Ecosystem measurement, manipulation and modeling

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MBL Biological Discovery in Woods Hole

BROWN

Outline

- Introduction: ecosystem processes
- Ecosystem measurement
- Ecosystem manipulation
- Ecosystem modeling

第六届现代生态学讲座

New Biology for the 21st Century

1. Generate food plants to adapt and grow sustainably in changing environments

2. Understand and sustain ecosystem function and biodiversity in the face of rapid change

3. Expand sustainable alternatives to fossil fuels

4. Understand individual health

U.S. National Research Council 2009,
http://www.nap.edu/catalog/12764.html

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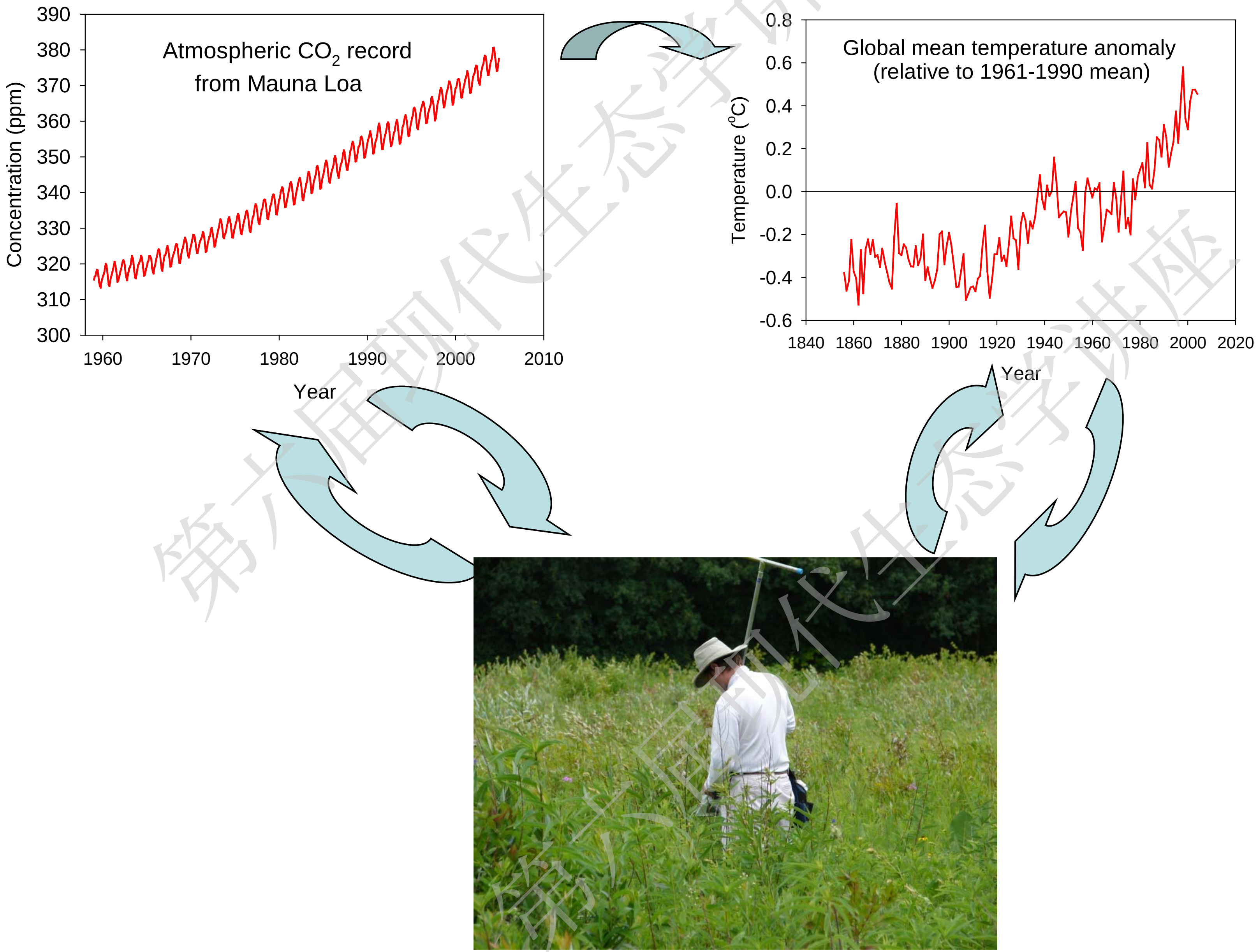
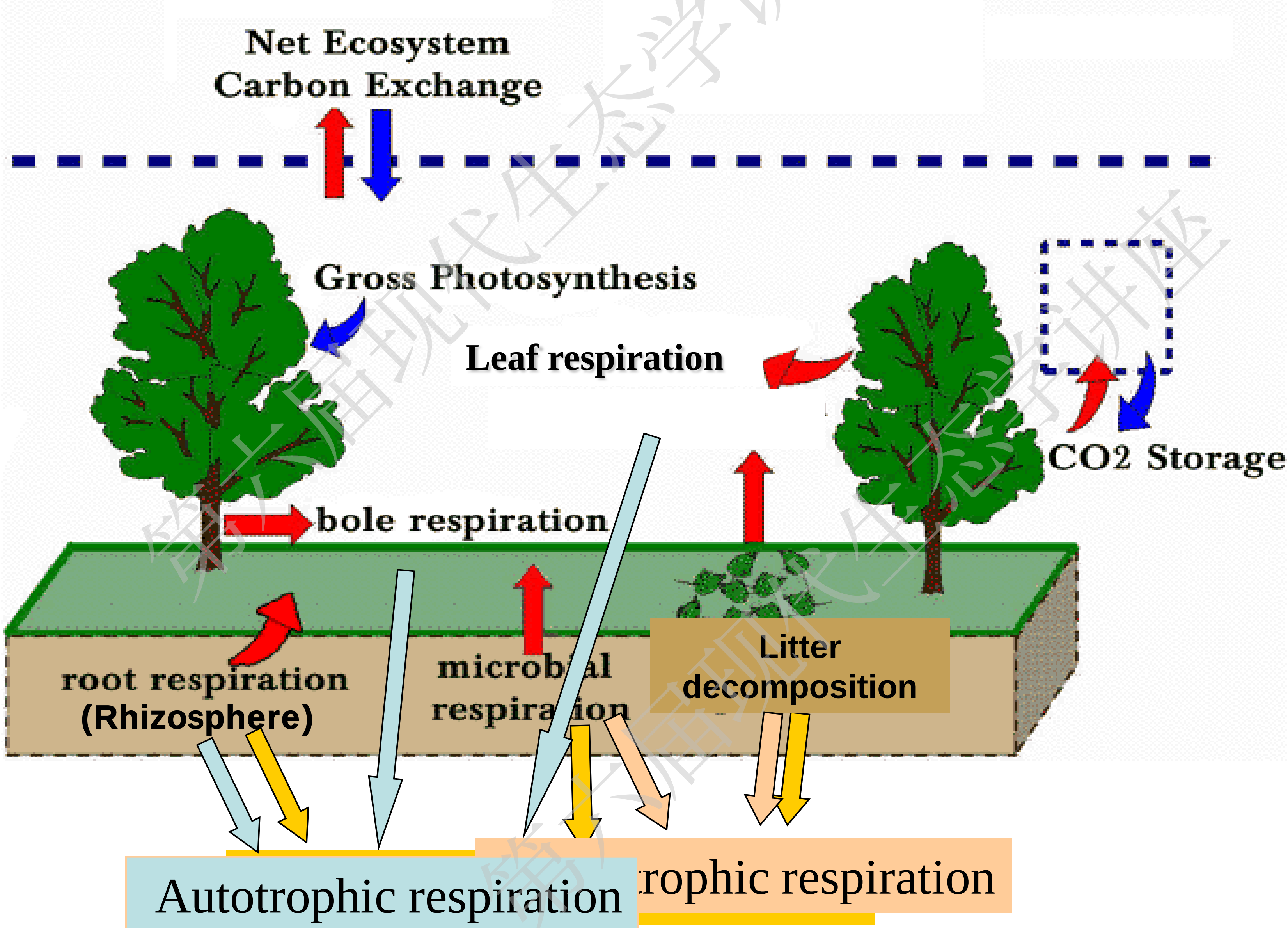
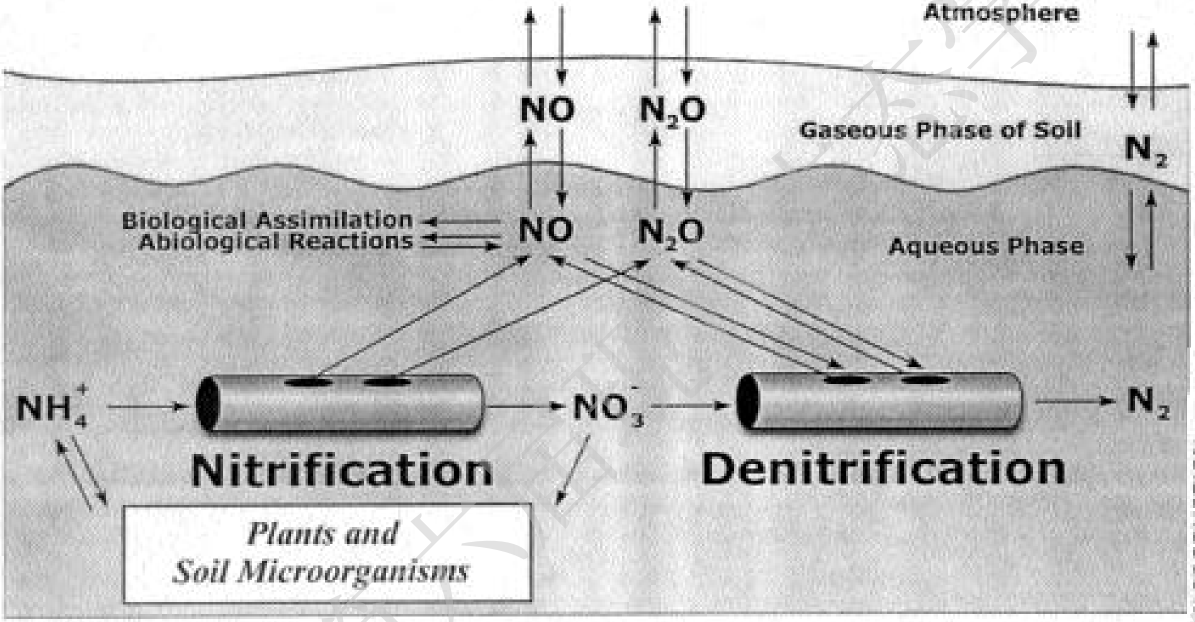
CO_2-climate-ecosystems interactions

