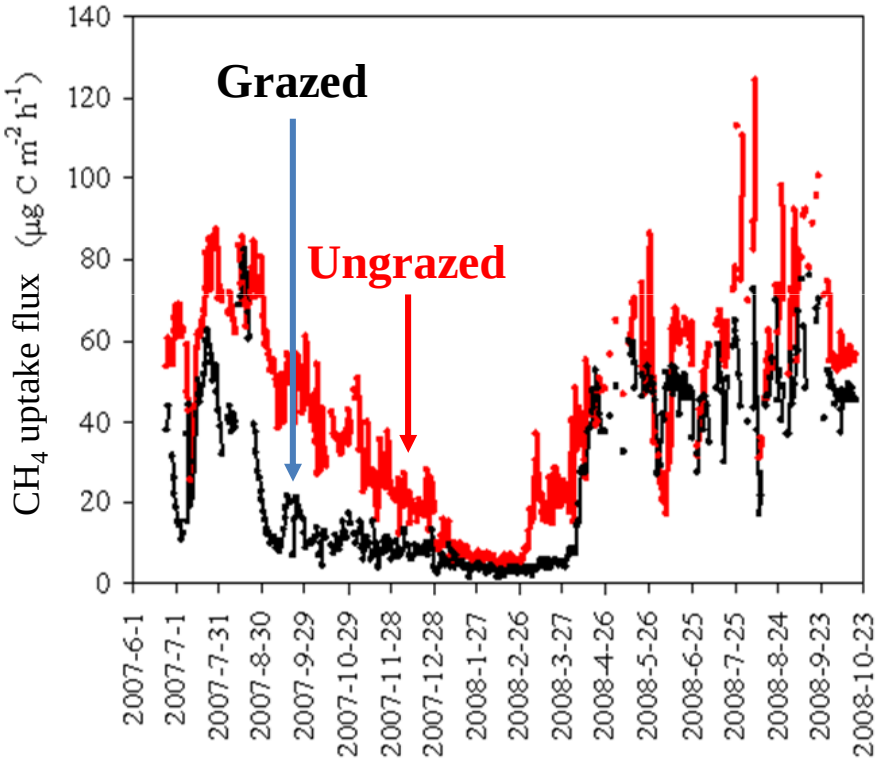


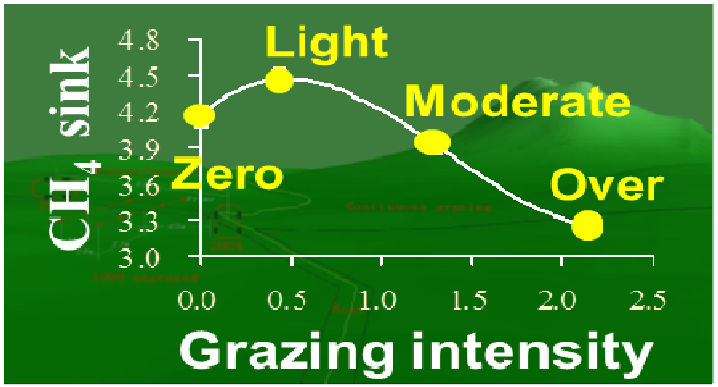
(Wolf # & Zheng et al., 2010, Nature)

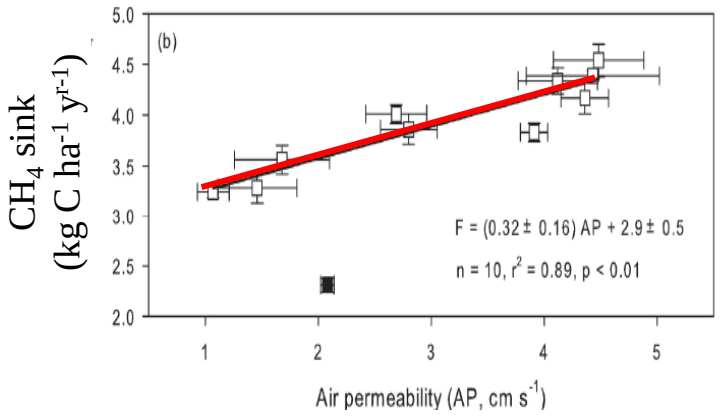


Process Understandings: CH_4

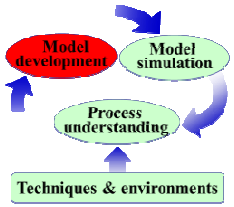
Effects of grazing in temperate semi-arid steppe





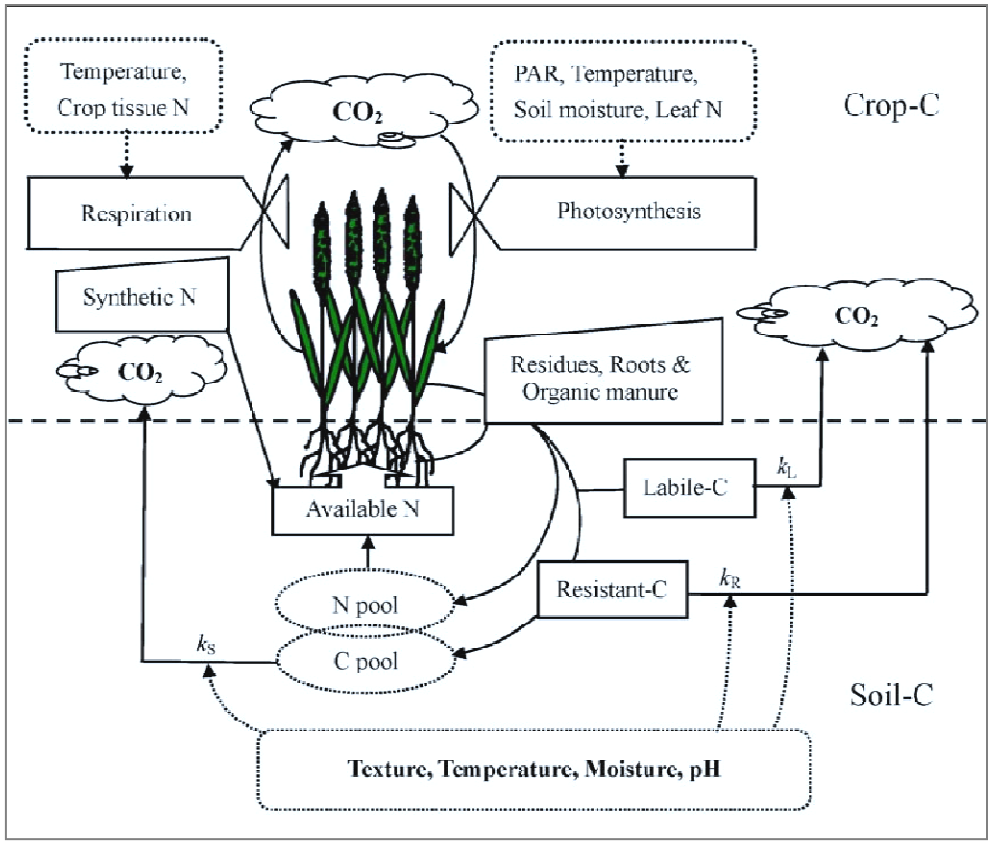


(Chen et al., 2010, JGR; Chen et al., 2011, GCB)



Model Design/Test: Agro-C

Tool for simulating terrestrial NEE & ΔSOC



$$NPP = \sum_{i=1}^{n} (GPP_i - RA_i)$$

$$= \sum_{i=1}^{n} (GPP_i - (RG_i + RM_i))$$

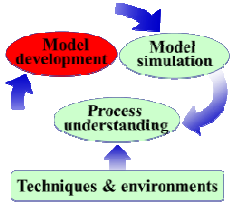
$$P_i = \frac{PM_i \times \overline{PAR_i}}{\beta + \overline{PAR_i}} \times f(T_i) \times f(W_i) \times f(CO_2)$$

$$\Delta N_{uptake} = Min\ (\Delta NA_i, \Delta ND_i)$$

$$\frac{dC_{i,j}}{dt} = -k_j \times F(T_{s\,i}) \times F(W_i) \times F(Clay) \times F(pH) \times C_{i,j}$$

$$RH_i = \frac{dC_{s,i}}{dt} + \frac{dC_{l,i}}{dt} + \frac{dC_{r,i}}{dt}$$

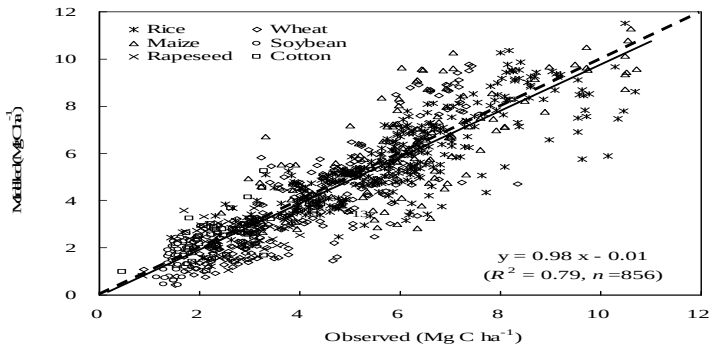
(Huang et al., 2009, AFM)



