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Evolution of ecosystem flux:

a critical role for a safe and sustainable future

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Context

1.Background

2.EC in Northeast China

3.EC in the world

4.EC Future

1. Background

- Eddy covariance method has become popular because
  - it provides a direct measure of the flux density across the atmosphere–ecosystem interface, without disturbance of the vegetation and the soil.
  - It also produces a spatially representative sample of the ecosystem by measuring gas exchange across an extended footprint, hundreds of meters in length.
  - When fluxes are integrated on the time scale of days, seasons and years, the eddy covariance method can provide information related to ecological, biogeochemical, and hydrological issues.

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- EC measurements are key to both
  - understand plant or microbial metabolism and climate-ecosystem interactions and
  - evaluate the carbon and water budgets from ecosystem to global levels
- Since 1984, EC-flux measurements and researches have made great progress. At present, vast networks of EC sensors ring the globe, providing continuous EC-flux data and having revealed a number of new insights.
- In this report, I will recall the EC observations and researches in the Northeast China and the world, and look forward to the future of EC.

2. EC in Northeast China

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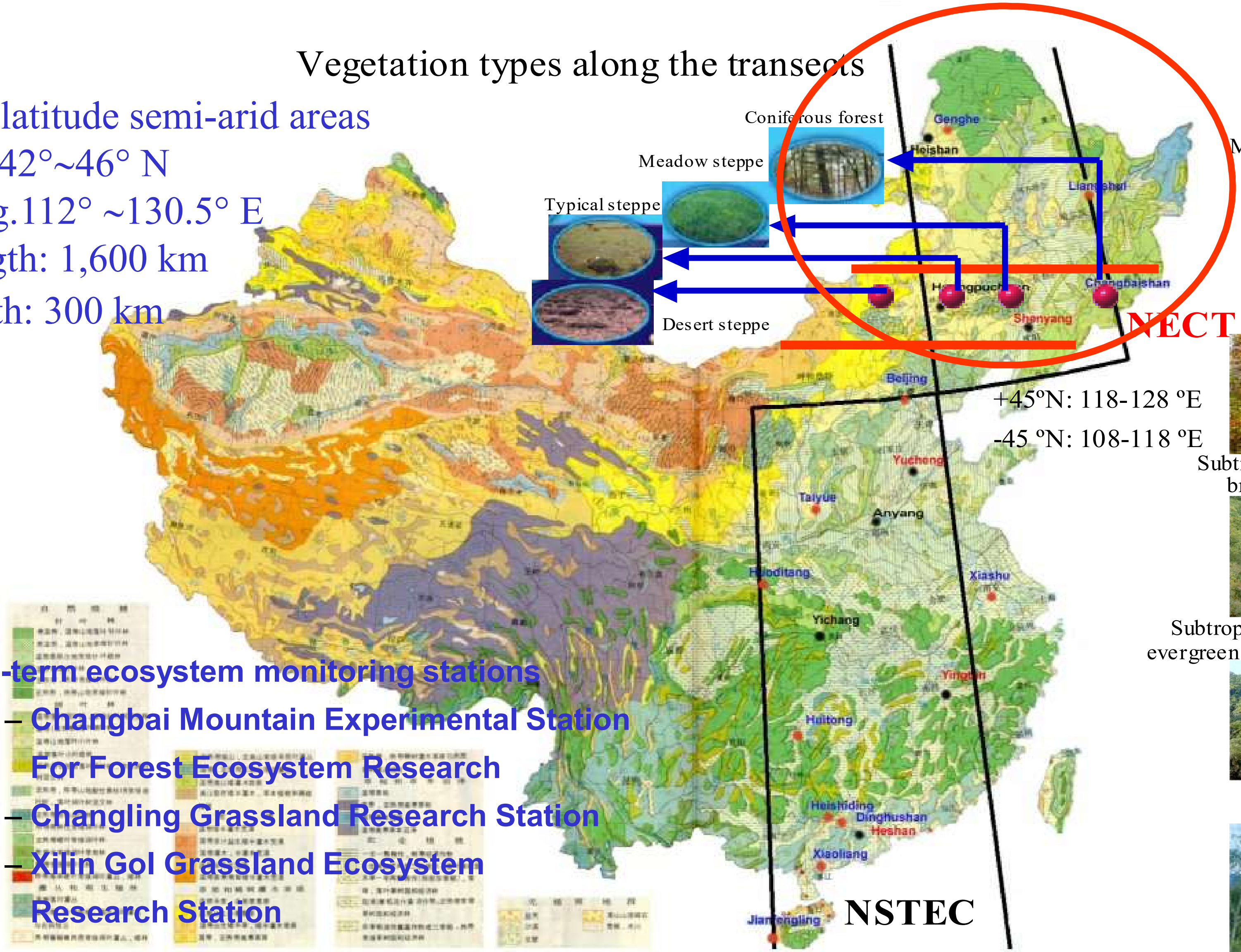
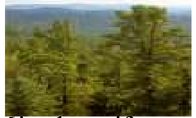
mid-latitude semi-arid areas
Lat. 42°~46° N
Long.112° ~130.5° E
Length: 1,600 km
Width: 300 km