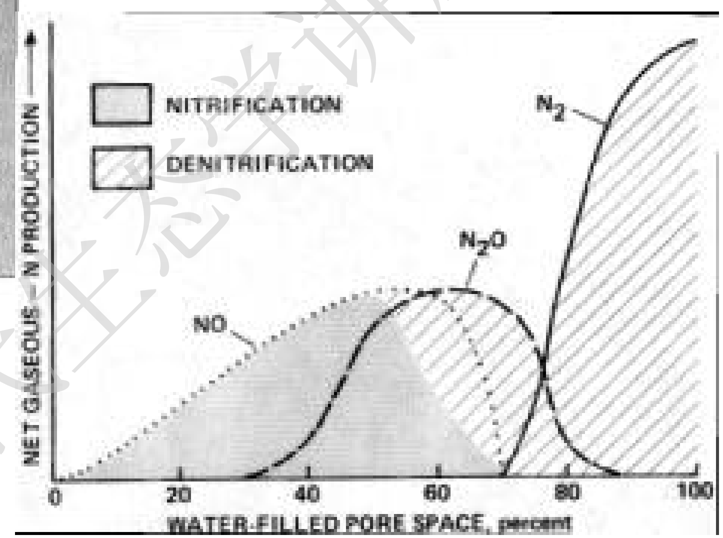


Terrestrial ecosystem carbon fluxes



N_2O production and emissions





Hole-in-the-piple model (Davidson et al. 2000)

C-N coupling

nature geoscience

FOCUS | REVIEW ARTICLE

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Reduction of forest soil respiration in response to nitrogen deposition

I. A. Janssens[1*], W. Dieleman[1], S. Luyssaert[2], J-A. Subke[3], M. Reichstein[4], R. Ceulemans[1], P. Ciais[2], A. J. Dolman[5], J. Grace[6], G. Matteucci[7], D. Papale[8], S. L. Piao[9], E-D. Schulze[4], J. Tang[10] and B. E. Law[11]

The use of fossil fuels and fertilizers has increased the amount of biologically reactive nitrogen in the atmosphere over the past century. As a consequence, forests in industrialized regions have experienced greater rates of nitrogen deposition in recent decades. This unintended fertilization has stimulated forest growth, but has also affected soil microbial activity, and thus the recycling of soil carbon and nutrients. A meta-analysis suggests that nitrogen deposition impedes organic matter decomposition, and thus stimulates carbon sequestration, in temperate forest soils where nitrogen is not limiting microbial growth. The concomitant reduction in soil carbon emissions is substantial, and equivalent in magnitude to the amount of carbon taken up by trees owing to nitrogen fertilization. As atmospheric nitrogen levels continue to rise, increased nitrogen deposition could spread to older, more weathered soils, as found in the tropics; however, soil carbon cycling in tropical forests cannot yet be assessed.

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Important ecosystem parameters

- State/stock
  - Vegetation structure (DBH, height, crown size, LAI) and spatial pattern
  - Species composition and diversity
  - Biomass and volume
  - Climate variables (air temperature, soil temperature, moisture, humidity, cloud coverage)

- Flux (flow)
  - Mass: Carbon, nutrient, water (evaporation, transpiration, precipitation)
  - Energy: heat (sensible and latent), solar radiation

Measurement interval

- Periodical (campaign based)
  - Biometric
  - Nutrient status
- Continuous
  - Sensors and dataloggers (convert voltage/current to digital files)
  - Data storage and download
  - Power supply
  - Calibration and quality control

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Biometric measurement

Measurement of photosynthesis

Measurement of respiration

Soil respiration measurement

Chambers

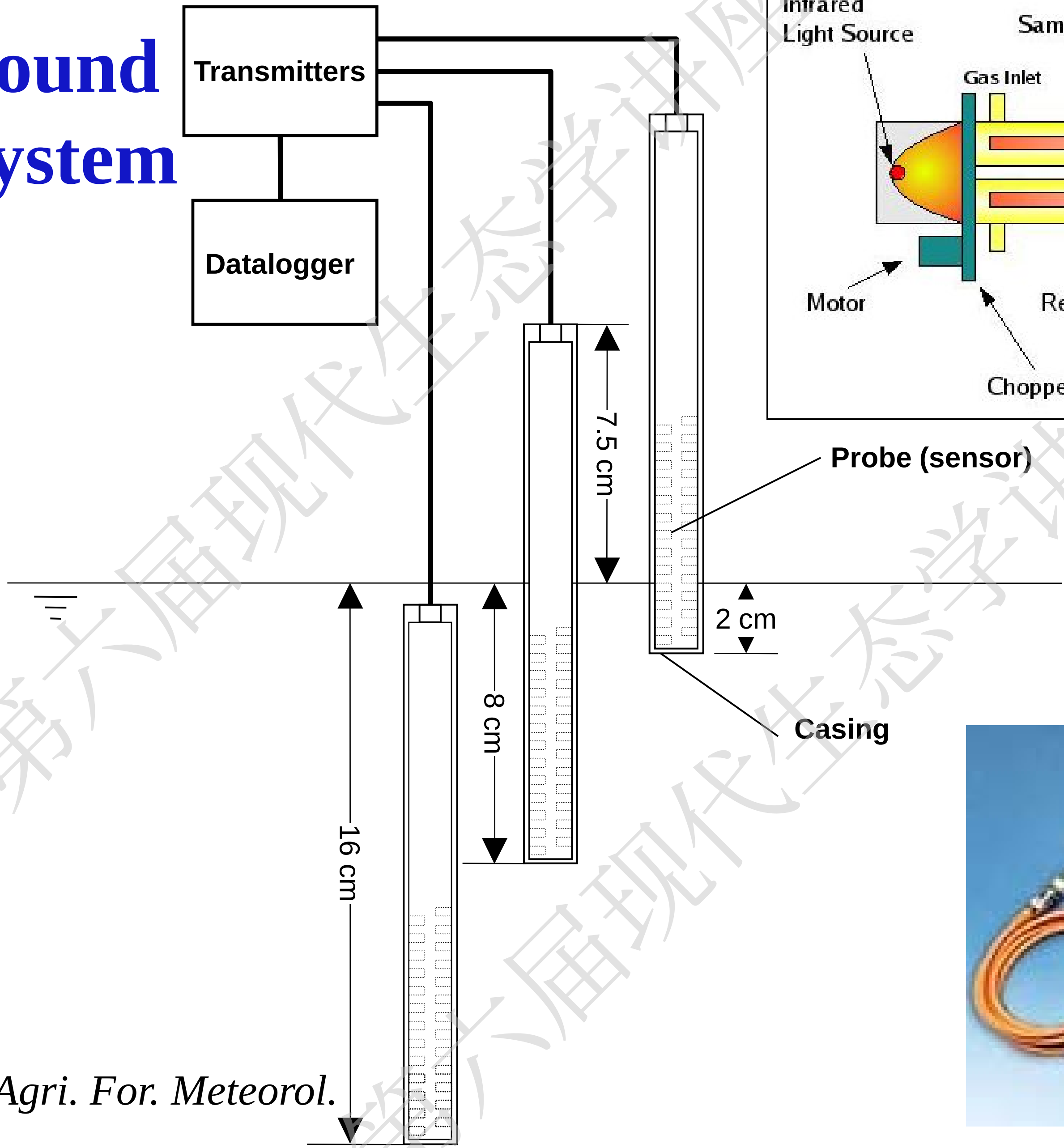
- Multiplex up to 16 long-term chambers (30 m diameter coverage)