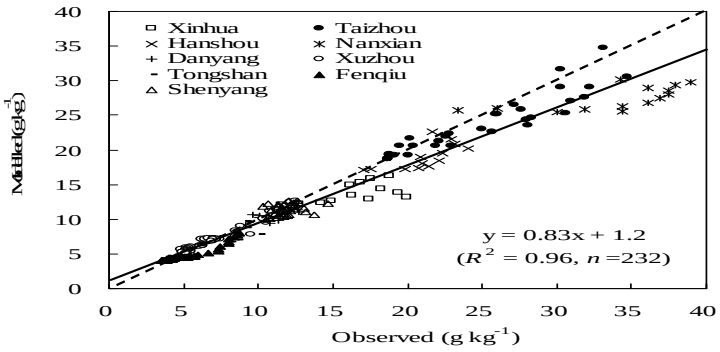
Model Design/Test: Agro-C

Validation of plant growth, NEE & SOC dynamics

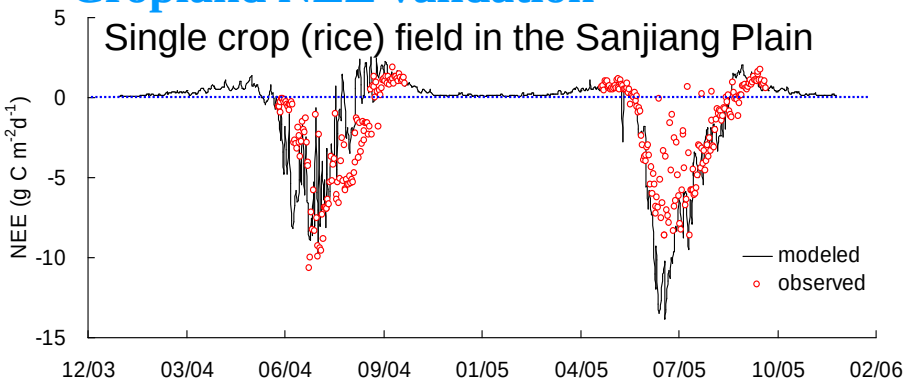
NPP validation

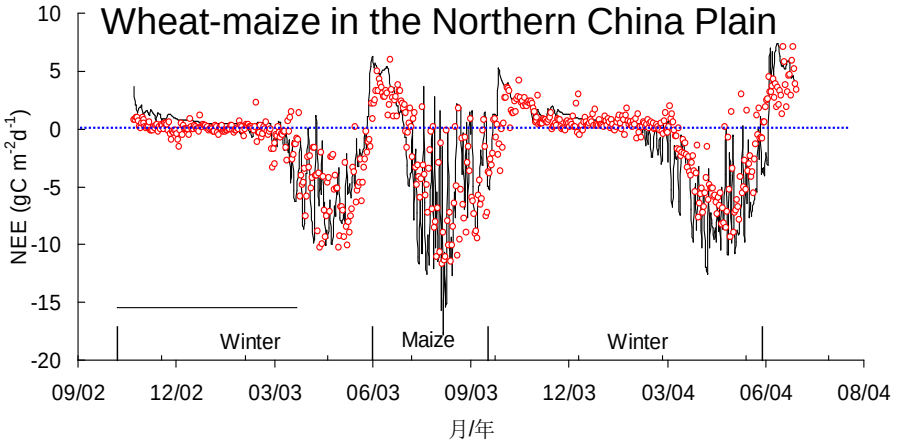


SOC content validation

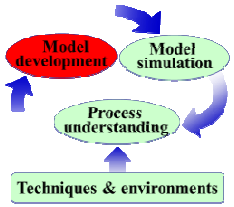


Cropland NEE validation



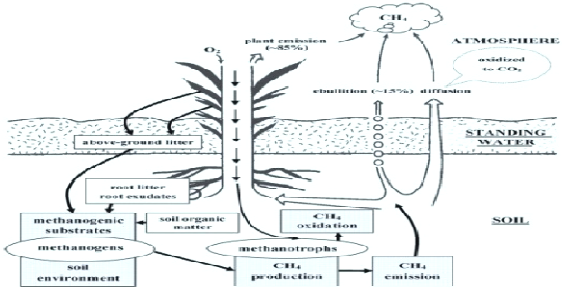


(Huang et al., 2009, AFM)



Model Design/Test: CH_4MOD

Tool for simulating managed/natural wetland CH_4



CH_4 production

$$\frac{dP}{dt} = \alpha F_{Eh} \times SI \times TI \times [\beta \frac{dC_R}{dt} + \gamma \frac{dC_{OM}}{dt}]$$

$$C_R = k_3 \times VI \times SI \times (f_{1_CO_2} \times W)^{1.25}$$

CH_4 emission

$$E_p = (1 - P_{ox}) \times (P - E_{bl})$$

$$E_{bl} = F_{bl} \times (1 - \frac{W}{W_{max}}) \times P$$

Soil Eh

$$Eh_i = Eh_{i-1} - \theta \times (Eh_{i-1} - Eh_c)$$

CO_2 & N effects

$$f_{1_CO_2} = e^{0.02\ N \times \ln(c/c_0)}$$

Water table

$$\Delta WT = \begin{cases} S_{in} - F_{out} - ET & (Apr \sim Oct) \\ P - ET & (Nov \sim Mar) \end{cases}$$

$$WT_i = WT_{i-1} + \Delta WT$$

$$S_{in} = b \times P$$

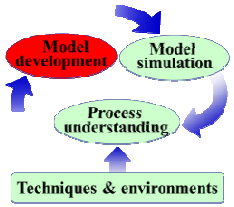
$$F_{out} = \begin{cases} a_1(WD - D_1) + a_2(WD - D_2) & (WD > D_1) \\ a_2(WD - D_2) & (D_2 < WD \le D_1) \\ 0 & (WD \le D_2) \end{cases}$$

$$ET = \alpha' \times \frac{\Delta \times (R_n - G)}{\Delta + \gamma}$$

$$\Delta = \frac{4098.17 e_s}{(T + 237.3)^2}$$

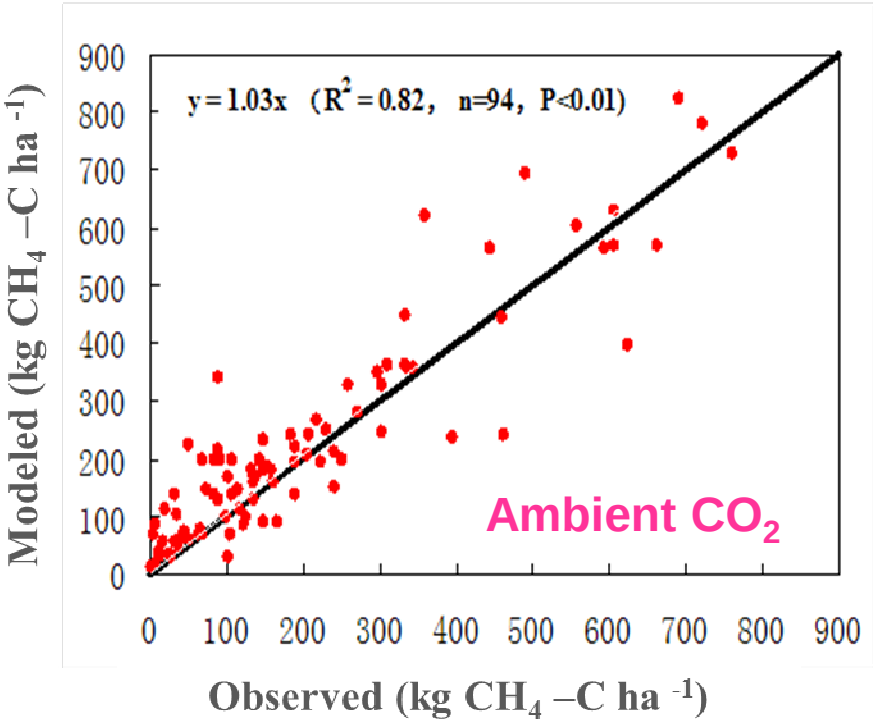
$$e_s = 6.11 \exp(\frac{17.27T}{T + 237.3})$$

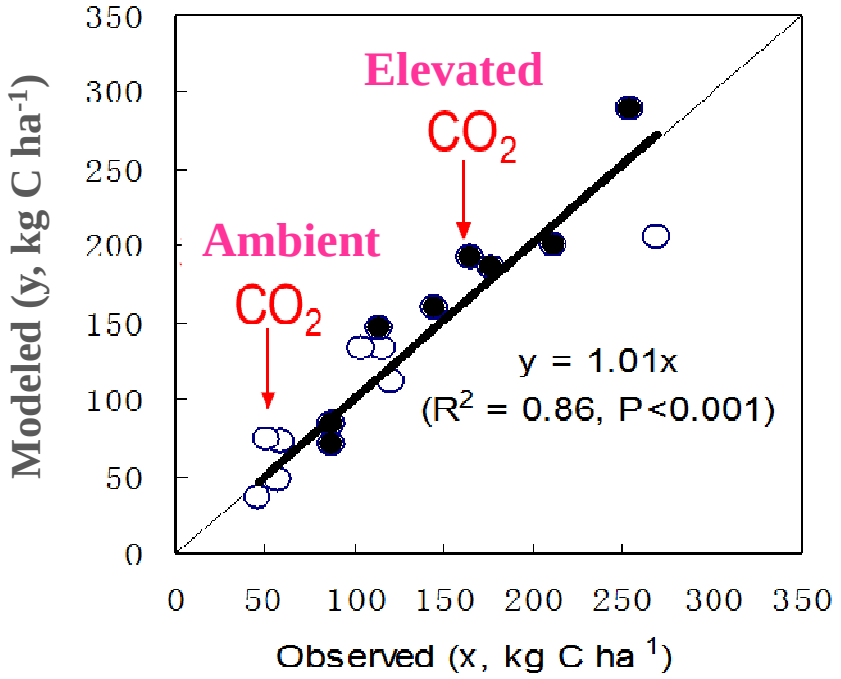
(Huang et al., 2004, JGR; Li et al., 2010, EM; Xie et al., 2010, AAS; Li et al., 2012, BG)