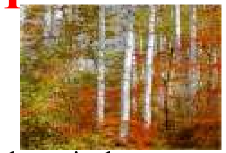


Coniferous forest



Mixed coniferous-broadleaf forest

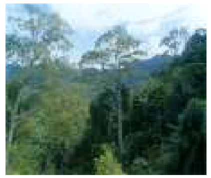
Temperate broadleaf forest



Subtropical evergreen broadleaf forest

Subtropical monsoon evergreen broadleaf forest

Tropical rain forest

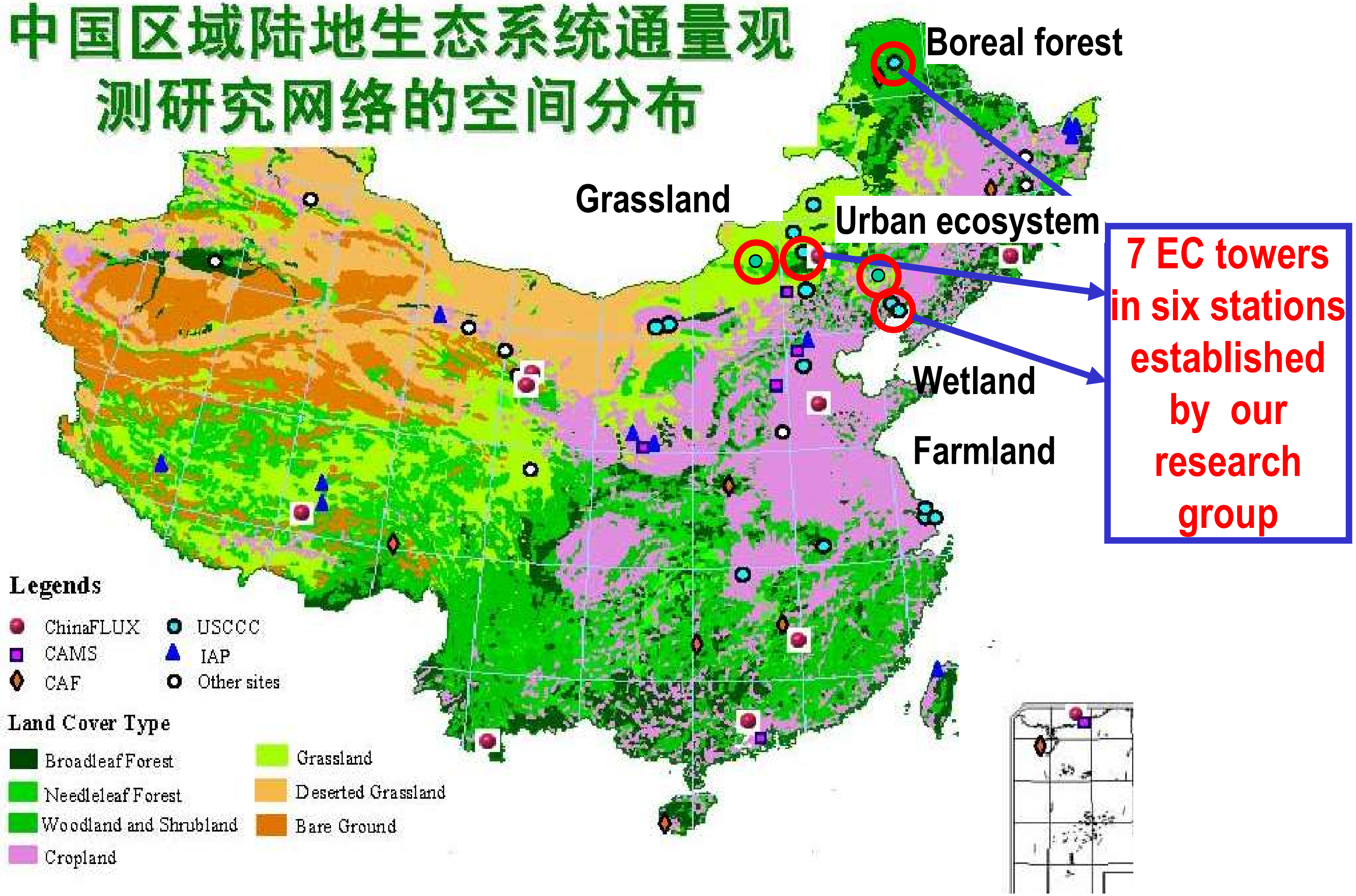


Long-term ecosystem monitoring stations
- Changbai Mountain Experimental Station For Forest Ecosystem Research
- Changling Grassland Research Station
- Xilin Gol Grassland Ecosystem Research Station

- Northeast China is a very sensitive region to climate change:
  - Temperature increases obviously in this region
  - Precipitation from the east to the west changes very strong
  - This region is often considered as carbon sinks: the analyses based on atmospheric transport models and CO_2 observations suggested that the northern portion of monsoon Asia has acted as a carbon sink (Bousquet et al., 1999).
  - To understand the carbon budget in monsoon Asia and to improve our understanding of the carbon cycle at various spatial and temporal scales, EC observation and research has been done in this region.

2.1 Carbon observation

- Since 2003, 7 EC towers in six stations have been established in the northeast China

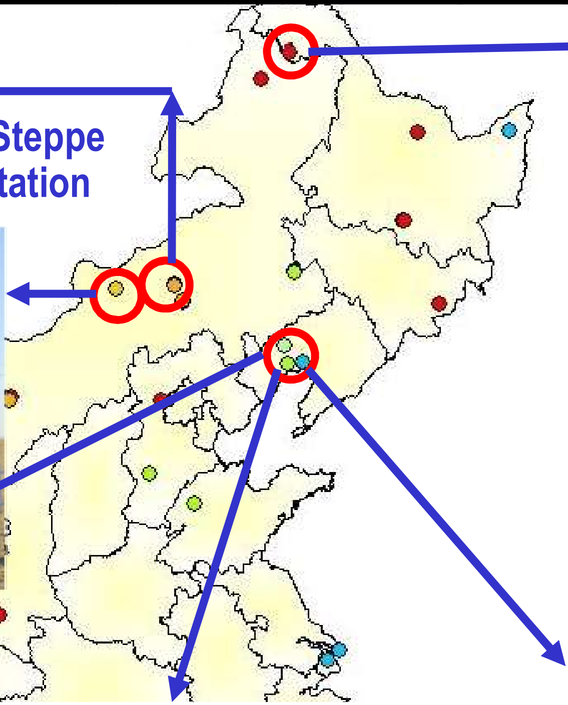


Long term EC towers of GCTE research group

Type	Forest	Grass-land	Farm-land	Wet-land	Urban	Total
EC tower	1	2	1	2	1	7

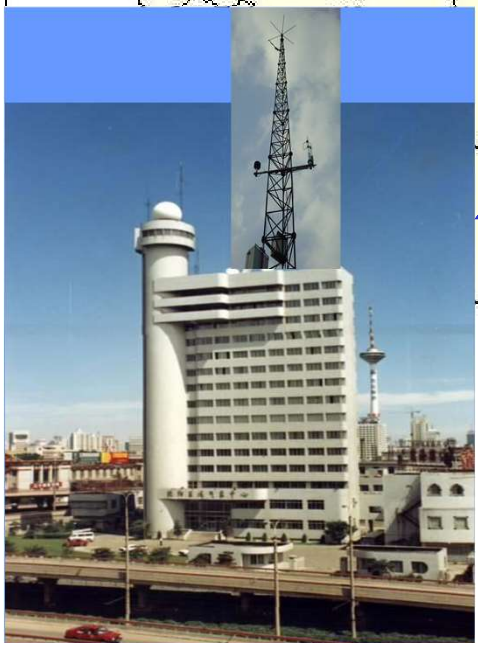
Inner Mongolia Typical Steppe Ecosystem Research Station