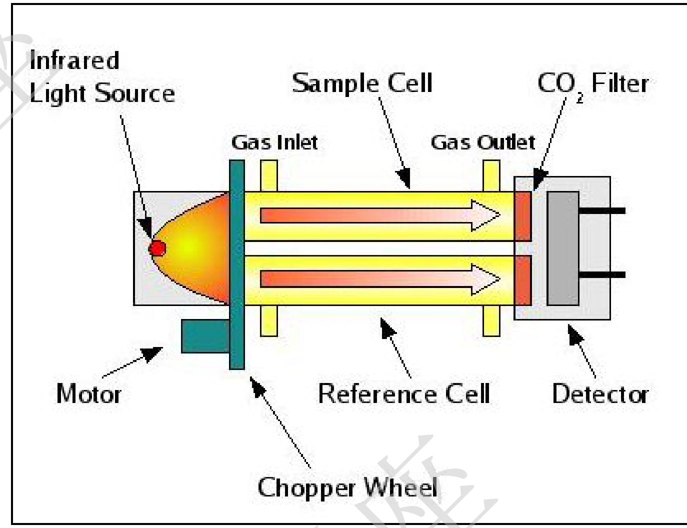
CO_2 gradient

Eddy covariance

Tang et al. 2003, 2005

Belowground profile system

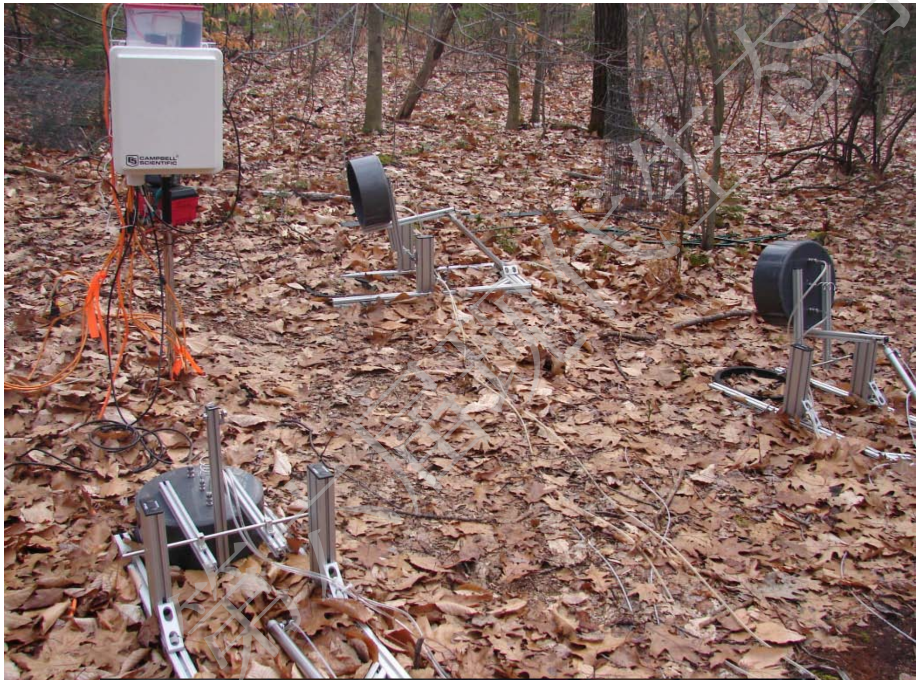


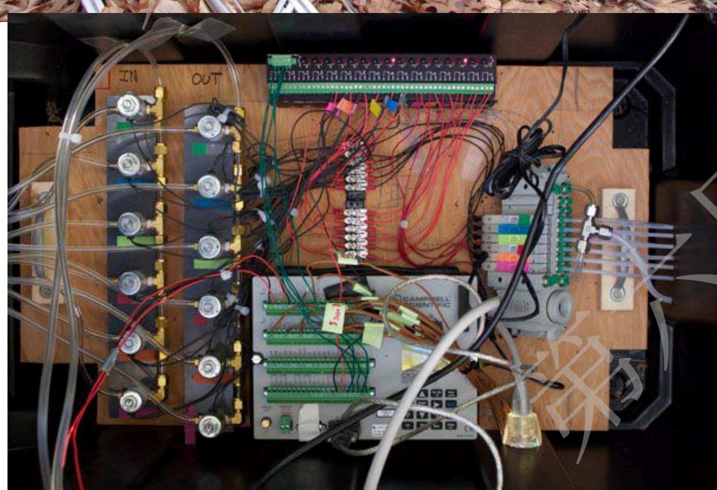


Tang et al. 2003, *Agri. For. Meteorol.*

Tang et al. 2005, *Agri. For. Meteorol.*

Chamber-based in situ measurement of greenhouse gases





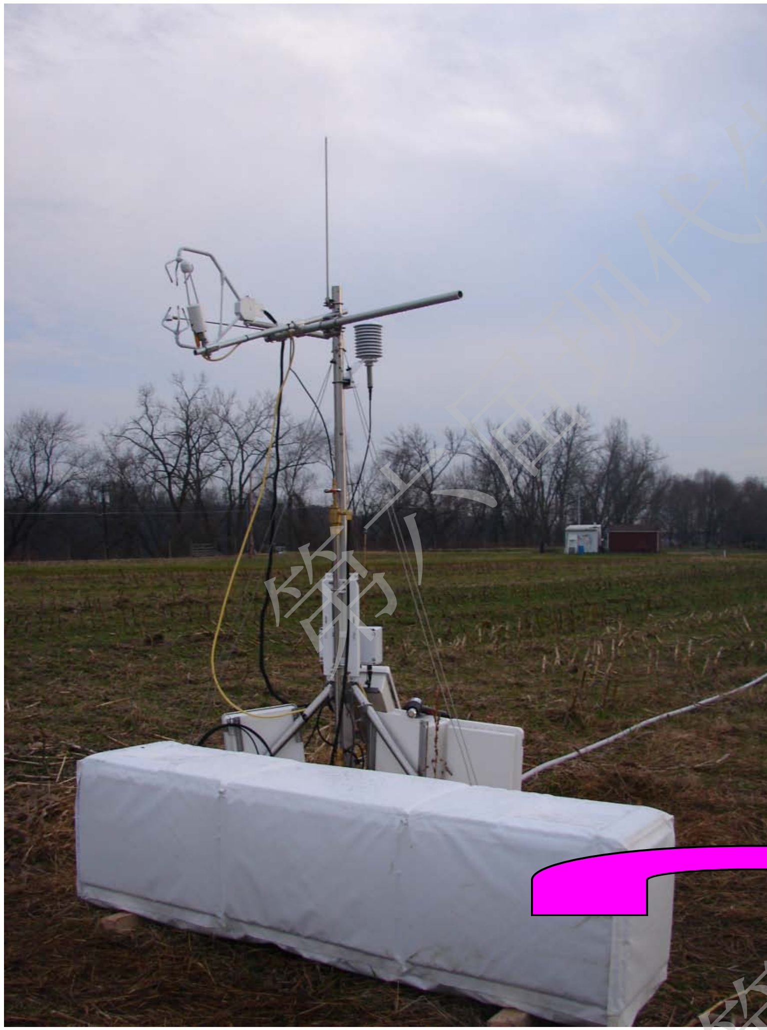
Tang et al. in preparation

Ecosystem-scale measurement of NEP:

Eddy covariance

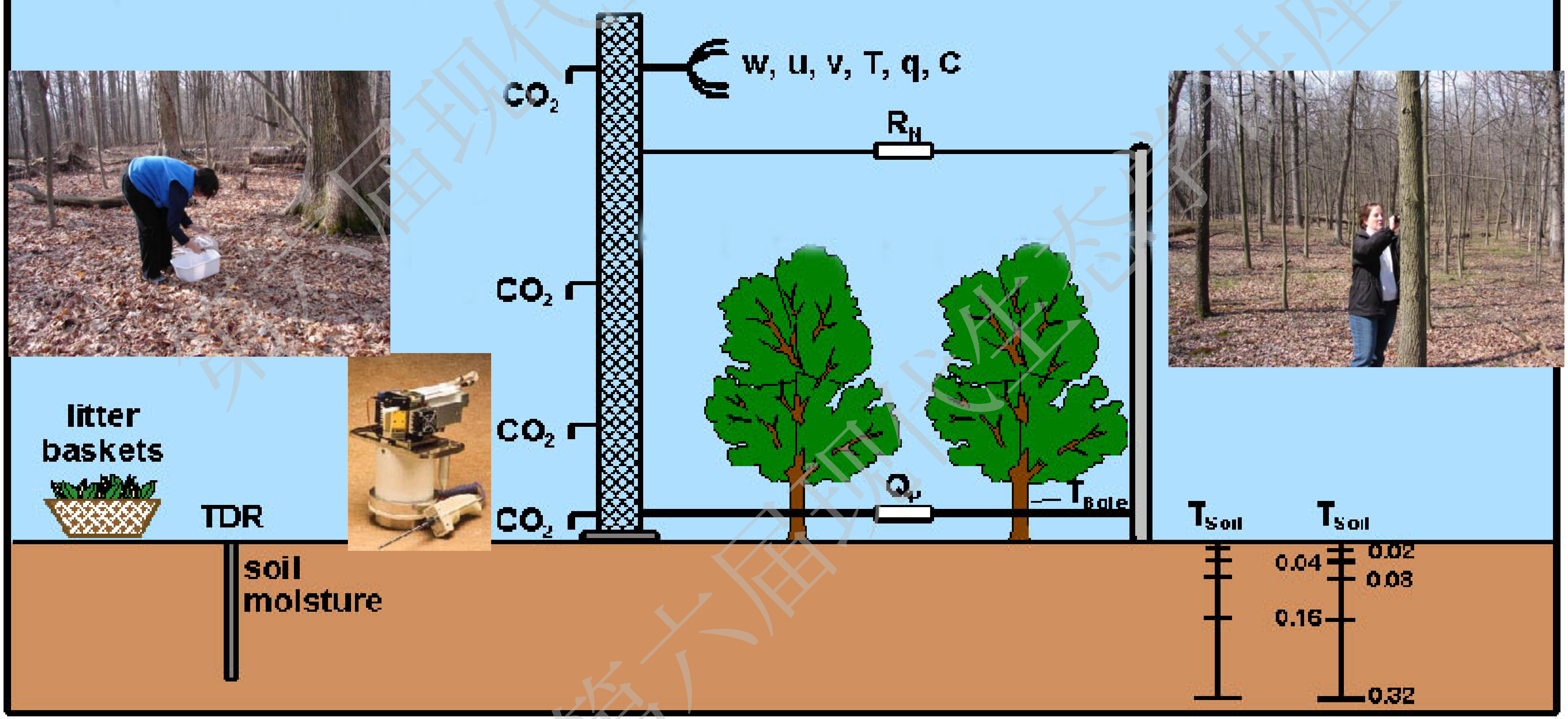
$$F = \overline{w'c'}$$

Agricultural impacts on greenhouse gas emissions (CO_2, N_2O, CH_4)

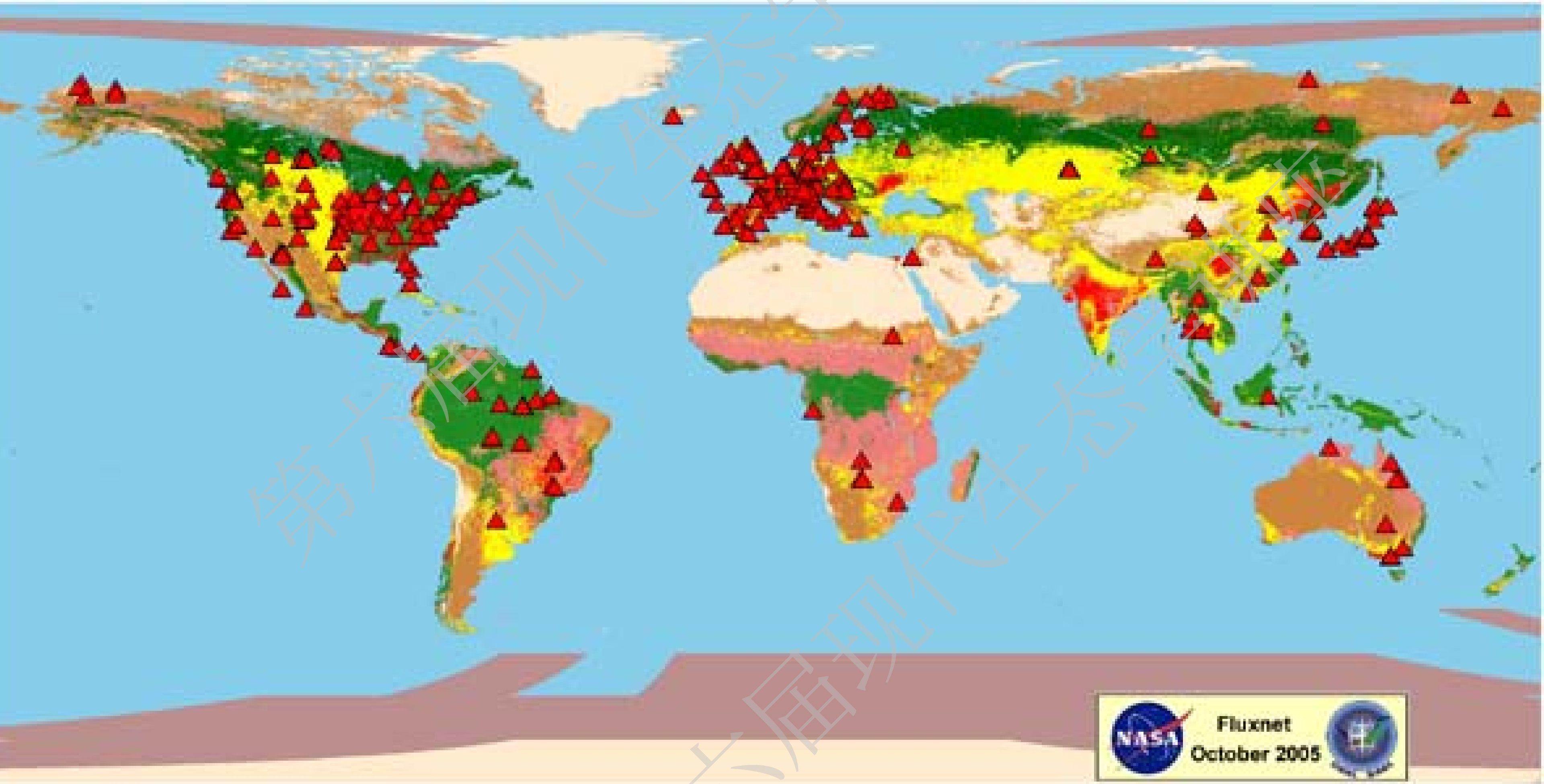


Tang et al.