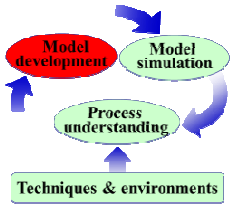
Model Design/Test: CH_4MOD

Test of simulation for rice-field CH_4



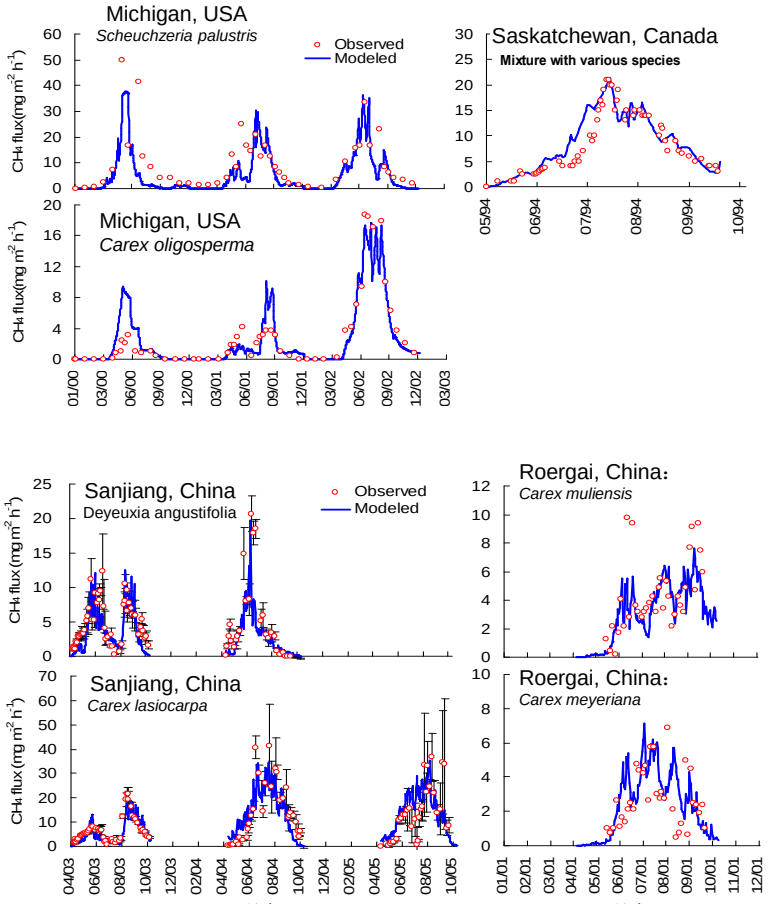


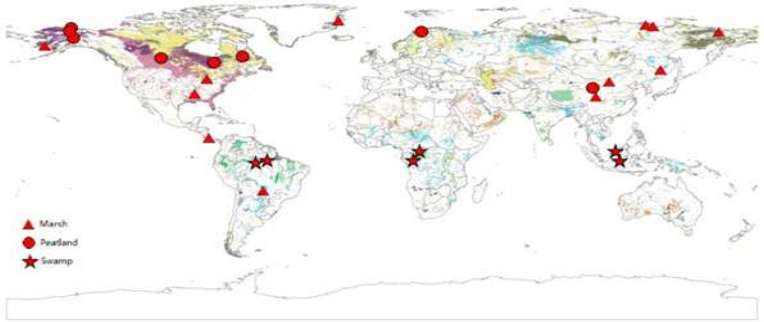
(Huang et al., 2004, JGR; Xie et al., 2010, AAS)

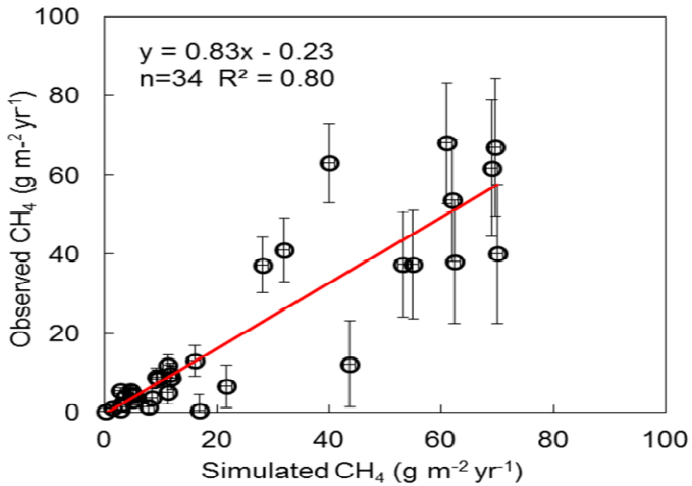


Model Design/Test: CH_4MOD

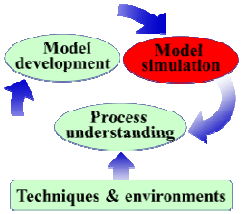
Test of simulation for natural wetland CH_4





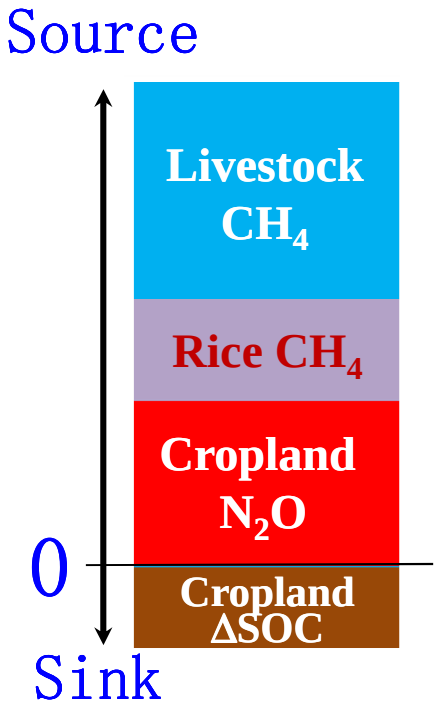


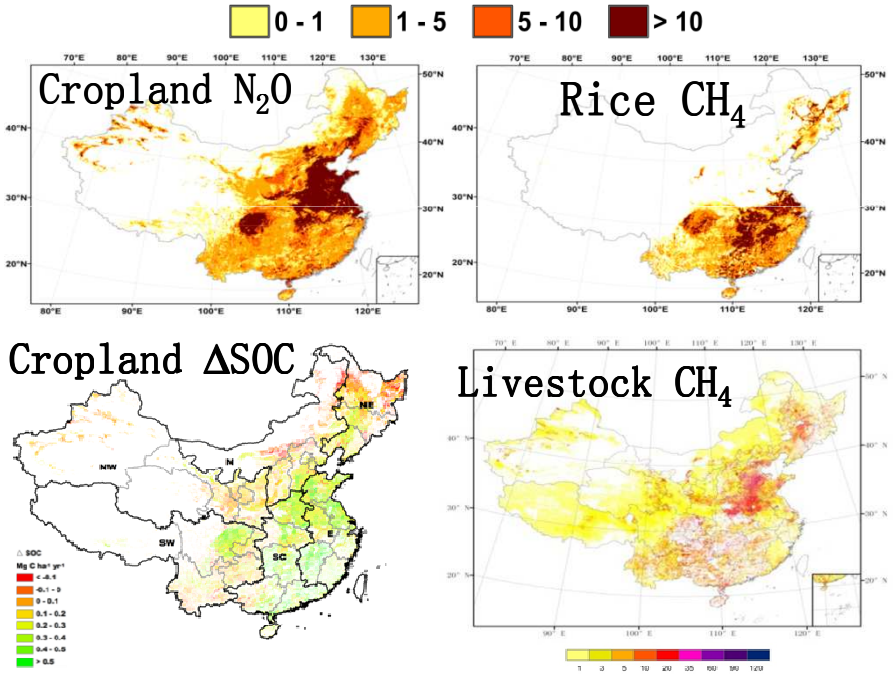
(Li et al., 2010, EM; Li et al., 2012, BG; Li et al., 2014, in preparation)



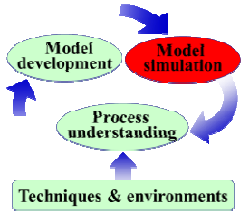
Model Application: GHG Inventories

Agricultural section of China annually emitted 0.62 Pg CO_2-eq (2000-2005)



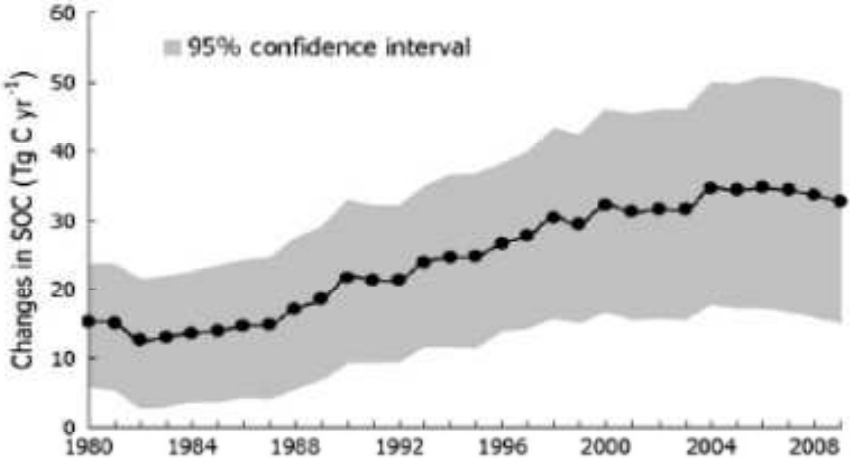


(Lin et al., 2011, Chinese J Environ. Sci. (in Chinese); Sun & Huang, 2012, EP; Yu et al., 2012, GPC; N_2O provided by Yao Huang)