Chinese Boreal Forest Ecosystem Research Station



Inner Mongolia Desert Steppe Ecosystem Research Station

Shenyang Urban Ecosystem Research Station



Panjin Wetland Ecosystem Research Station

Jinzhou Maize Agriculture Ecosystem Research Station

Terrestrial carbon cycle observation

- Flux observation
- Microclimate gradient observation
- Soil respiration
- Leaf ecophysiology of dominant species
- Dynamical biomass
- Soil property

Soil respiration/Plant community photosynthesis

Leaf ecophysiology

Micro-climate gradient observation

Soil property

Biomass measurement

2.2 Environmental controls on fluxes

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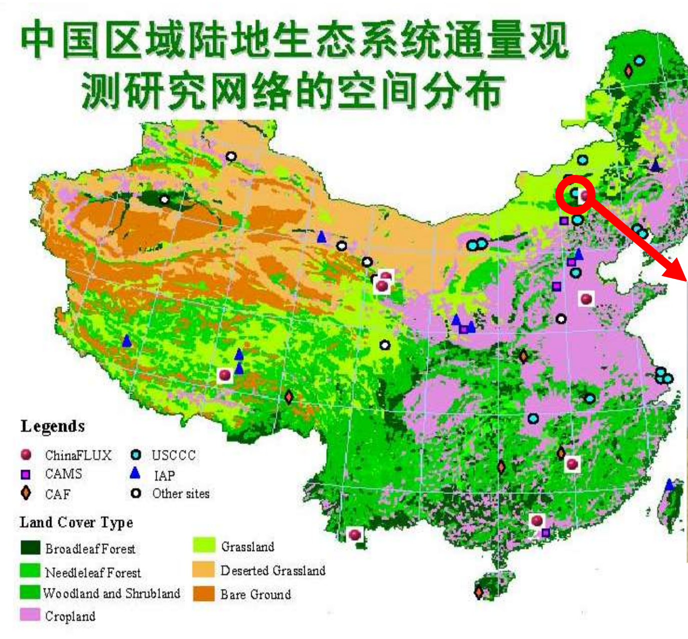
(1) Dynamical characteristics of NEE in different ecosystems

(2) Environmental effects on net ecosystem CO_2 exchange

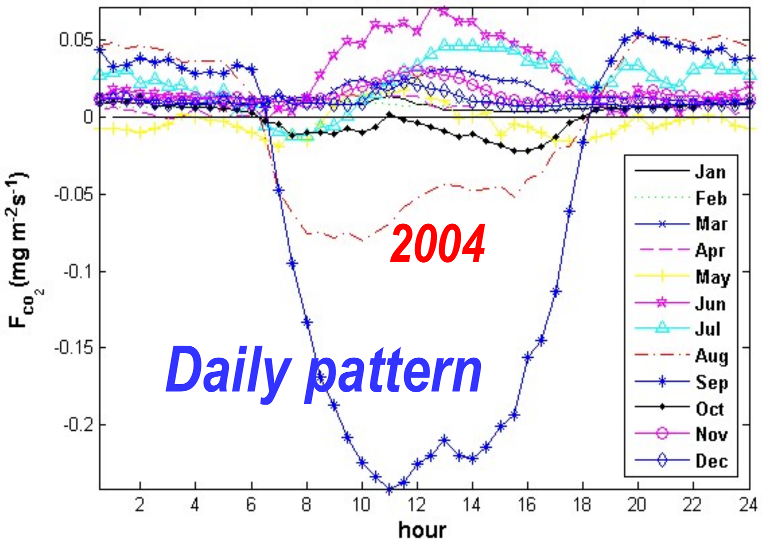
(1) Dynamical characteristics of NEE in different ecosystems

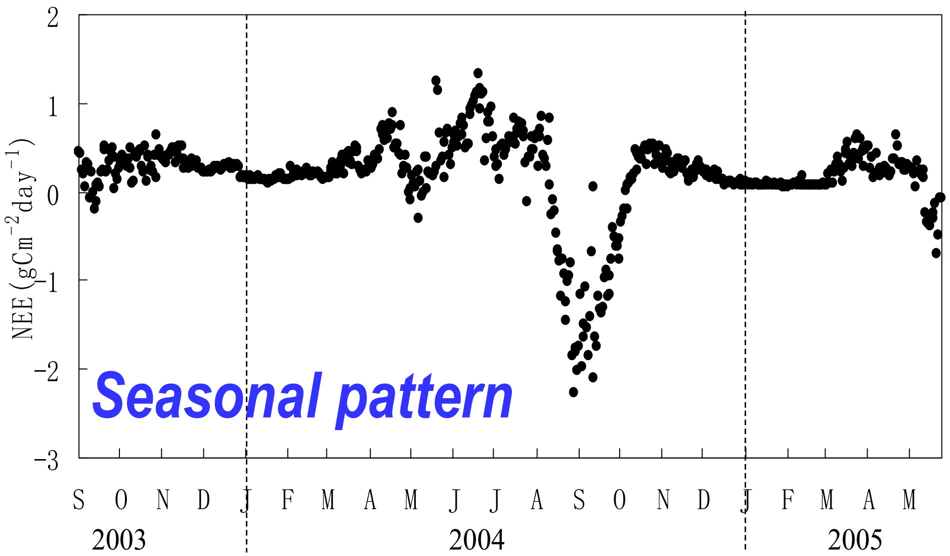
1) Inner Mongolia Typical Steppe Ecosystem Research Station



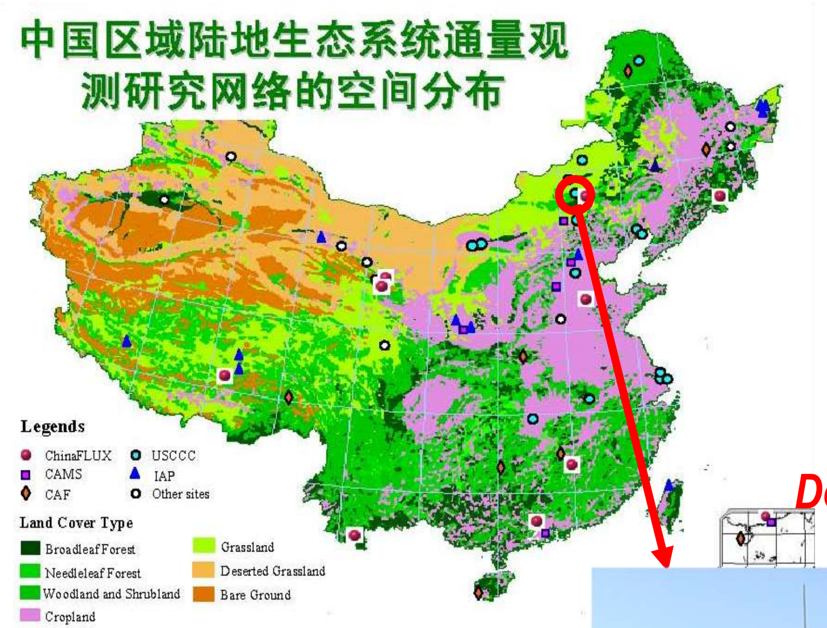
Typical steppe

- Location: Northeast to Xilinhot city, Inner Mongolia, China (44°08’03” N, 116°19’43” E)
- Elevation:1100m
- Temperature: 2℃
- Precipitation: 290mm
- Species: *Stipa Krylovii, Leymus chinensis*
- Tower Height:2m
- Observation time: August 25, 2003