A full suite of field measurement

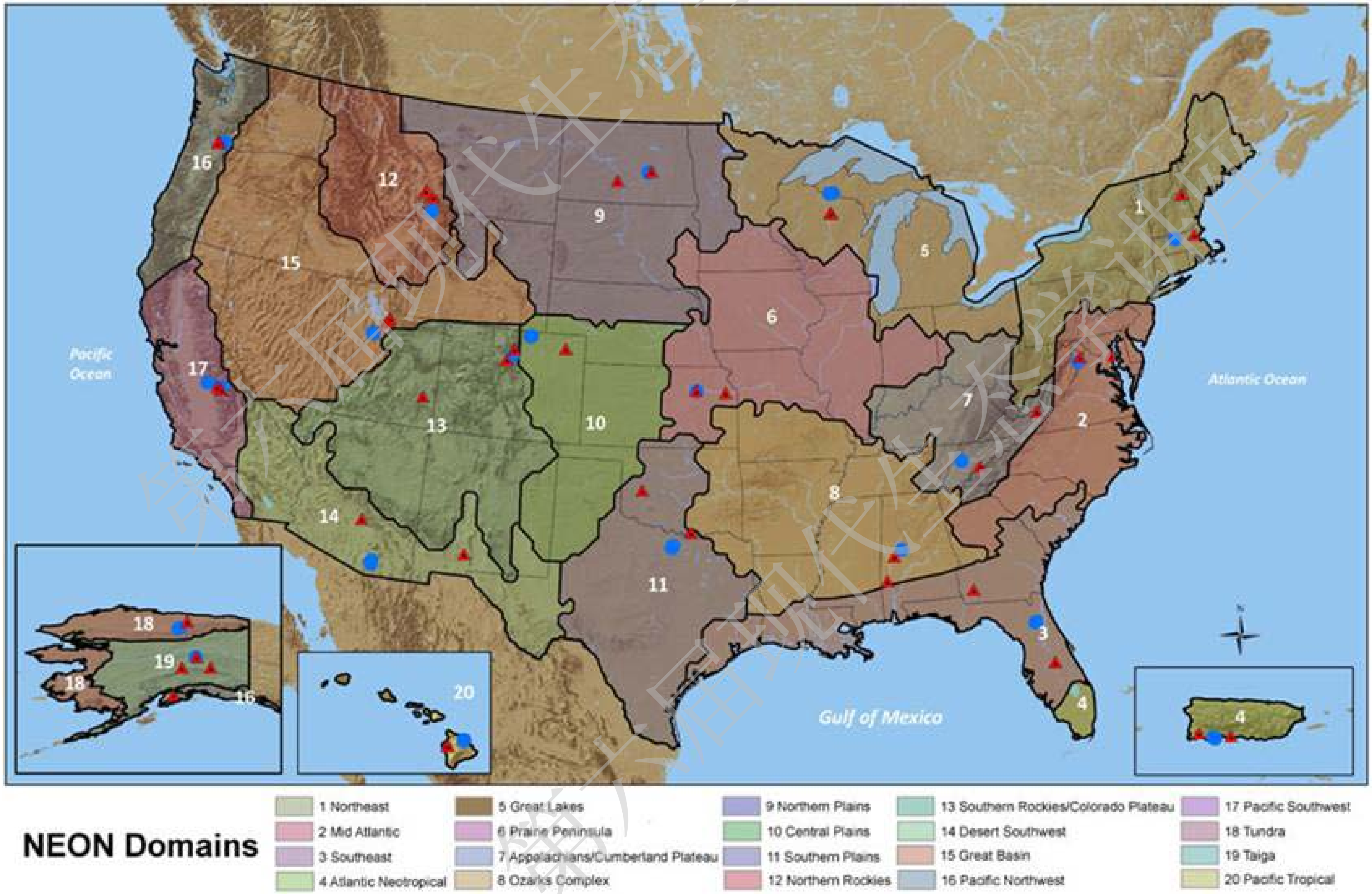


Global flux network



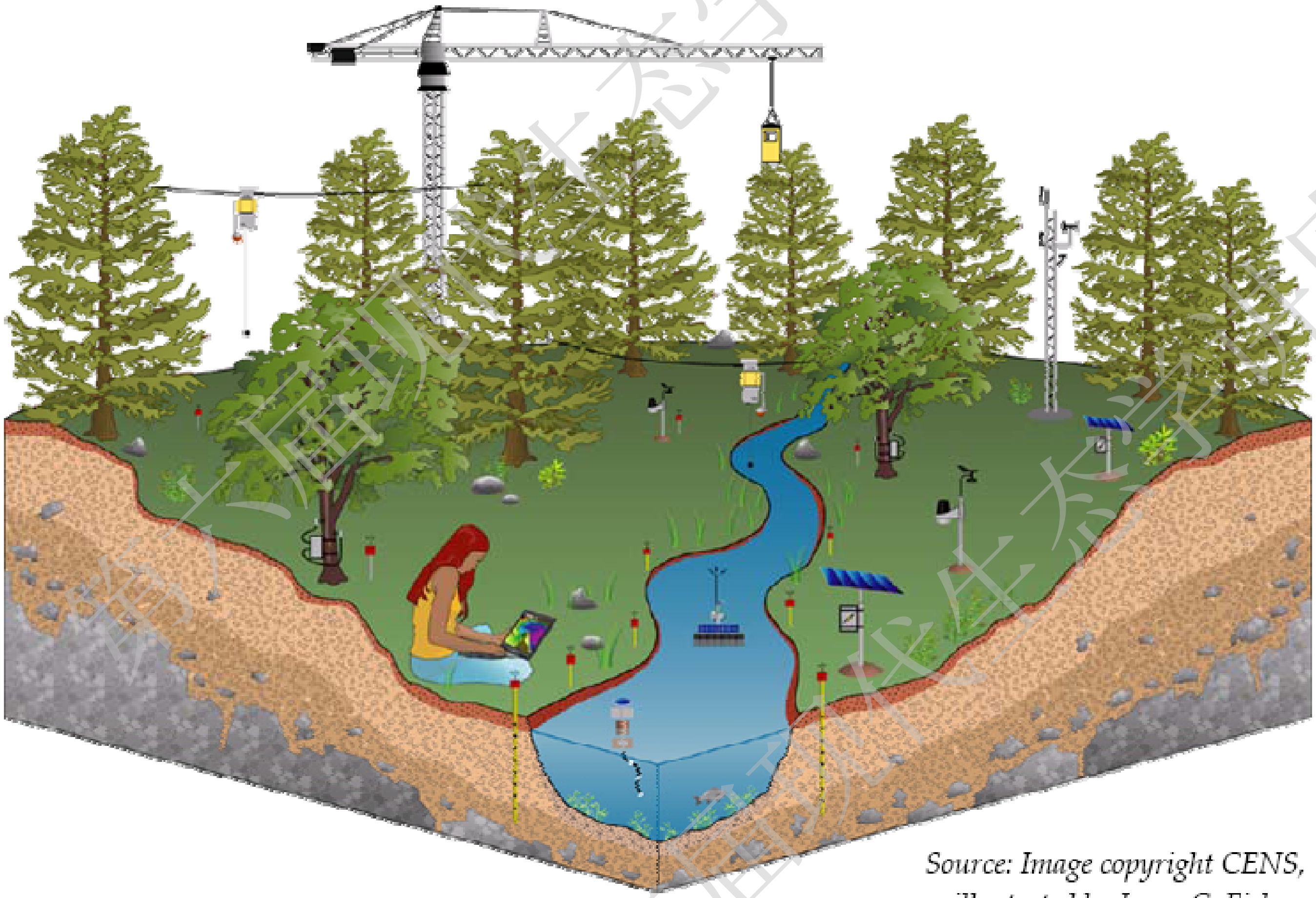
http://www.daac.ornl.gov/FLUXNET

U.S. National Ecological Observatory Network (NEON)



NEON baseline design

Figure 4 A Fundamental Instrument Unit (FIU) within a NEON Domain



Source: Image copyright CENS, illustrated by Jason C. Fisher.

An array of SensorNets (terrestrial, aquatic, climatic), a canopy crane, BioMesoNet tower, and other embedded or robotically-controlled sensors are depicted.

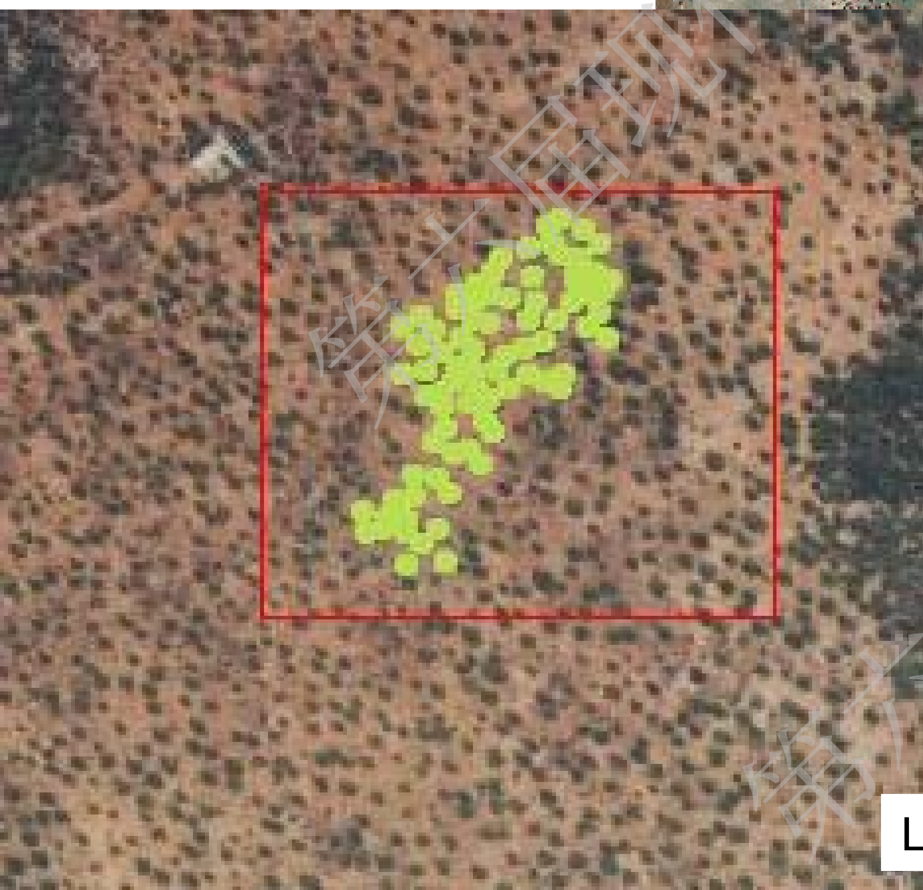
U.S. National Ecological Observatory Network (NEON)