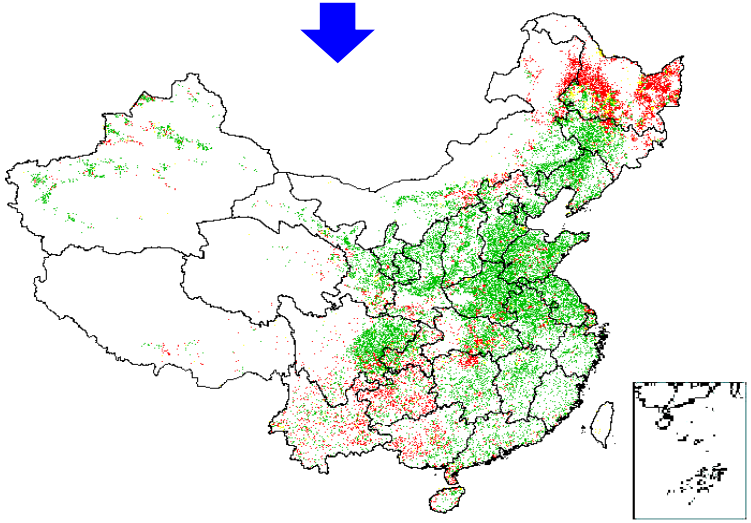


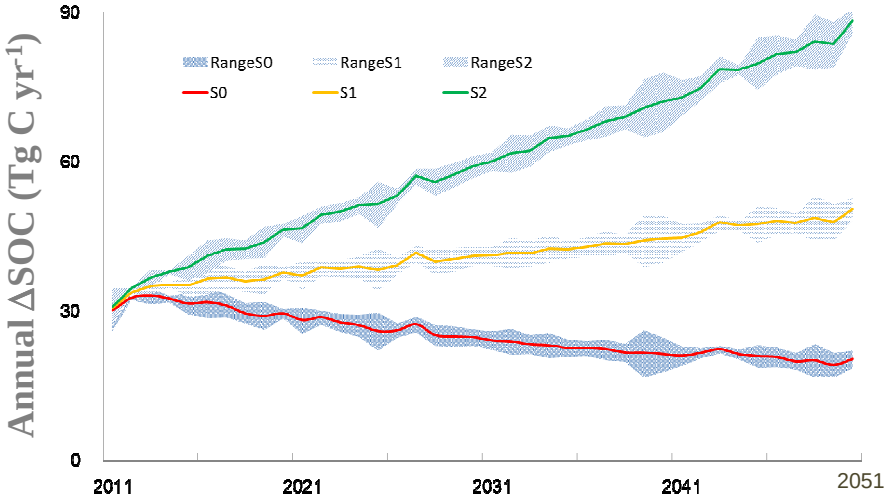
Model Application: Agro-C

cropland ΔSOC and its responses to management and climate change

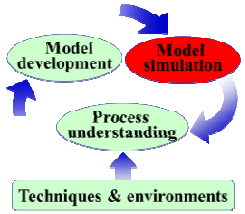


ΔSOC between 1980-2000



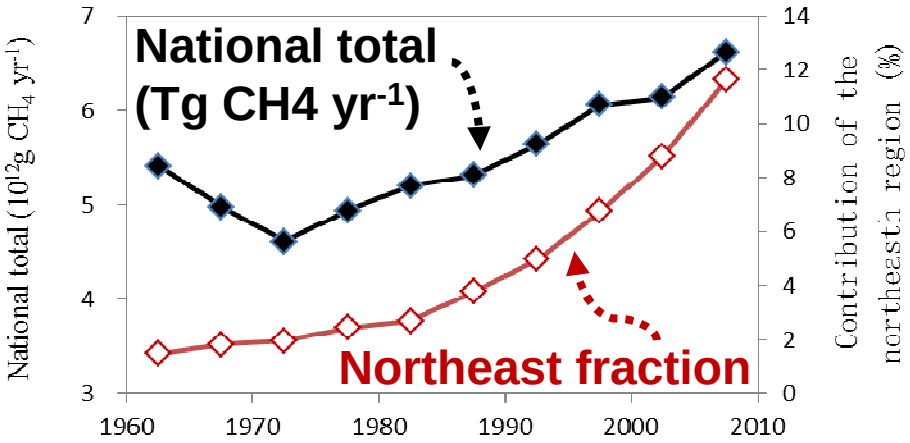


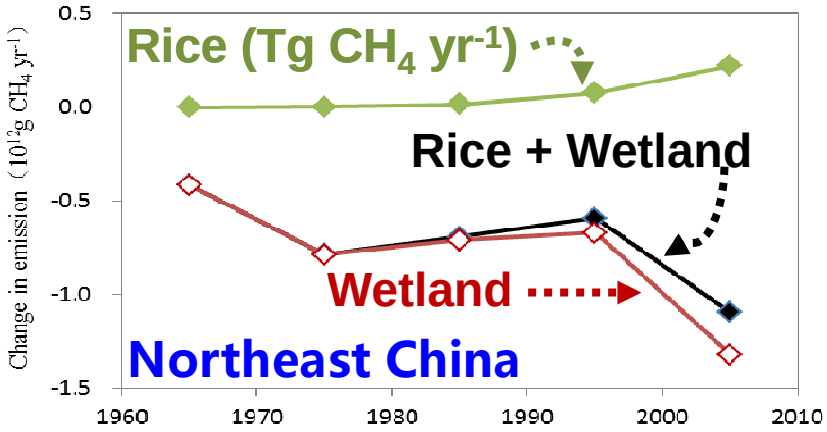
(Yu et al., 2012, GPC; Yu et al., 2013, AGEE)

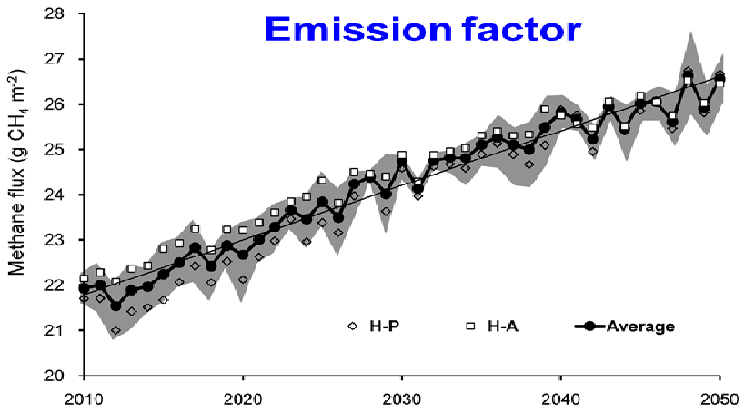


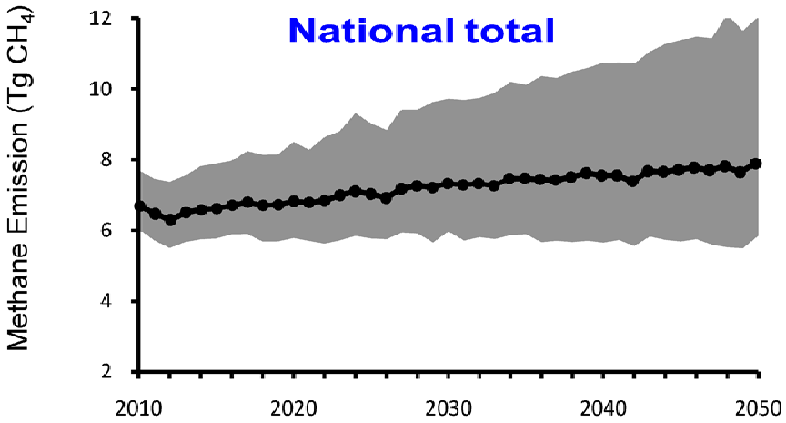
Model Application: CH4MOD

Global change effects on rice CH_4

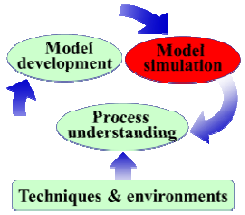








(Zhang et al., 2011, GCB; Huang et al., 2010, GCB)



Model Application: CH4MOD

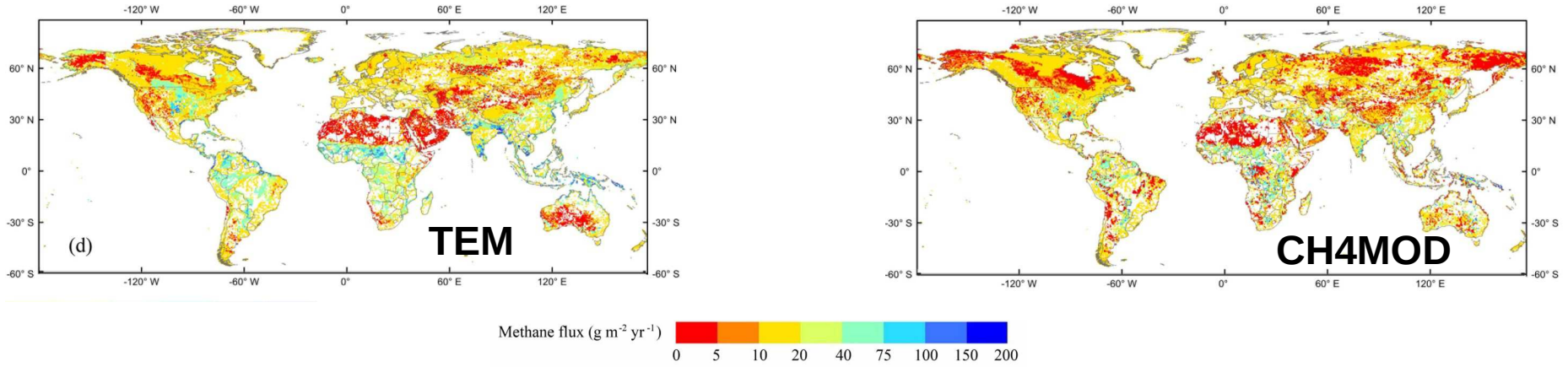
Methane emission from global wetlands (CH4MOD vs. TEM)

Annual flooding (assumed):

173 Tg yr^{-1}

Seasonal flooding:

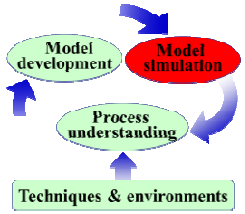
98 Tg yr^{-1}



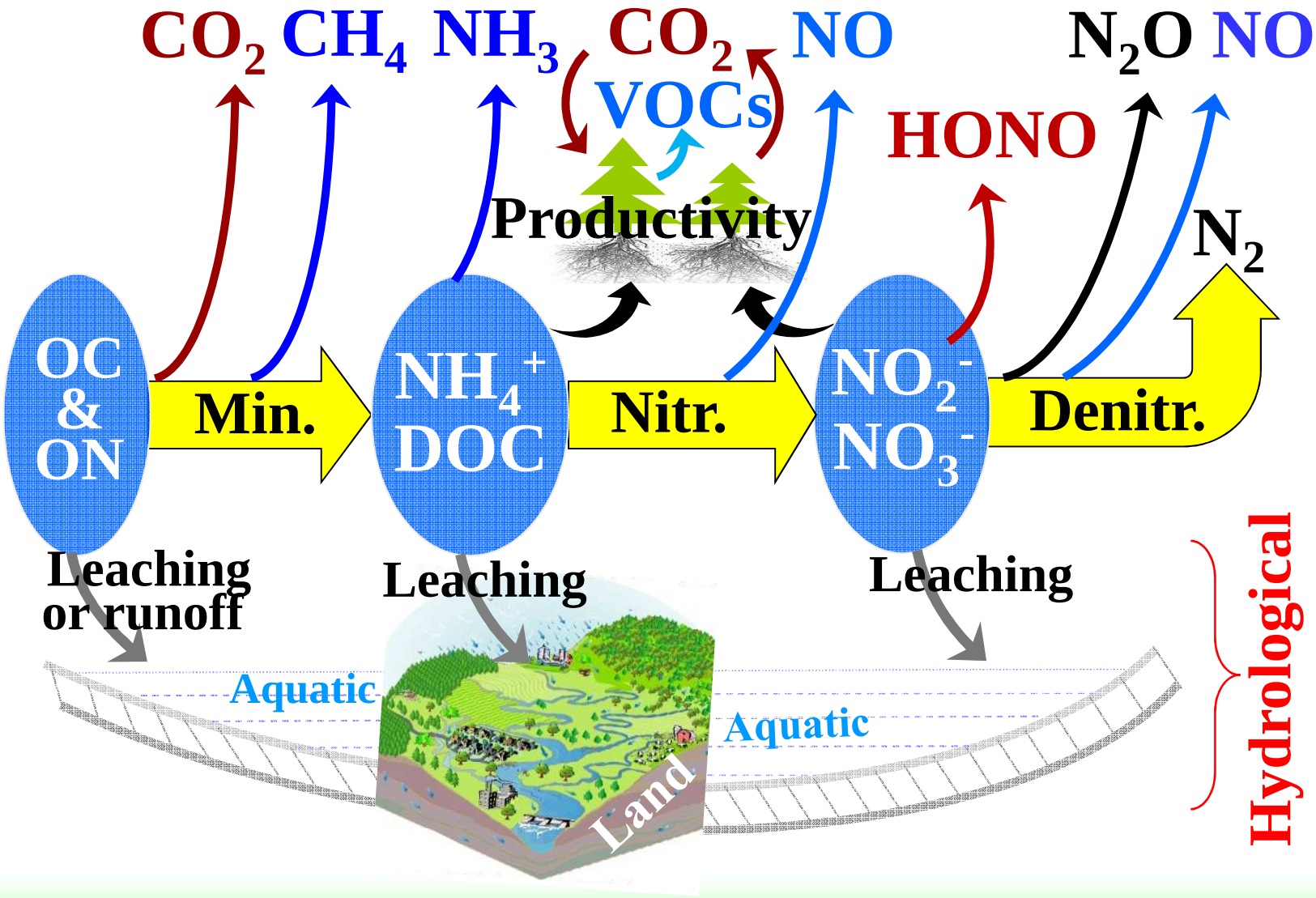
0.5° × 0.5° grids

Area: 585 M km^2

(Li et al., 2014, in preparation)



Principles of multi-goal management



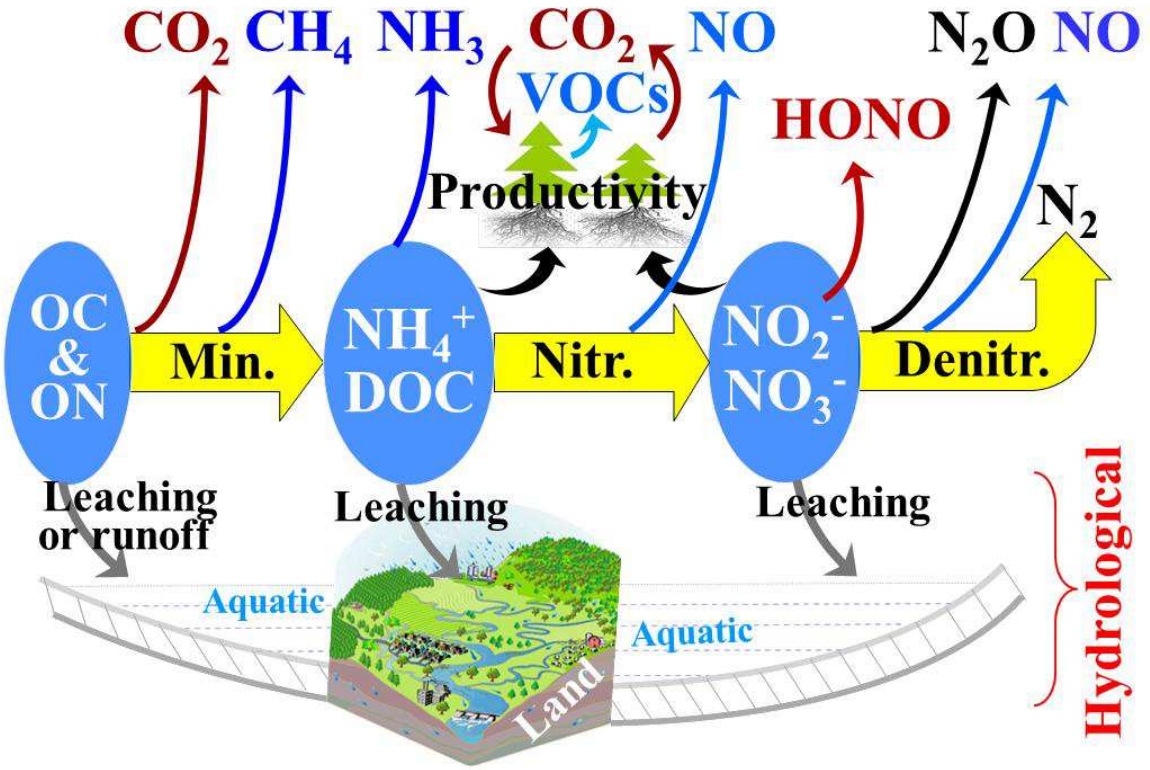
Measurement ability for the processes

Processes that an be precisely measured at

Site or

Catchment ecosystem scale

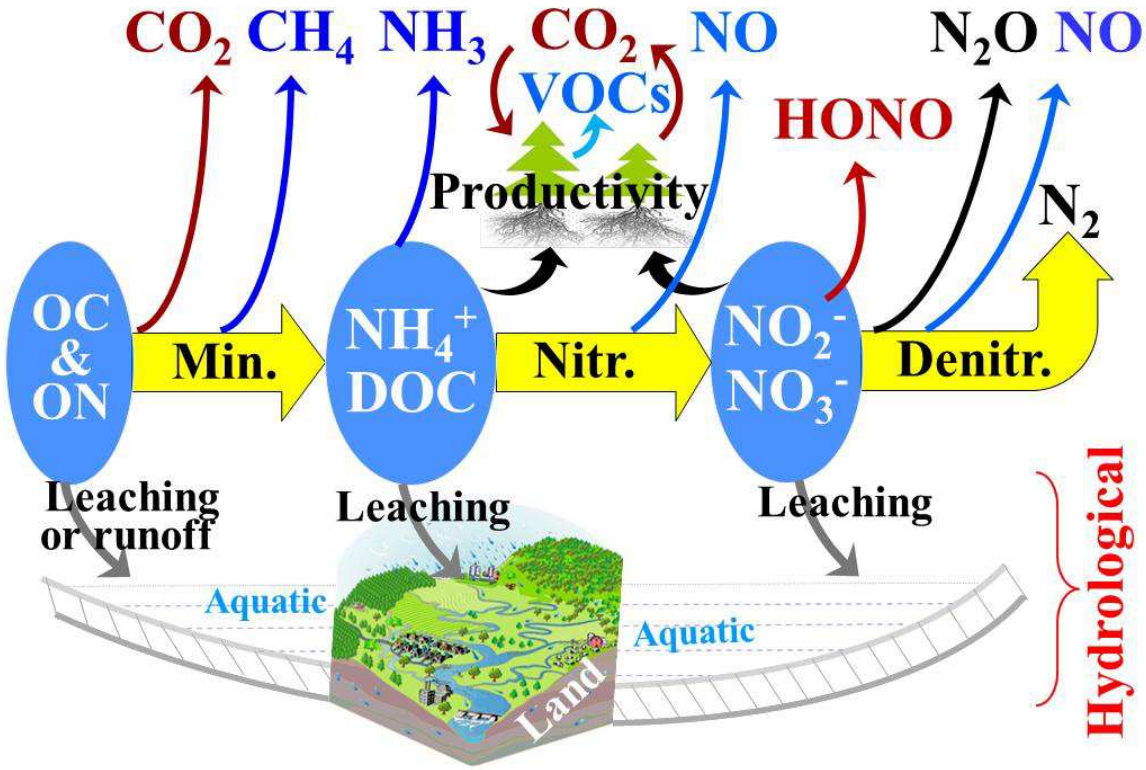
scale



Current ability of process models

3-D models at catchment scale

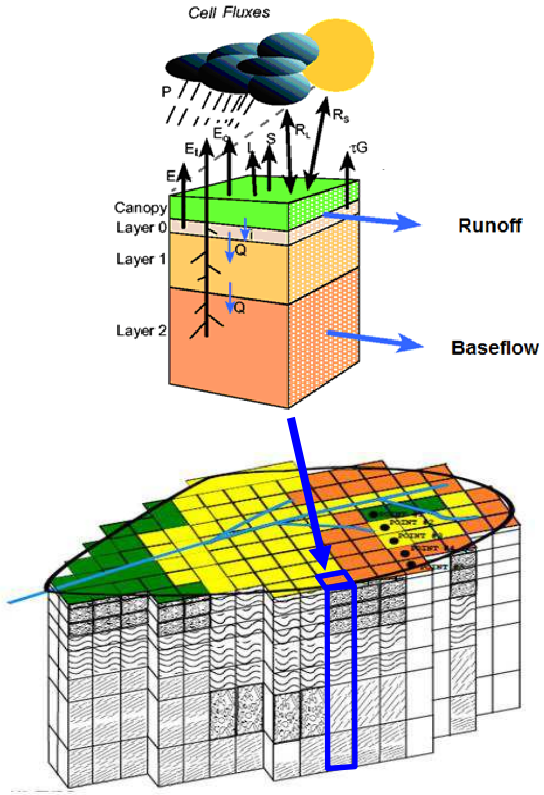
1-D models at site or ecosystem scale



Designing 3-D models (Challenge 1)