2) Inner Mongolia Desert Steppe Ecosystem Research Station

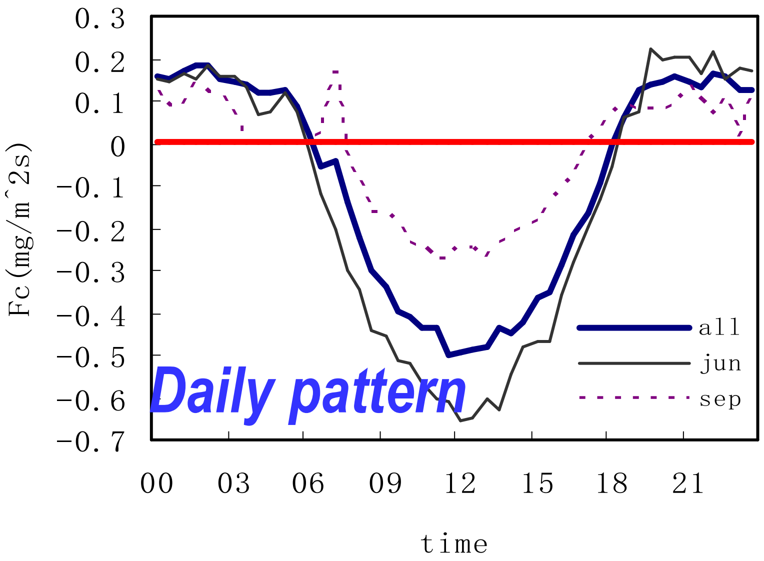


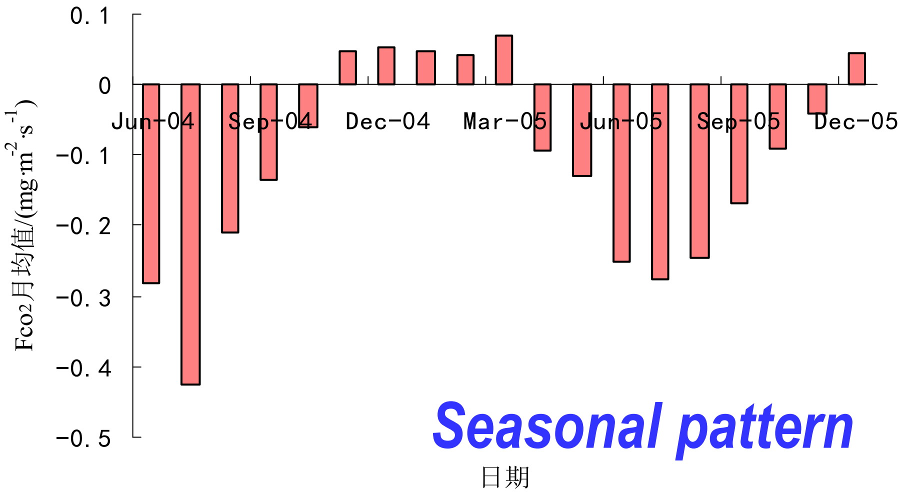
Desert steppe

- **Location:** Left Sunite Banner, Xilinhot city, Inner Mongolia, China (44º05'22" N, 113º34'27" E)
- **Elevation:**970m
- **Temperature:** 3.1℃
- **Precipitation:** 185mm
- **Species:** *Stipa gobica and Allium polyrrhizum*
- **Tower Height:**2m
- Observation time: Nov. 15, 2007

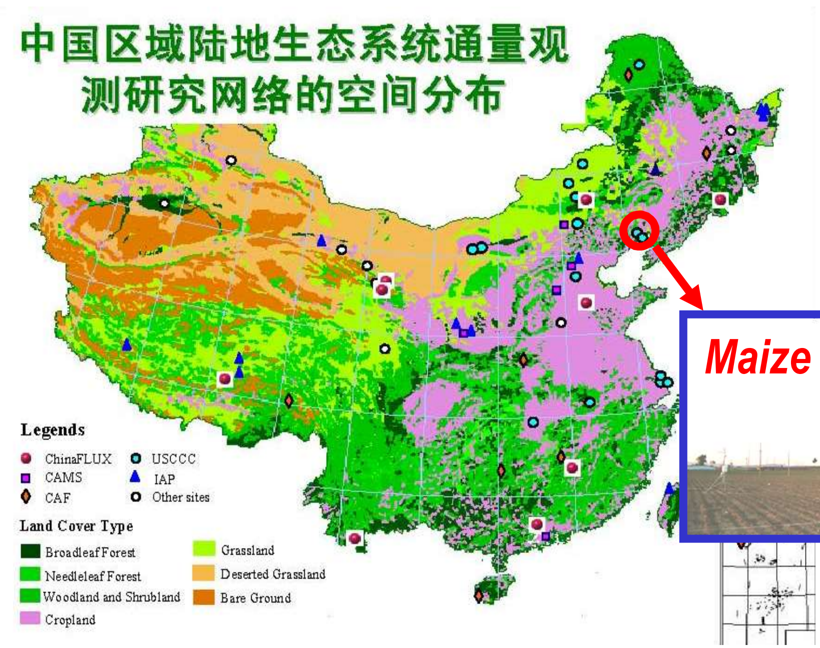
3) Panjin Wetland Ecosystem Research Station

- Location: Panjin, Liaohe delta, Liaoning Province, China (41° 08.440'N，121° 54.710'E)
- Temperature: 8.6℃
- Precipitation: 631mm
- Species: *Phragmites communis, Paddy rice*
- Tower Height: 3.5m & 2m
- Observation time: June 25, 2004