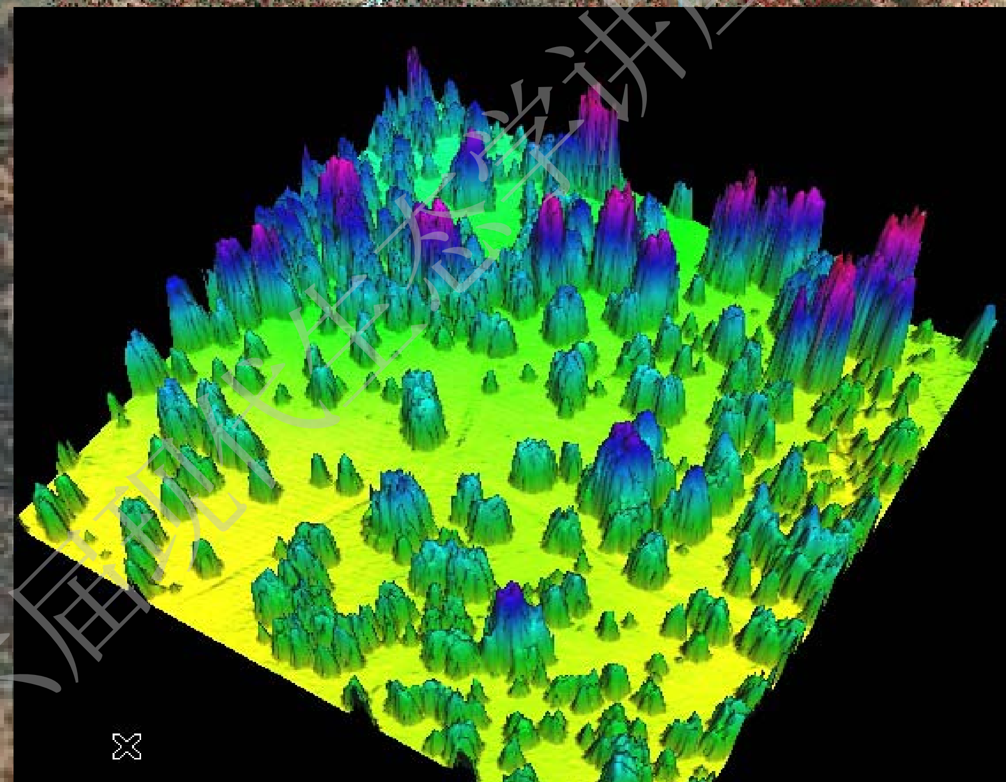
- Headquarters –Boulder, CO
- 20 Domains

  -- 20 Core sites (wildland)

  -- 40 Relocatable sites (land-use sites)
- 10 Mobile laboratories (AK, HI, CONUS+PR)
- Human-based observations
- 3 Airborne Observation Platforms
- Land Use Analysis Package
- STREON Experiment

Remote sensing





LIDAR generated 3D tree map, data of Qi et al.

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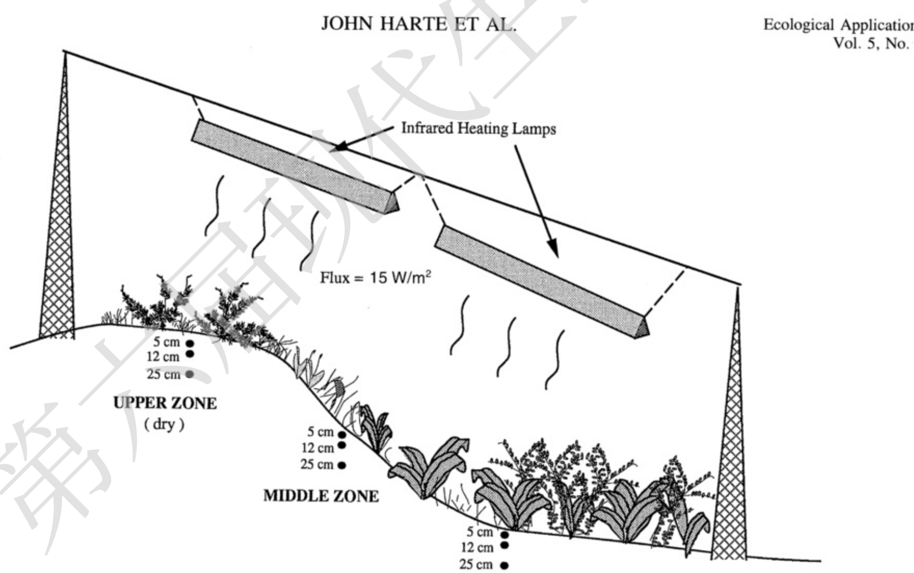
Closed-top-chamber

Saxe et al. 1998

Large-scale manipulative experiments

FACE (Free air CO_2 enrichment)

Soil warming experiment



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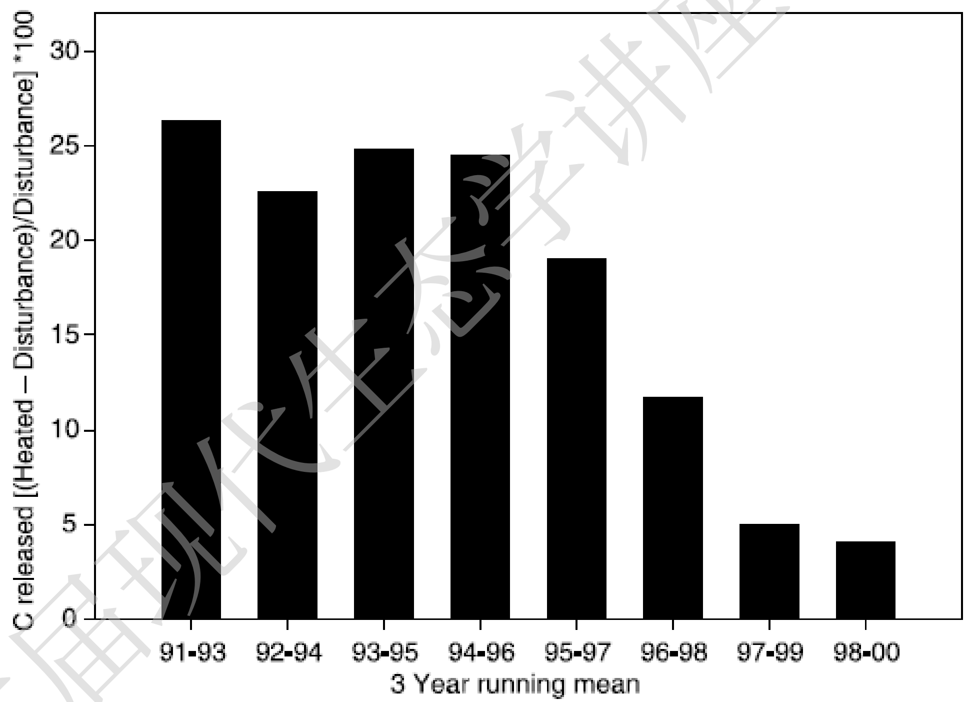
Warming Arctic

Air warming

Warming effects on soil respiration at Harvard Forest



Melillo et al. 2002. *Science*

Warming and C-N coupling

Soil warming, carbon–nitrogen interactions, and forest carbon budgets

Jerry M. Melillo[a,1], Sarah Butler[a], Jennifer Johnson[a,b], Jacqueline Mohan[a,c], Paul Steudler[a], Heidi Lux[a,d], Elizabeth Burrows[a,e], Francis Bowles[f], Rose Smith[a], Lindsay Scott[a], Chelsea Vario[a,g], Troy Hill[a,h], Andrew Burton[i], Yu-Mei Zhou[j], and Jim Tang[a]

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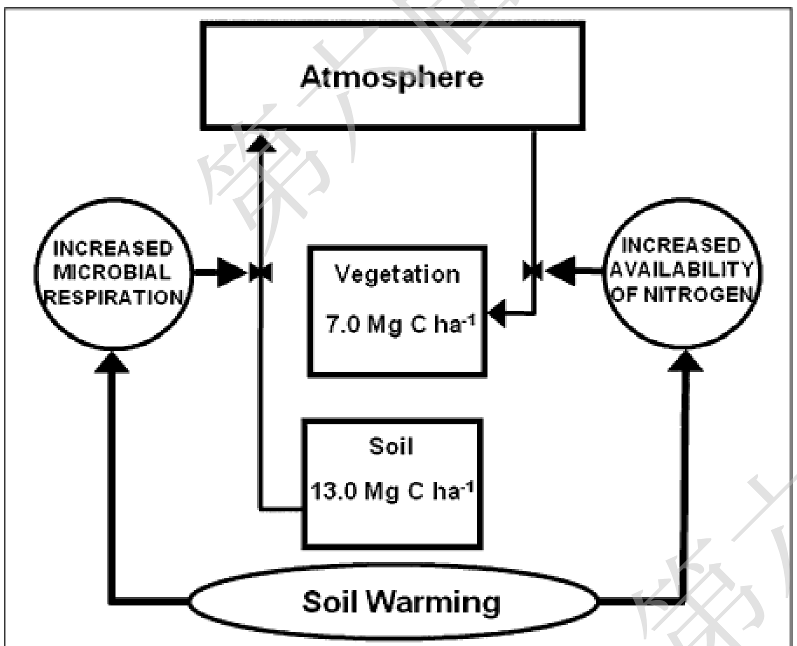
ook, NY, and approved April 12, 2011 (received for review December 5, 2010)



Melillo et al. 2011

Greenhouse gas fluxes in an agricultural farm in Maseno, Kenya

5 fertilizer treatments

- 0, 50, 75, 100, and 200 kg N ha^{-1} applied by hand
- Replicated in 4 blocks of 5 plots each
- Sampled weekly (+ daily for 7 days after fertilization)

Hickman et al.