which are essential, but currently missing tools

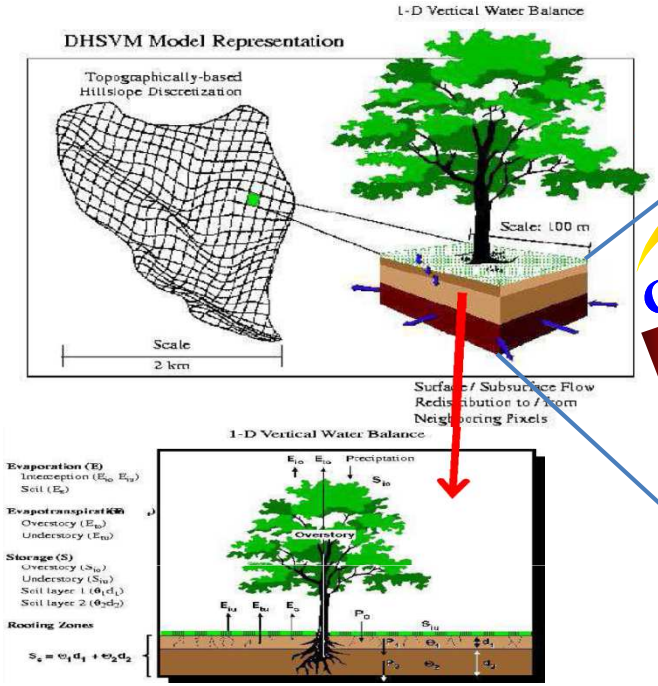
- **3-D model is required:**
  - to fuse data of different spatial and/or temporal scales;
  - to integrate understandings of the complex processes within a catchment; and,
  - to explore strategies of multi-goal ecosystem management under changing environment & climate.



(from Y. Li, personal commun.)

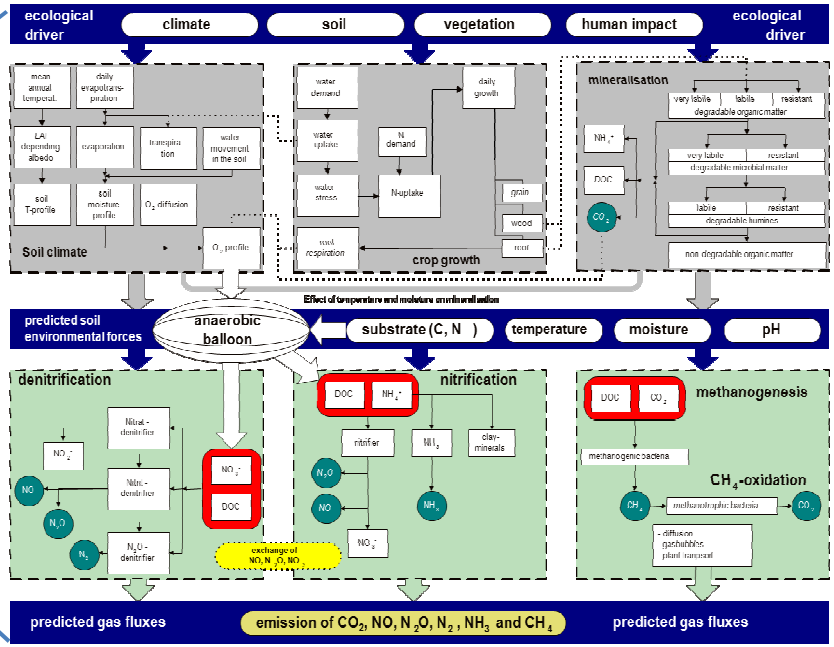
- **3-D model is expected:**
  - to be capable of simulating horizontal and vertical movement and biogeochemical transformation of C and N within a catchment.

DHSVM (Wigmosta *et al*., 2001)



Coupling

DNDC (Li et al., 2007, 2012)



3-D catchment-ecosystem model:

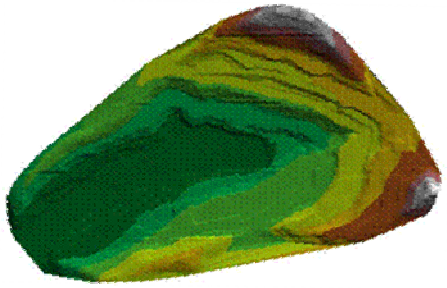
may be developed by coupling 1-D process-based biogeochemical models (e.g. DNDC) into 3-D distributed hydrological models (e.g. DHSVM)

3-D model validation (Challenge 2)

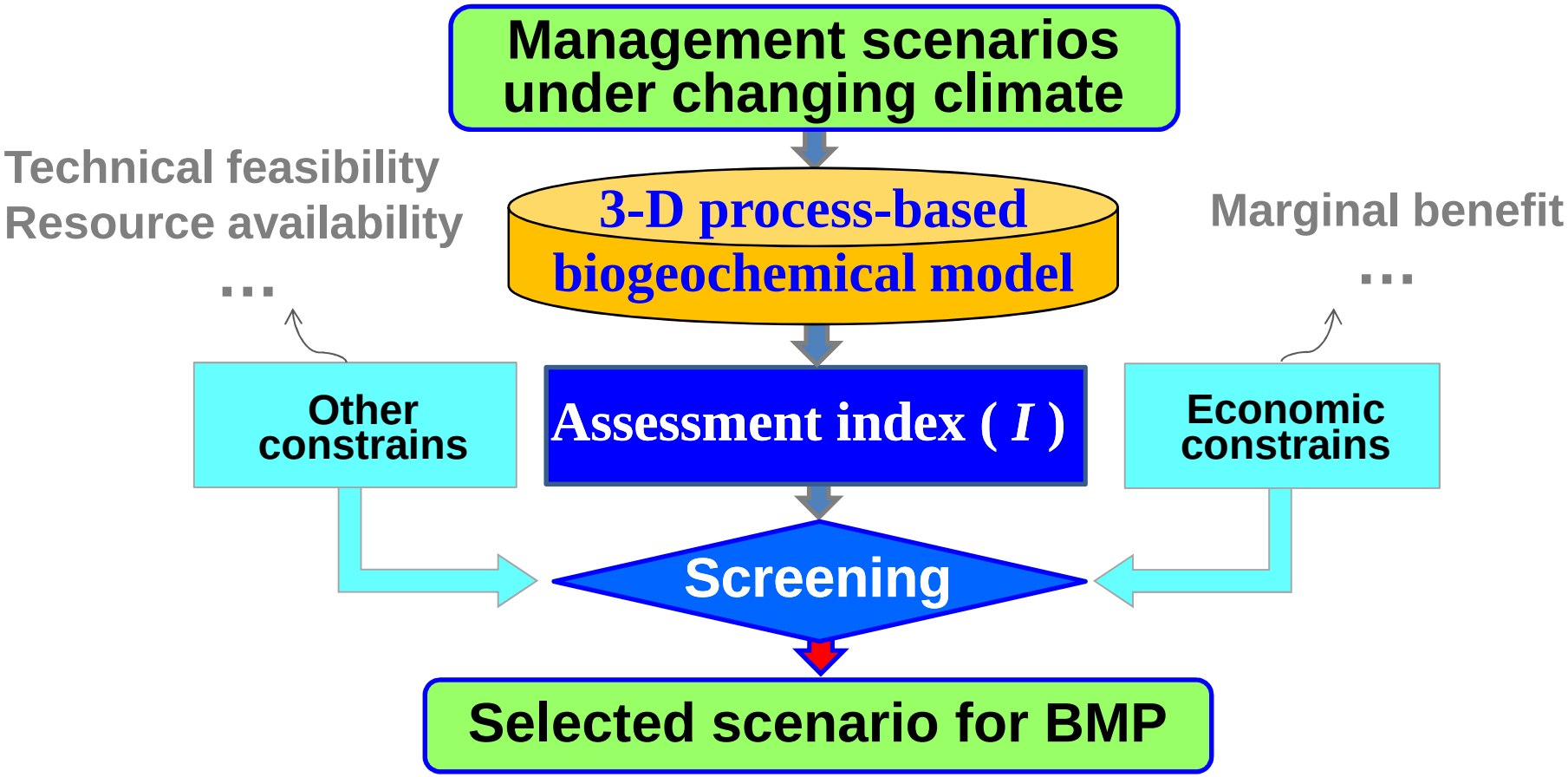
which is lacking of complete datasets

Few datasets can be found, which require:

- validated parameters of soil, vegetation, hydrology;
- validated driving data to facilitate model running;
- simultaneously measured data in a catchment on:
  - dynamical gas fluxes (CO_2, CH_4, N_2O, NO, NH_3, …) for ecosystems;
  - slope or stream fluxes (runoff, PN, SOC, DOC, IN, DON, …); and,
  - other variable dynamics (e.g. soil NH_4^+, NO_3^-, DOC, …).