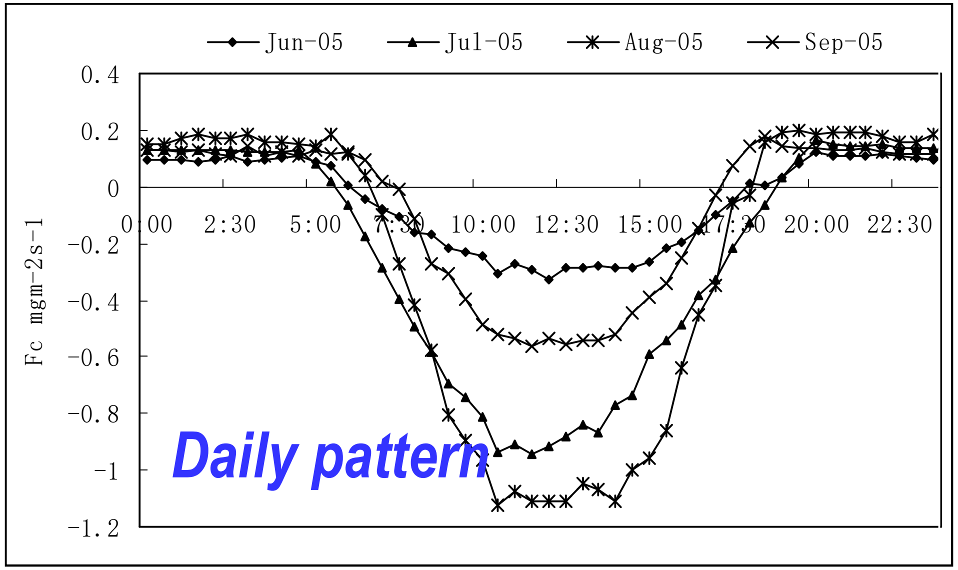


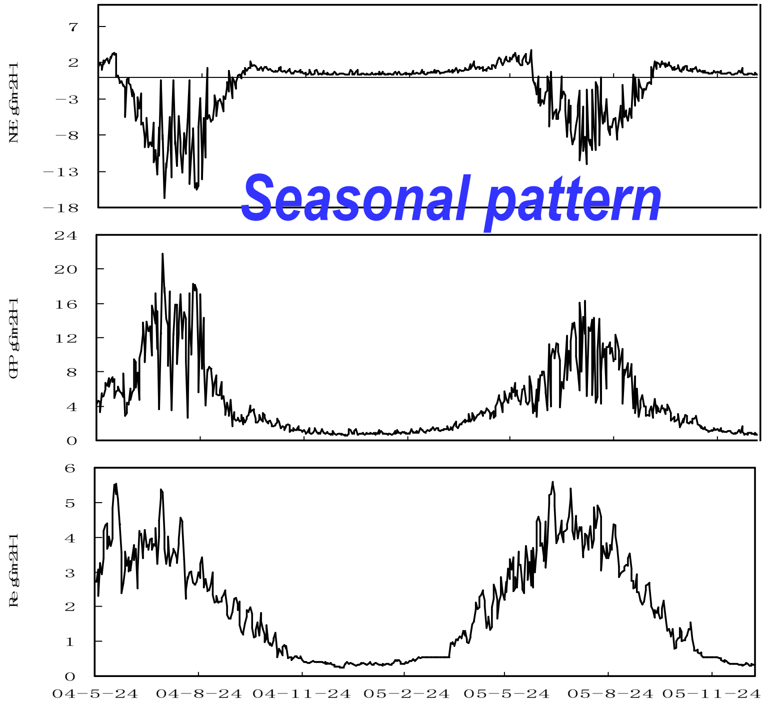
4) Jinzhou Maize Agriculture Ecosystem Research Station



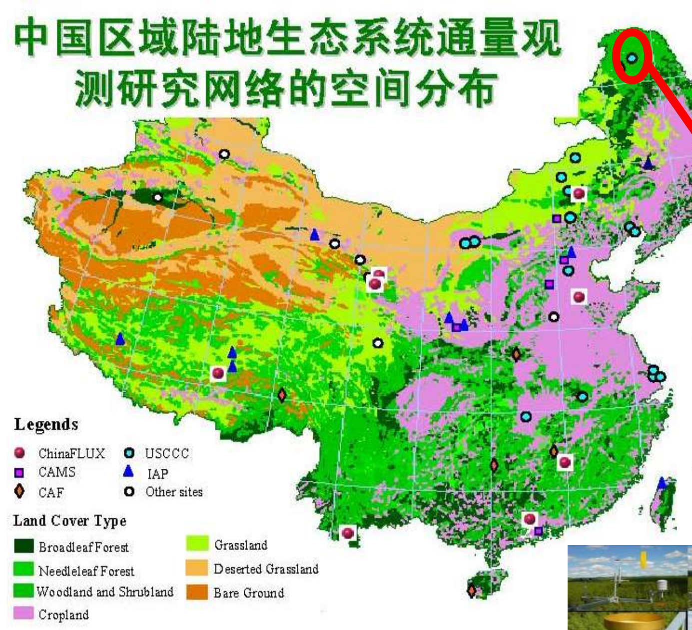
Maize ecosystem

- Location: Jinzhou, Liaoning Province, China (41° 08.59'N, 121° 12.13' E)
- Temperature: 8.5℃
- Precipitation: 590mm
- Species: *maize*
- Tower Height:3.5m
- Observation time: August 25, 2004