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Modeling global carbon cycle

- Model input: climate, ecosystem parameters, management scenarios, etc., which are easy to measure
- Model output: carbon fluxes (GPP, R, NEP) and pools (biomass, soil carbon)
- Models should simulate previous carbon cycles (validated by measurement data), and predict future (under certain scenarios)
- Coupled climate-ecosystem models

Farquhar photosynthesis model

$$A = V_{cMax}\frac{C-\Gamma_*}{C+K_c(1+OK_C)} - R_d, \text{ if light is saturate}$$

$$A = J\frac{C-\Gamma_*}{4.5C+10.5\Gamma_*} - R_d, J = f(J_{Max}), \text{ if light is limited}$$

V_{cMax} : maximum rate of carboxylation

J_{Max} : maximum rate of eclectron transport

Γ_* : CO_2 compensation point (when net carbon fixation is 0)

C and O : intracellular $[CO_2]$ and $[O_2]$, controlled by stomatal conductance

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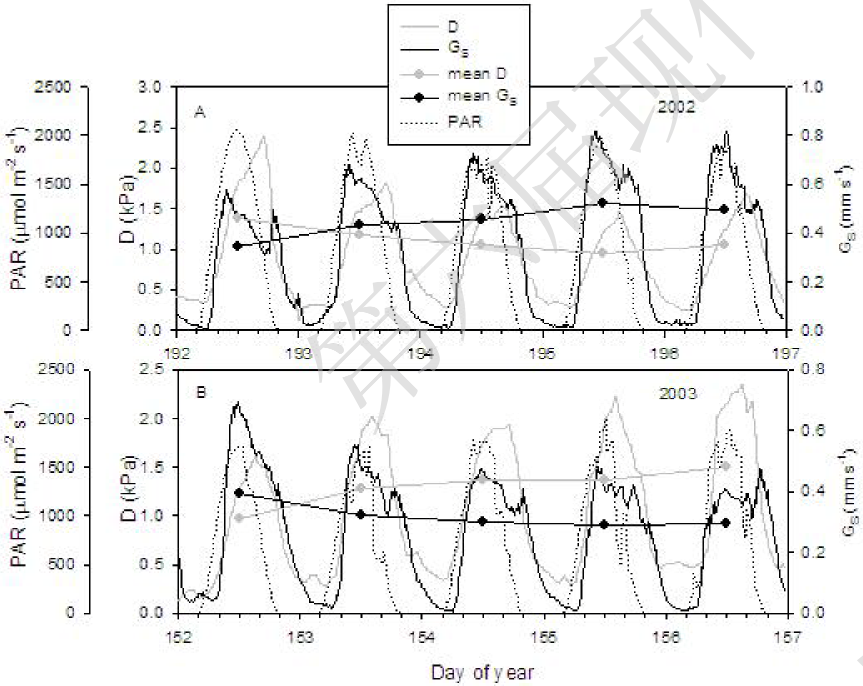
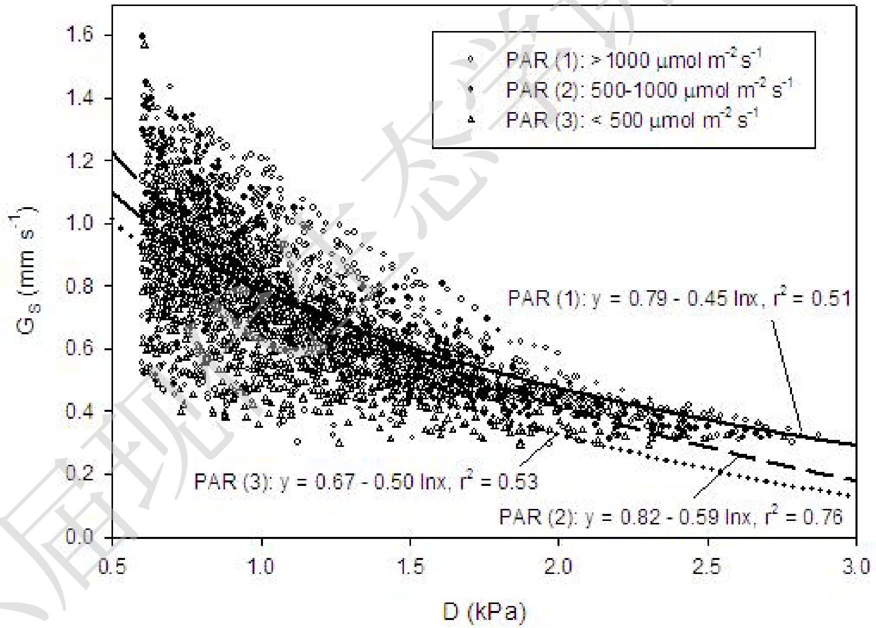
Stomate

• A tiny opening or pore on the leaf surface, used for gas exchange –fixing CO_2 and releasing water.

• Plants can regulate stomatal conductance to maximize photosynthesis while minimize water loss.

Control of stomatal conductance





Tang et al. 2006, *JGR*

Respiration models

Q_{10} model

$$R = \beta_0 Q_{10}^{T/10}, \text{ where } Q_{10} = e^{10\beta_1}$$

Cox et al. (2000, *Nature*): Acceleration of global warming due to positive feedbacks of respiration ---- $Q_{10} = 2$

Michaelis-Menten function (Davidson et al. 2006)

$$R = \frac{V_{max} C}{K_m + C}$$

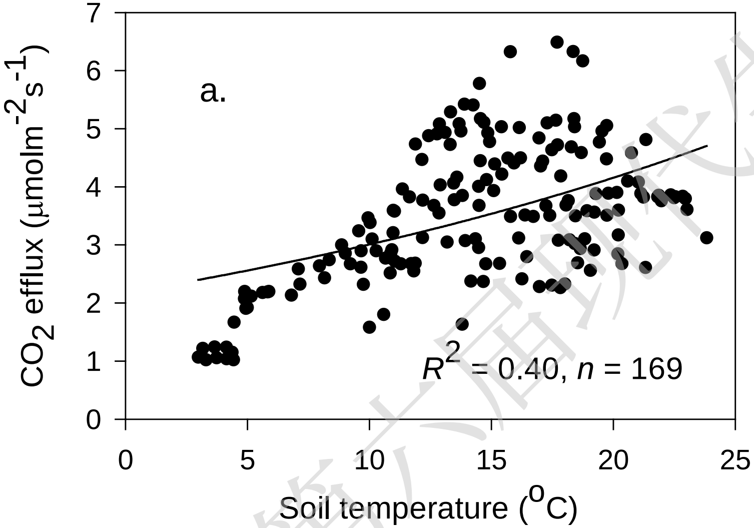
V_{max}: maximum enzyme activity

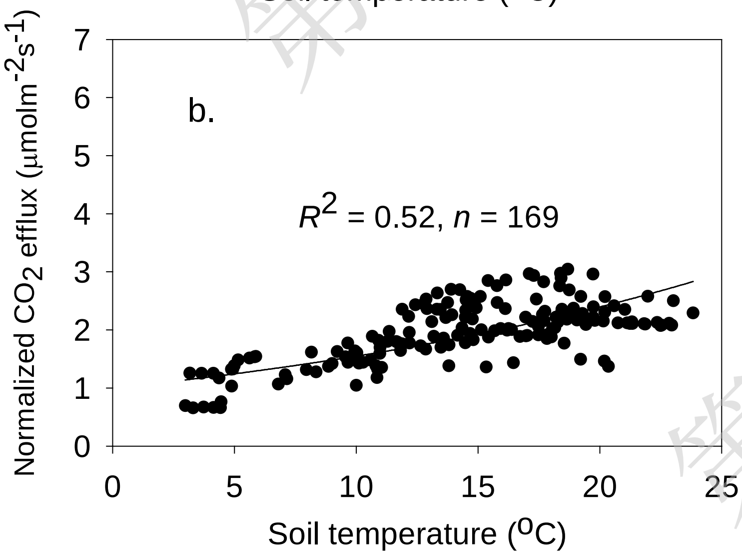
C: concentration of the soluble substrate (carbon availability)