Best management (Challenge 3)
is limited by lacking of strategy-developing tools



BMP scenario: under given constrains the scenario with the largest *I* value is the best

(Adapted from Cui et al., 2014, BG)

Best management (Challenge 3)
is limited by lacking of strategy-developing tools

Function to determine the *I* value of a given scenario

A price-based proxy; Productivities (e.g. crop yield); $CO_2+CH_4+N_2O_{GHG}$; N leaching; O_3-layer depletion matter

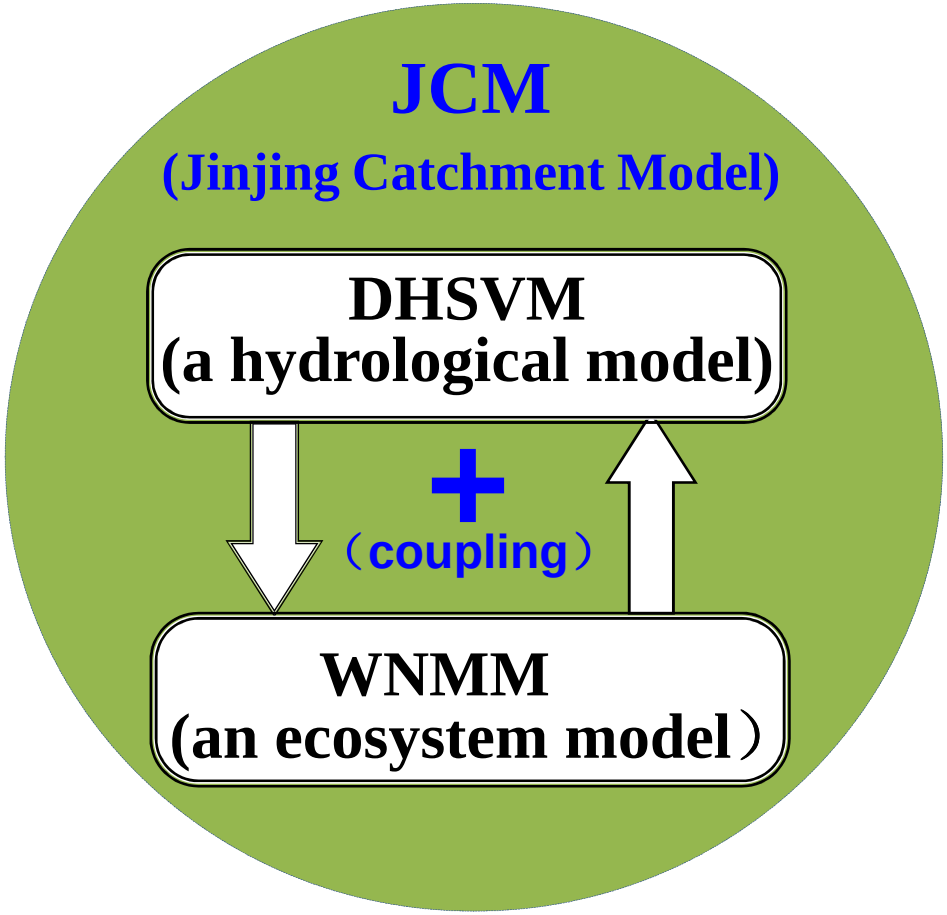
$$I = \sum_{i=1}^{n} a_i \cdot P_i - b \cdot NEGE - c \cdot NH_3 - d \cdot NL - e \cdot NO - f \cdot N_2O_{ODM}$$

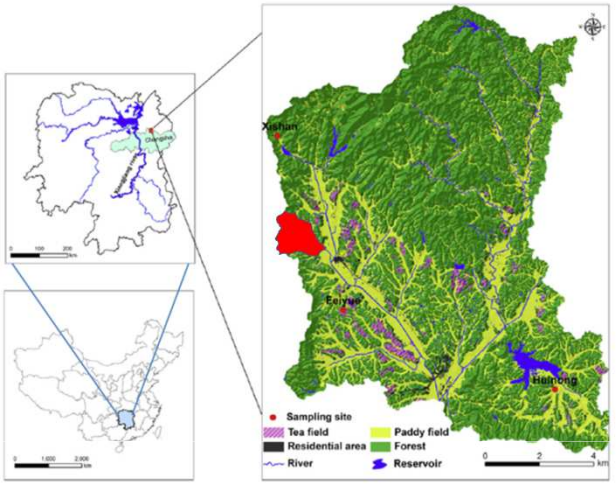
Protocol-based parameters

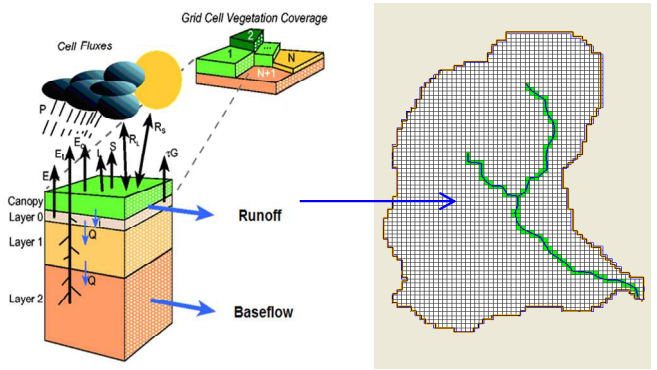
a_1	891	$ ton^{-1} C	E.g. referred to market
a_2	938	$ ton^{-1} C	prices of wheat and maize (For a double-crop regime)
b	7.00	$ ton^{-1} CO_2 eq	Referred to market price of carbon trade
c	5.02	$ kg^{-1} N	Birch et al. 2010
d	1.92	$ kg^{-1} N	van Grinsven et al. 2010; Dodds et al. 2009; Compton et al. 2011
e	25.78	$ kg^{-1} N	Birch et al. 2010, Compton et al. 2011
f	1.33	$ kg^{-1} N	Compton et al. 2011

(Cui et al., 2014, BG)

Ongoing attempts for catchments

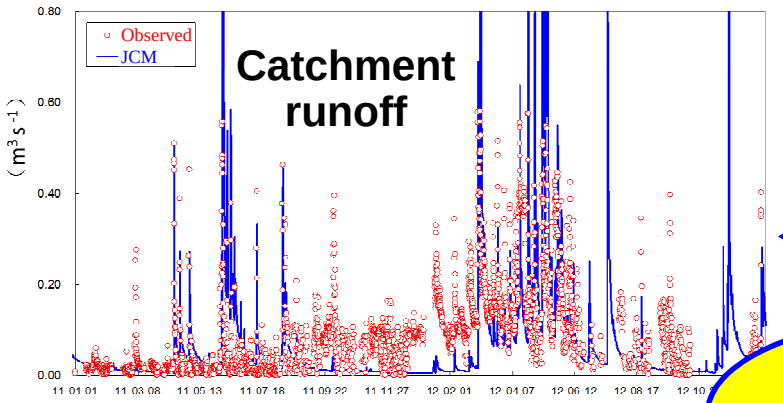


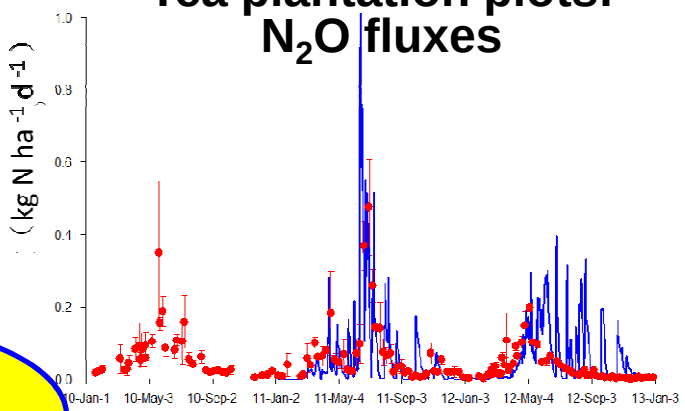




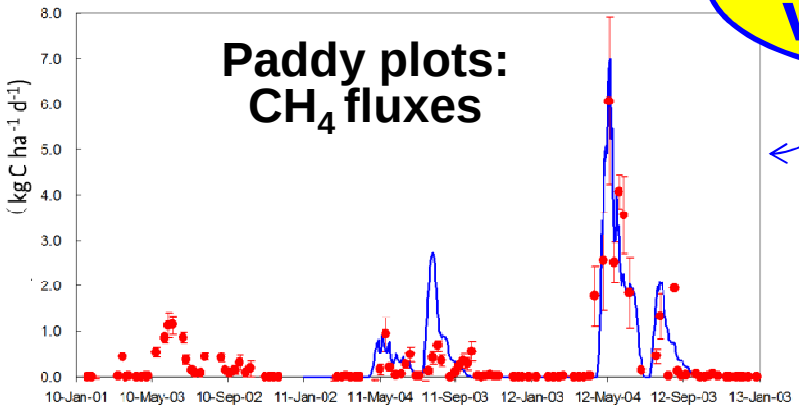
(from Yong. Li, personal commun.)