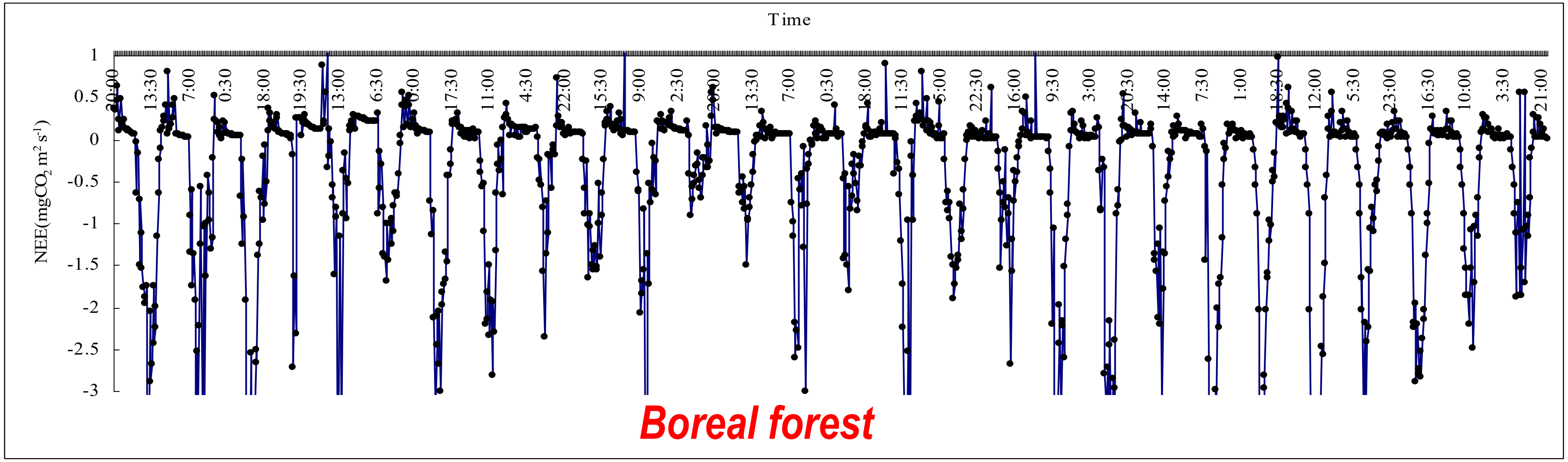




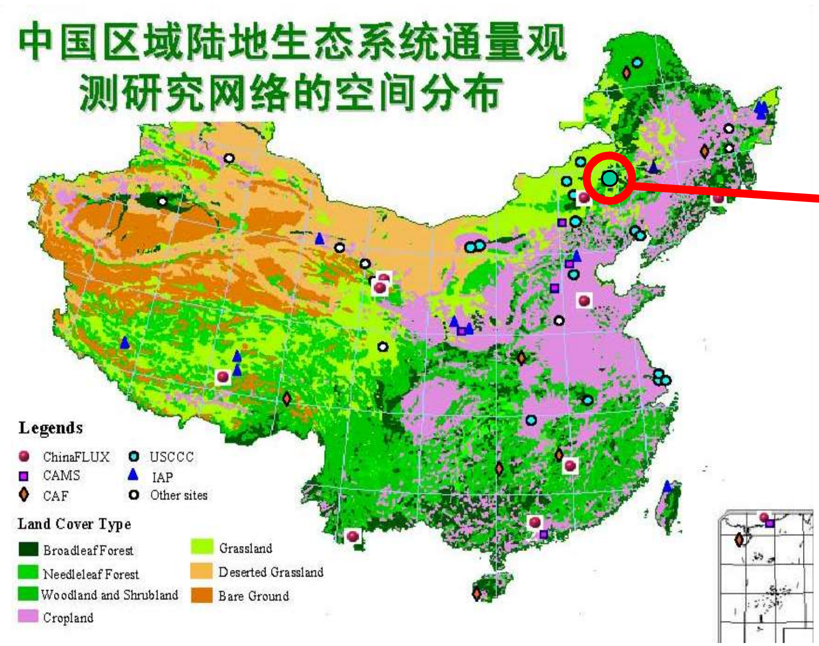
5) Chinese Boreal Forest Ecosystem Research Station



- Location: Huzhong, Helongjiang Province, China (123° 01′ 04″ E， 51° 46′ 52″ N)
- Elevation:773m
- Temperature: -4.4℃
- Precipitation: 458.3mm
- Species: *Larix gmelinii, Betula costata*
- Tower Height:35m
- Observation time: July 15, 2006



6) Shenyang Urban Ecosystem Research Station

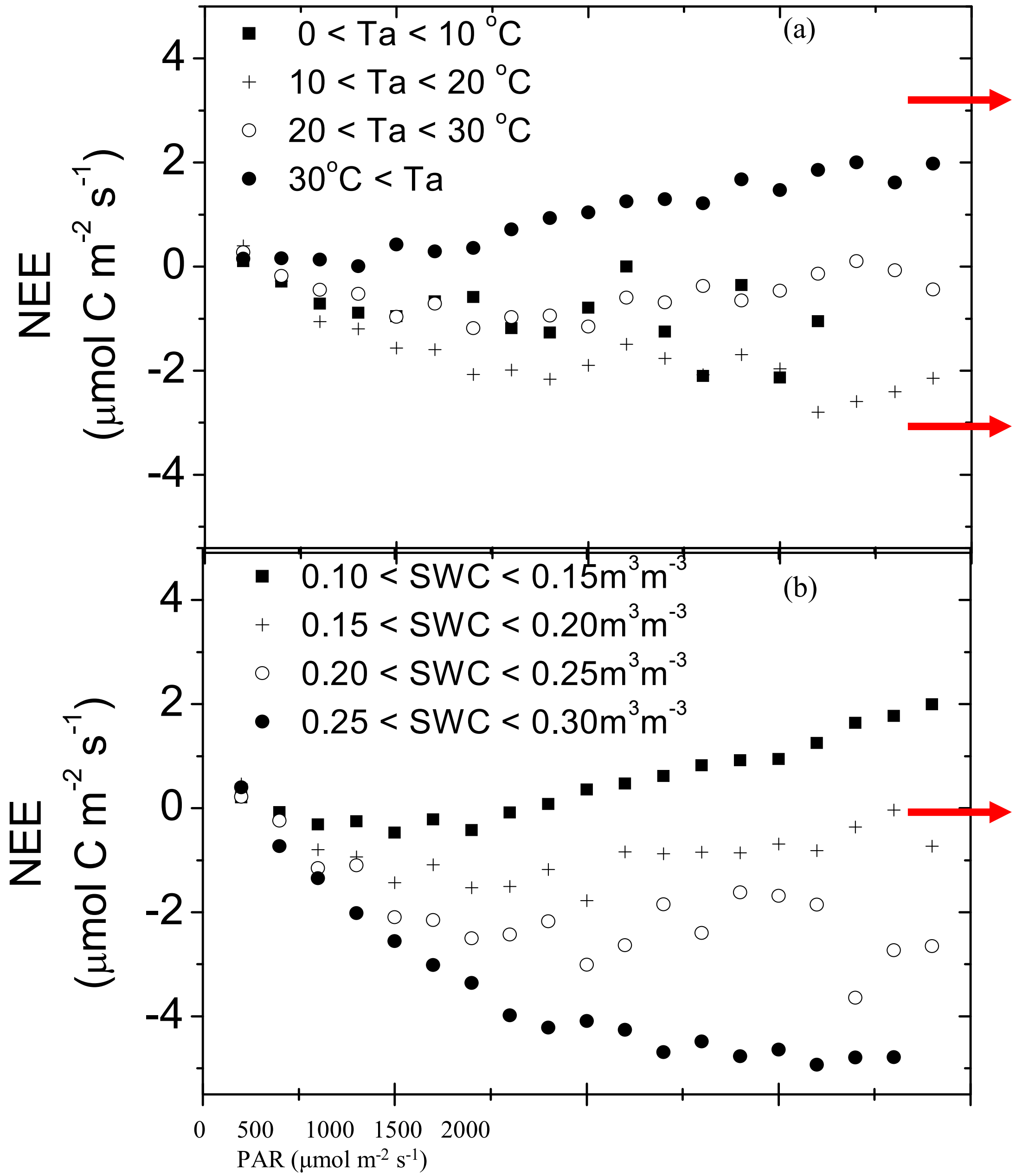


- Location: Shenyan, China (43°02' N, 123°48' E)
- Elevation:447.2m
- Temperature: 8.3℃
- Precipitation: 500mm
- Tower Height:55m
- Observation time: Sept. 5, 2008