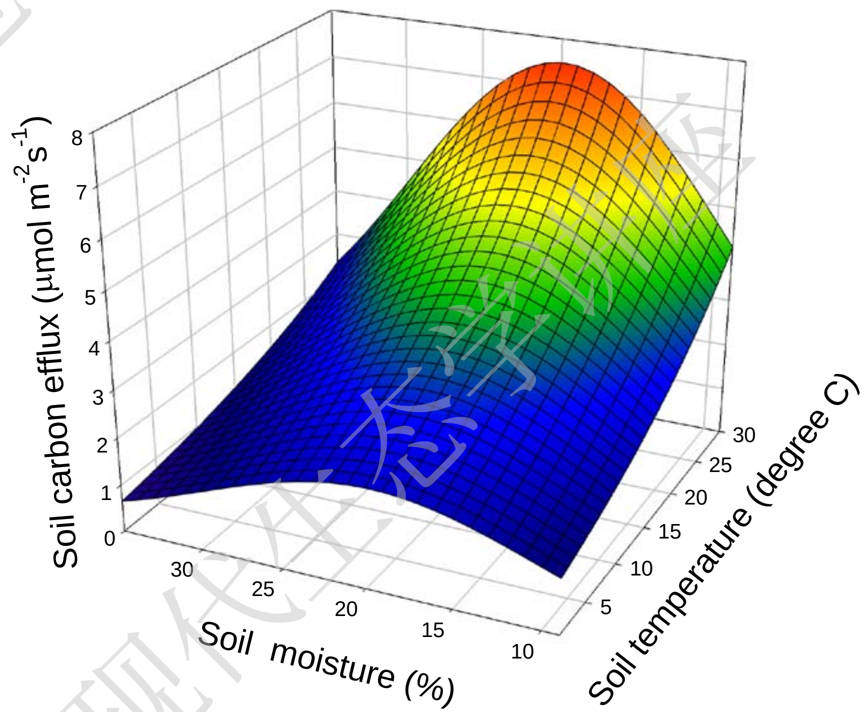
K_m: half-saturation constant

All are temperature dependent

Soil respiration controlled by soil temperature and moisture



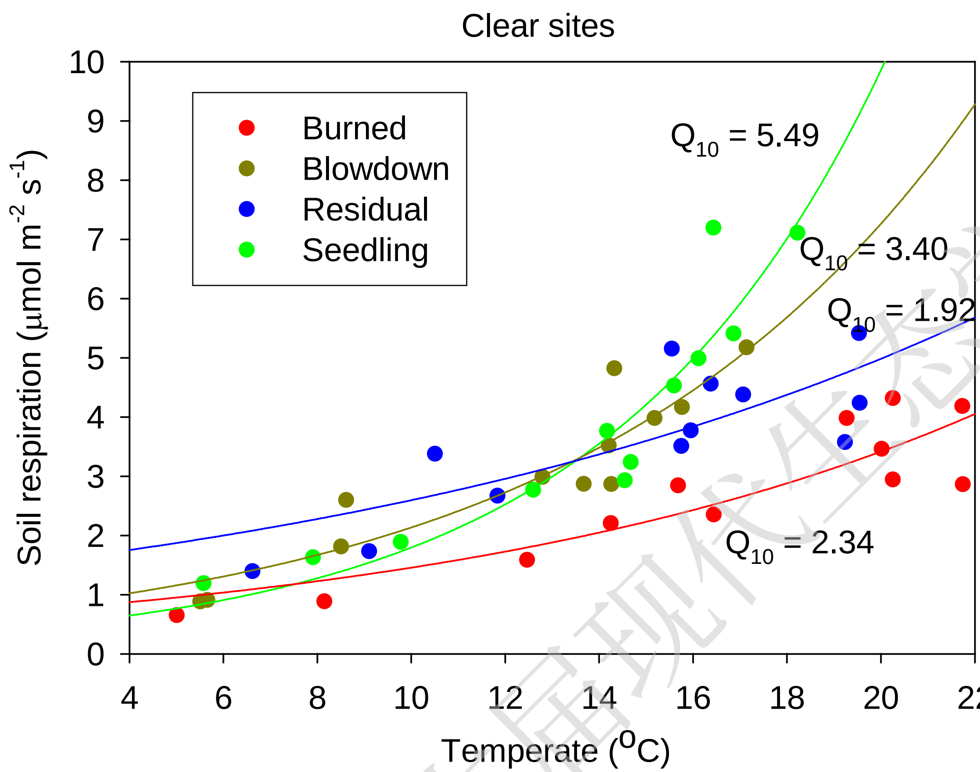


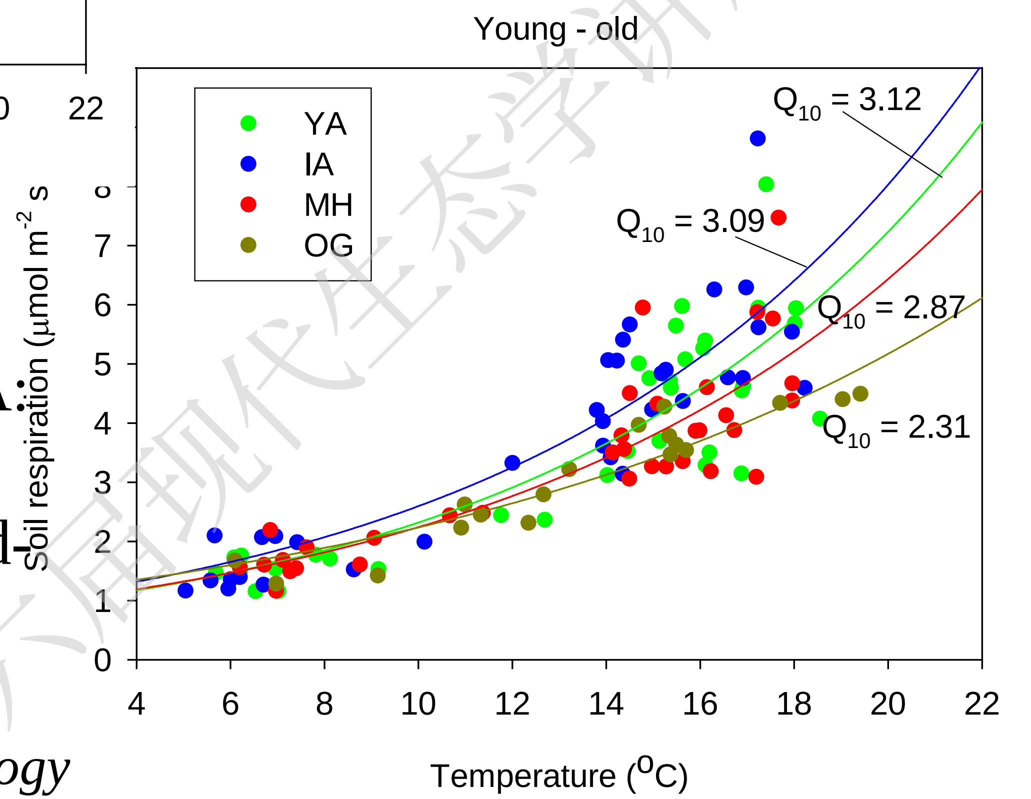


$$R = \beta_0 e^{\beta_1 T} e^{\beta_2 \theta + \beta_3 \theta^2}$$

Tang et al. 2005, *Tree Physiology*

Chronosequence of soil respiration in response to temperature

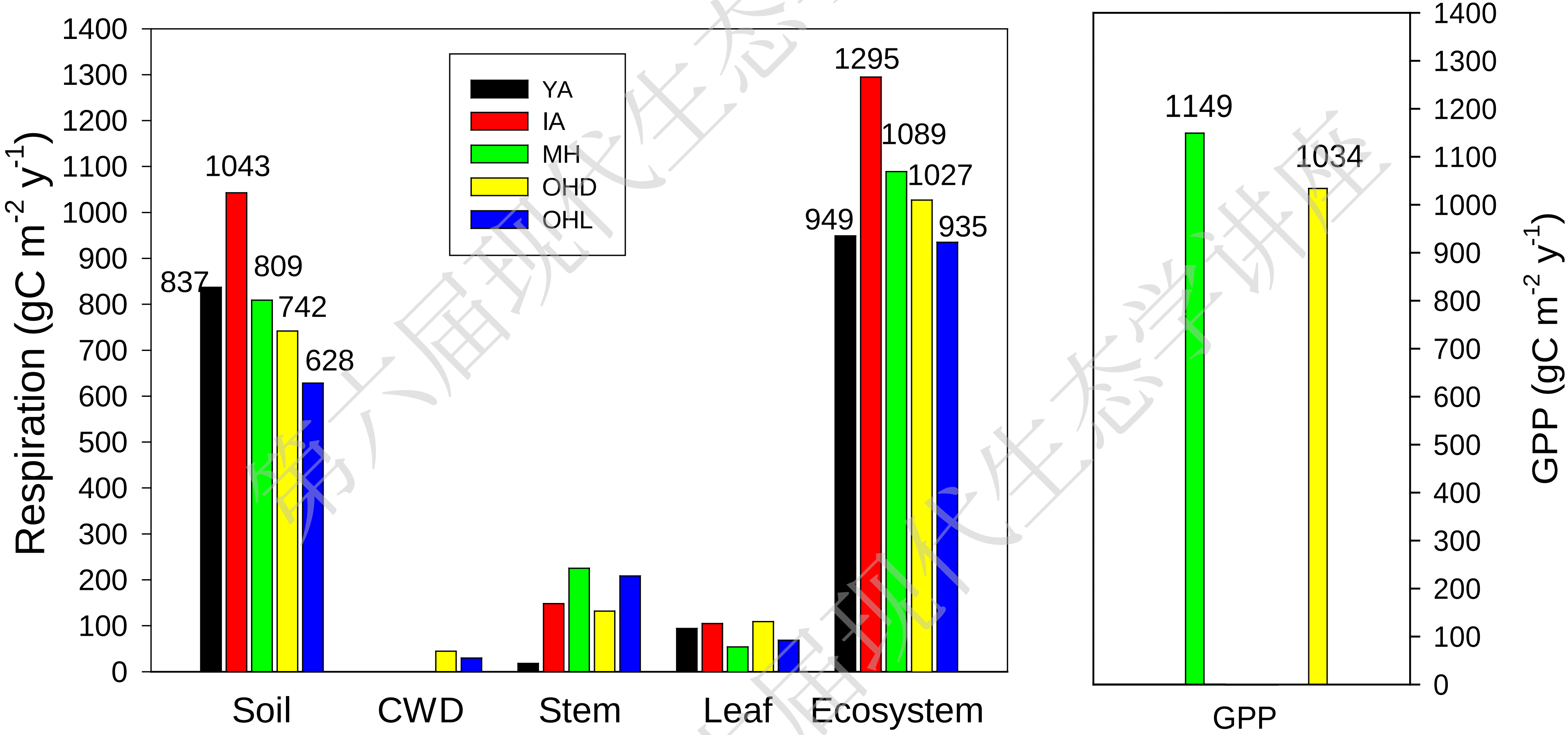




YA: Young aspen IA: intermediate aspen MH: mature hardwood OG: old-growth

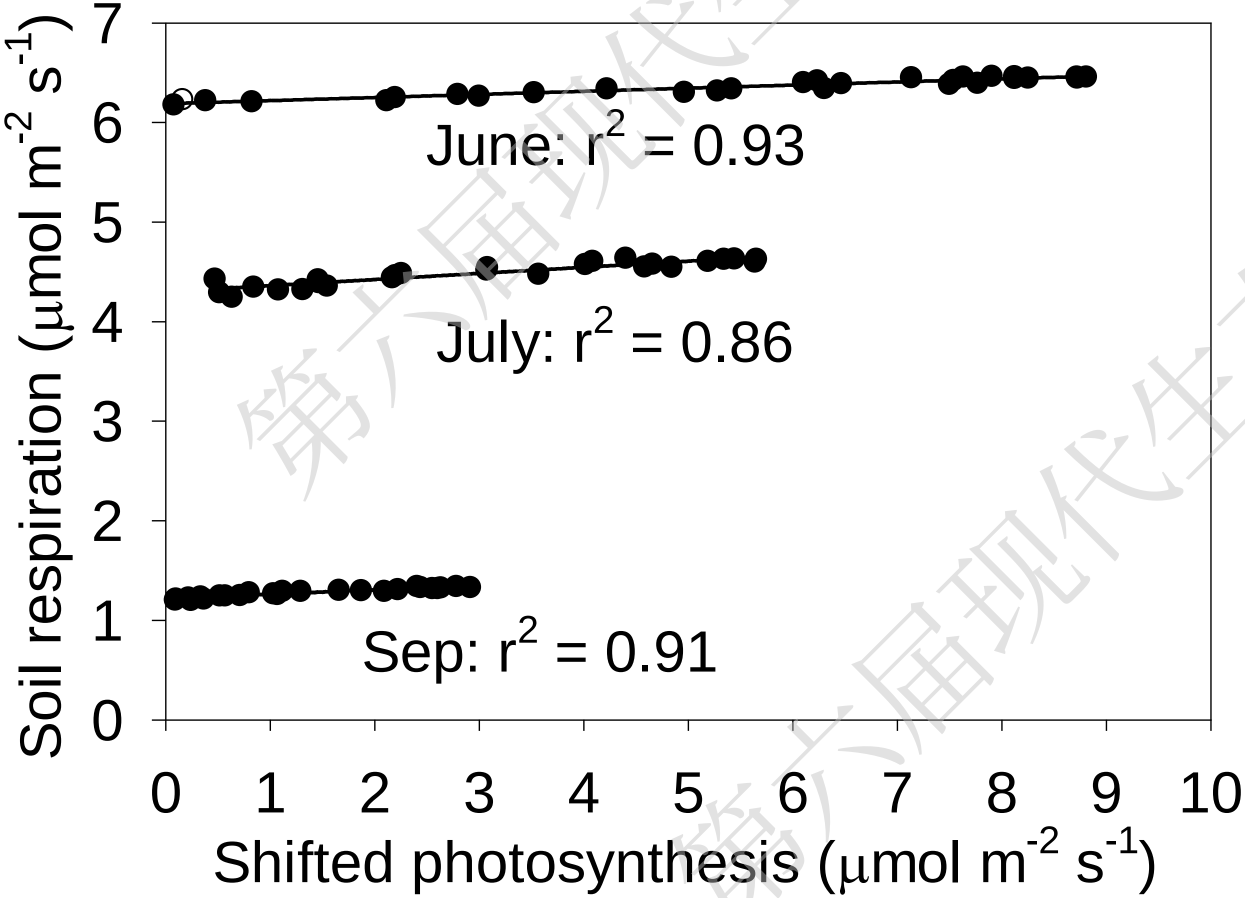
Tang et al. 2009. *Global Change Biology*