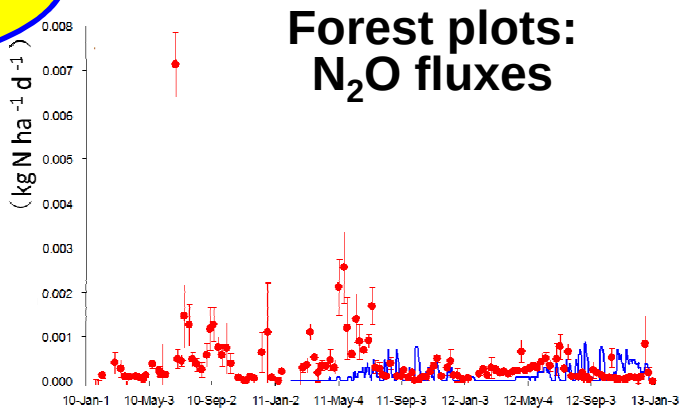
Ongoing attempts for catchments

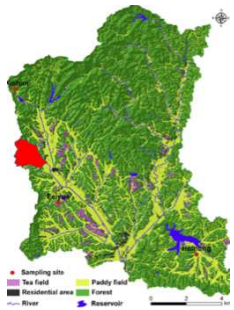




JCM validation





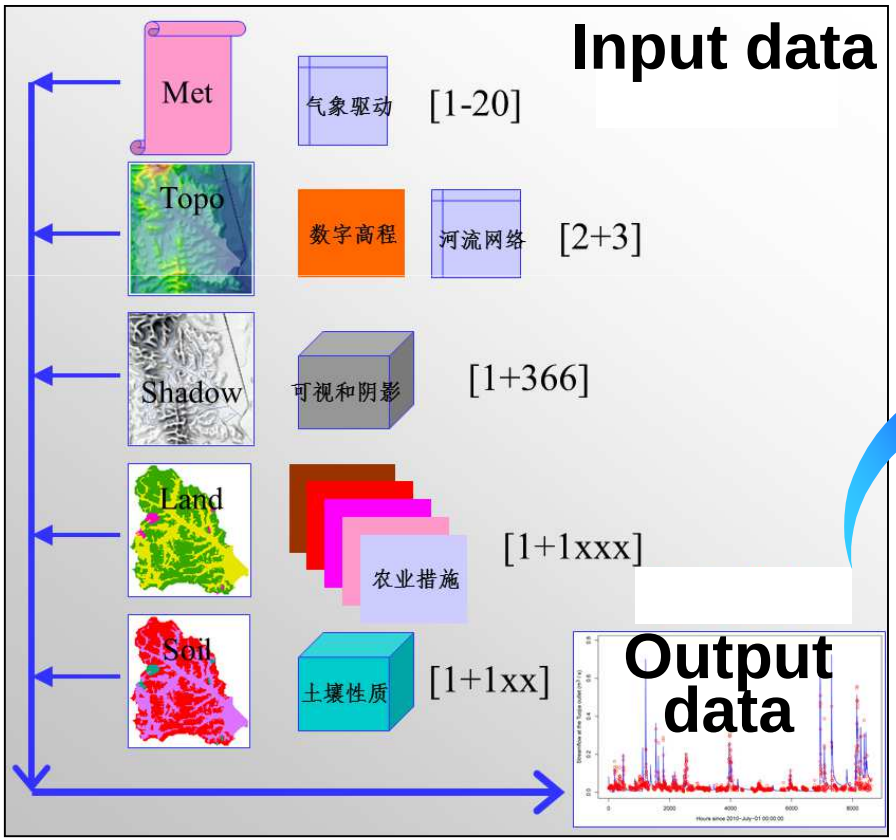


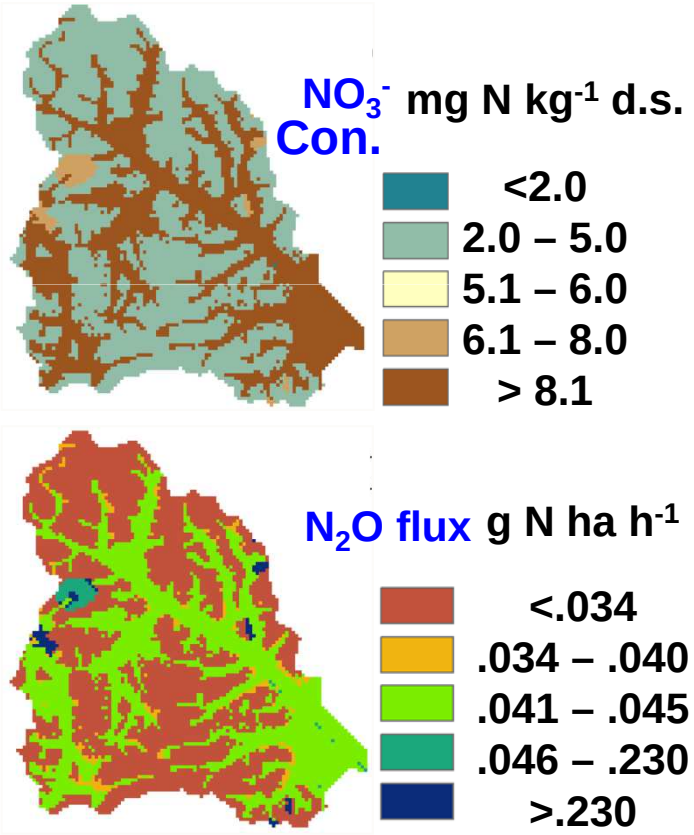
Jinjing catchment

(from Yong. Li, personal commun.)

Ongoing attempts for catchments

Catchment simulation test with JCM



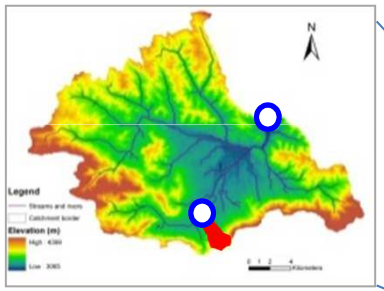


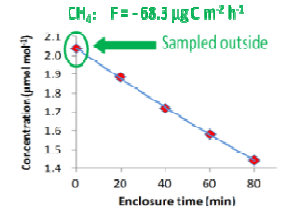
(from Yong. Li, personal commun.)

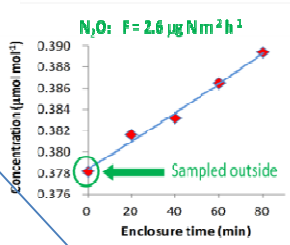
Ongoing attempts for catchments

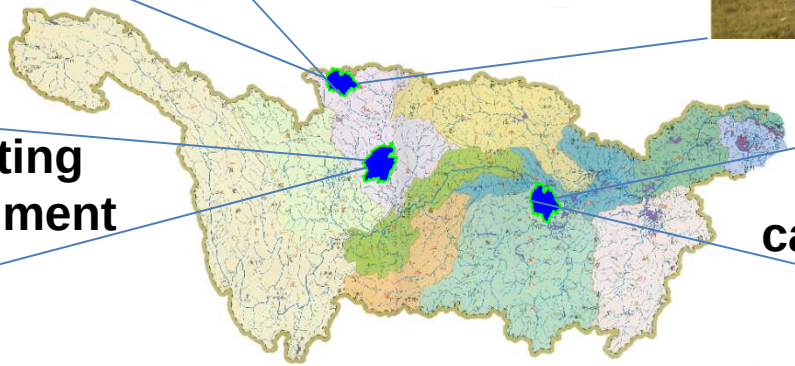
Comprehensive observation to validate 3-D catchment-ecosystem model(s)

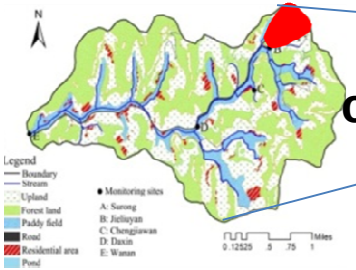
Zoige catchment (seasonal frost, alpine)





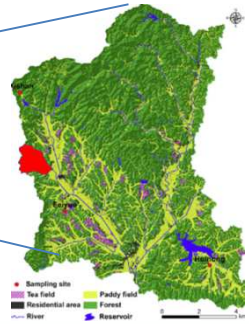






Yanting catchment

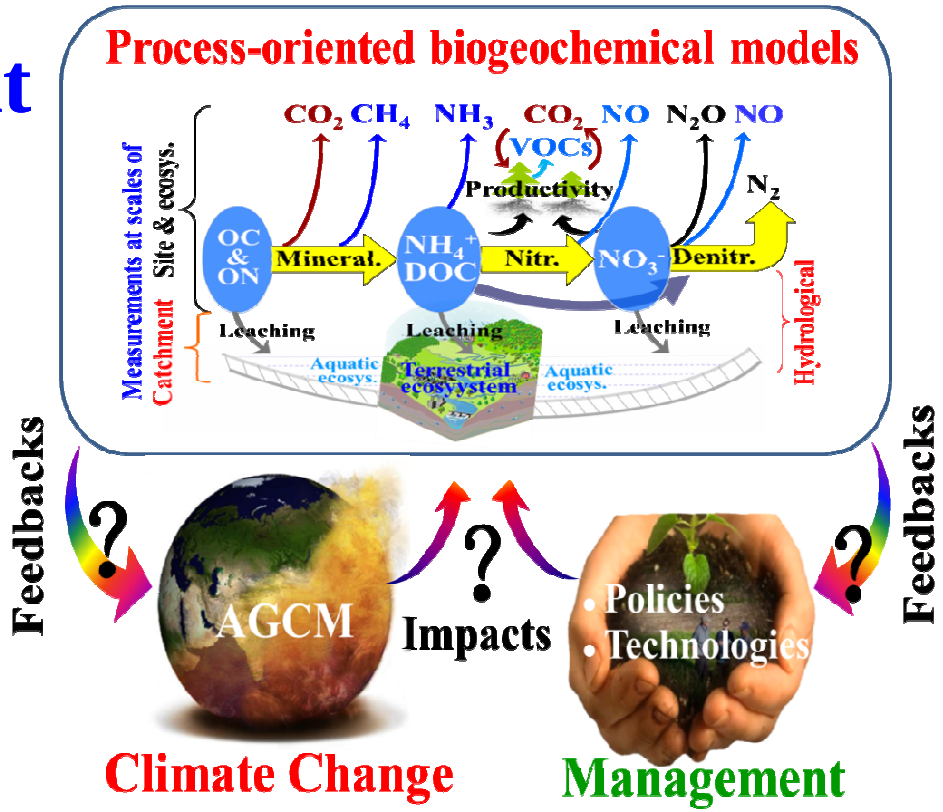
Jinjing catchment



Yangtze watershed

Future Studies

- To improve and couple 3-D catchment -ecosystem models of critical zone with AGCM
- To understand the feedbacks between exchanges of C- and N-gases and global changes so as to support proper management.



Thanks for your attention !
LAPC / IAP-CAS