(2) Environmental effects on net ecosystem CO_2 exchange

- **For example,** the environmental variables controlling CO_2 exchange at half-hour and month time scales were studied based on the eddy covariance data for 3 years in a semiarid *S. krylovii* steppe in northern China.

At half-hour time scale

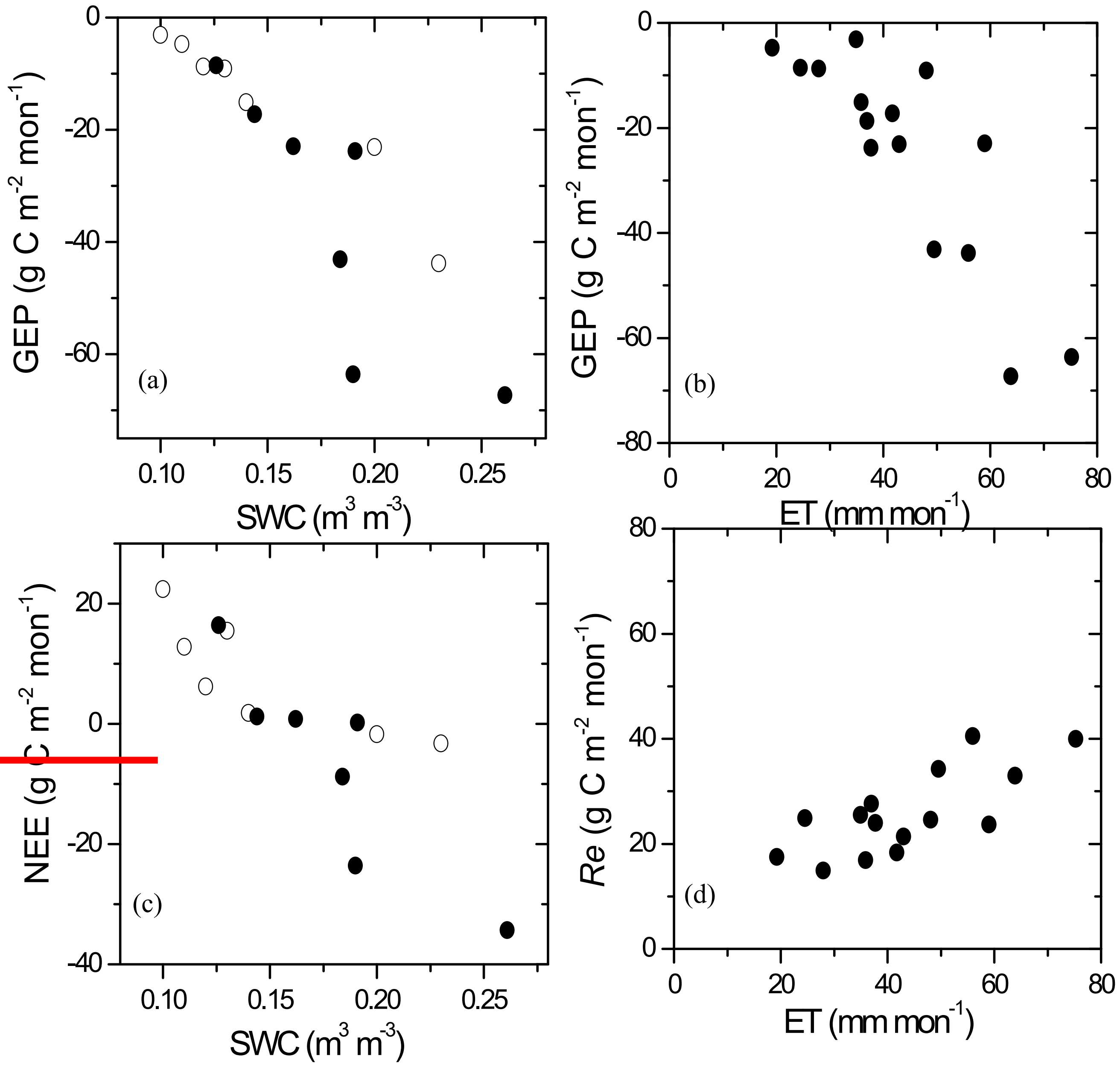


PAR was a primary variable controlling daytime NEE (Fig. 3), accounting for 60% to 80% variations of NEE during optimum environmental conditions.

Air temperature (Ta) was another factor influencing the NEE-PAR relationship.

SWC was the dominant factor limiting the NEE-PAR response during growing seasons

At monthly time scale



SWC was also the most important factor controlling the seasonal variation in NEE during the growing seasons

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Environmental controls on ET over a reed marsh: Li Zhou

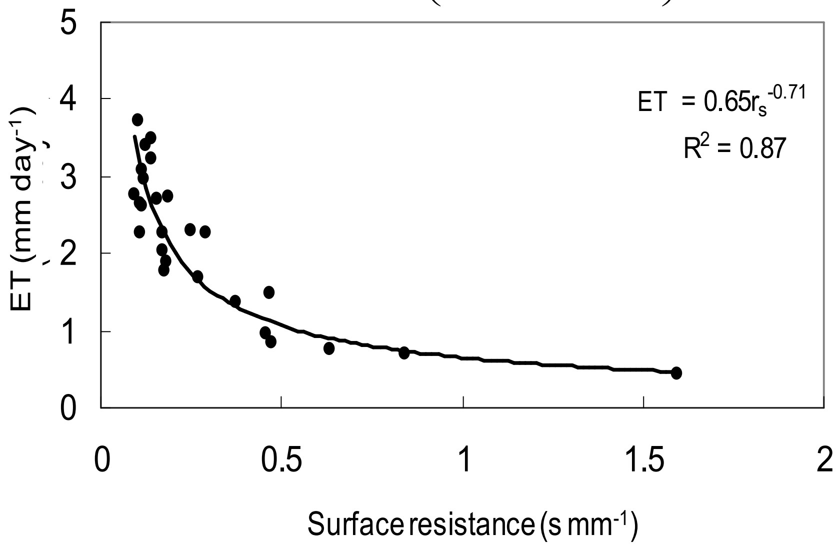
- Land surface conductance (g_s) determined ET directly
- Surface resistance, $r_s=1/g_s$