Age effects on photosynthesis and respiration

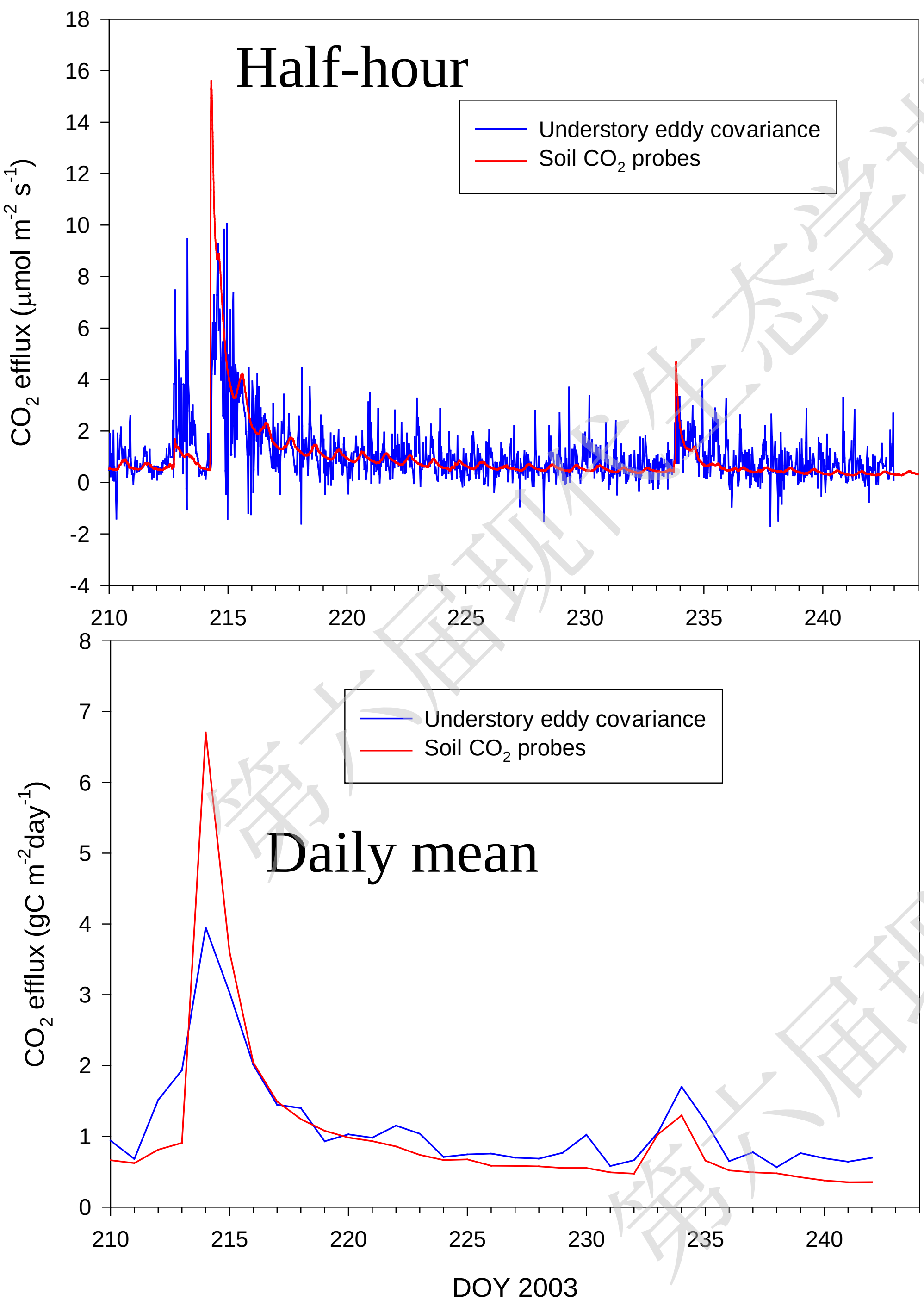


Tang et al., 2008. *Agric. For. Meteorol.*

Root respiration regulated by photosynthesis with time lags (7-12 hours)



Tang et al. 2005, *Global Change Biology*



The soil CO_2 gradient method and eddy covariance method are consistent

Decay of the rain pulse:

$$R_R = R_b + ae^{-t/\tau}$$

Tang et al. 2005, *Agric. For. Meteorol.*

Calculating flux from gradient measurement

Tang et al. 2005

$$F = -D_s \frac{\mathrm{d}C}{\mathrm{d}z}$$

Fick's law

$$\frac{D_s}{D_a} = \phi^2 \left(\frac{\varepsilon}{\phi}\right)^{\beta \cdot S} \qquad \phi = 1 - \frac{\rho_b}{\rho_m} = \varepsilon + \theta$$

Moldrup et al., 1999

$$D_a = D_{a0} \left(\frac{T}{T_0}\right)^{1.75} \left(\frac{P_0}{P}\right)$$

ϕ is the porosity, sum of the volumetric air content ε and the volumetric water content θ. *S* = silt + sand content

ρ_b is the bulk density and ρ_m is the particle density for the mineral soil.

$$F_i = -\left(\frac{D_{a0} P_0 \phi^2}{R T_0^{1.75}}\right) \left(\frac{\phi - \theta}{\phi}\right)^{2.9S} \left(\frac{T_i + T_{i+1}}{2}\right)^{1.75} \frac{(\mathrm{C_{i+1}/T_{i+1} - C_i/T_i})}{\mathrm{z_{i+1}} - z_i}$$

Simulating production and transport of CO_2 in soil (Jassal et al. 2004)

$$\frac{\partial C_\mathrm{T}}{\partial t} = \frac{\partial}{\partial z}\left[D_\mathrm{CG}\frac{\partial C_G}{\partial z} + D^*_\mathrm{CL}\frac{\partial C_\mathrm{L}}{\partial z} - \frac{q_\mathrm{w}}{\rho_\mathrm{w}}C_\mathrm{L}\right] + R_\mathrm{C} - U_\mathrm{C}$$

CO_2 in gas

CO_2 in liquid

Dissolved

CO_2 production

CO_2 removed with root water

(Rh) (Ra)

Temperature and water effects (0~1)

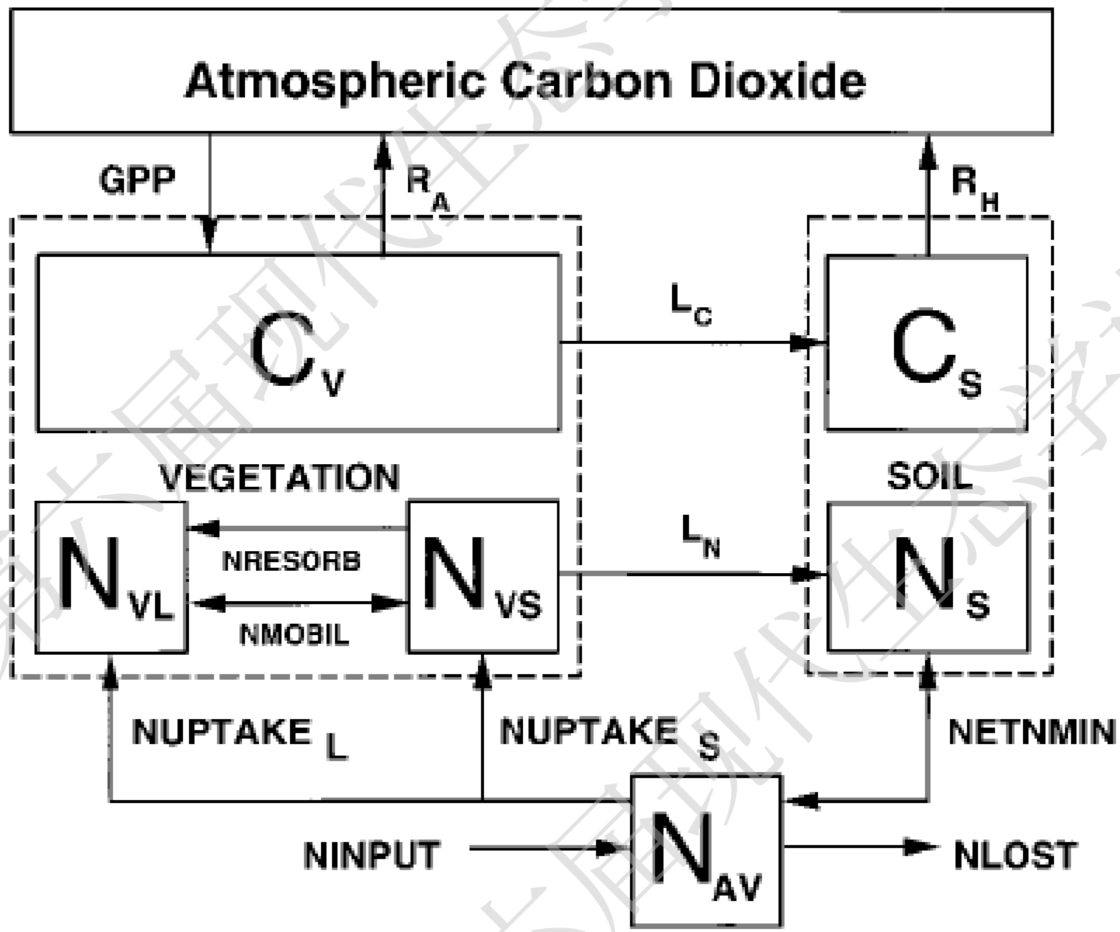
$$R_\mathrm{C} = \sum_{i=1}^{n}((R_\mathrm{CS} + R_\mathrm{CR})\alpha(T)\alpha(\theta)\Delta z)_i$$

$$R_\mathrm{CS} = k_\mathrm{L}C_\mathrm{soil\_L} + k_\mathrm{R}C_\mathrm{soil\_R}$$

$$R_\mathrm{CR} = k_{F_\mathrm{root}}M_{F_\mathrm{root}} + k_{C_\mathrm{root}}M_{C_\mathrm{root}}$$

Both CO_2 concentration and flux can be validated.

Terrestrial Ecosystem Model (TEM)



Tian et al. 1999

Summary

- Both in-situ monitoring and manipulation methods are important in understanding ecosystem functions and processes.
- Ecosystem modeling requires thorough understanding of processes and mechanisms.