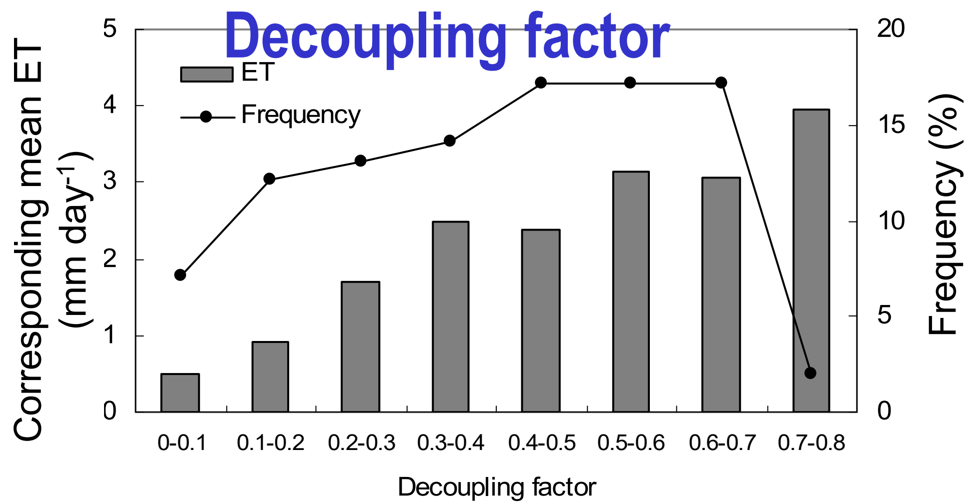
$$\frac{1}{g_s}=r_s=\frac{1}{g_a}+\frac{1}{g_c}$$

- g_a: aerodynamic conductance, g_c: canopy conductance

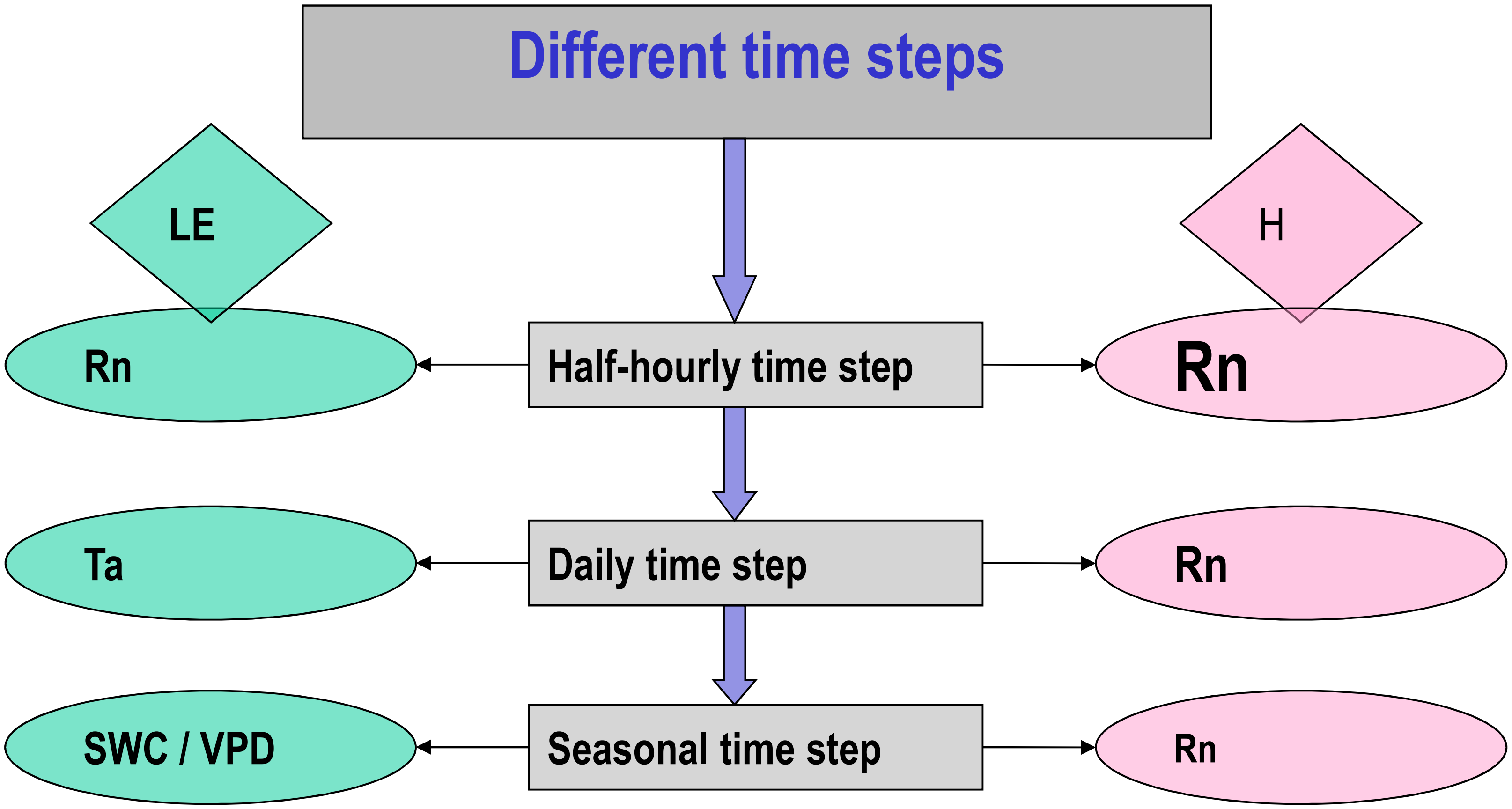
$$g_a=\left(\frac{\bar{u}}{u_*^2}+6.2u_*^{-0.67}\right)^{-1}$$

$$g_c=\frac{\gamma LEg_a}{\Delta(R_n-G)+\rho C_p VPDg_a-LE(\Delta+\gamma)}$$





Environmental controls



Comparison study on annual NEE over typical steppe and maize ecosystems: Yunlong Wang

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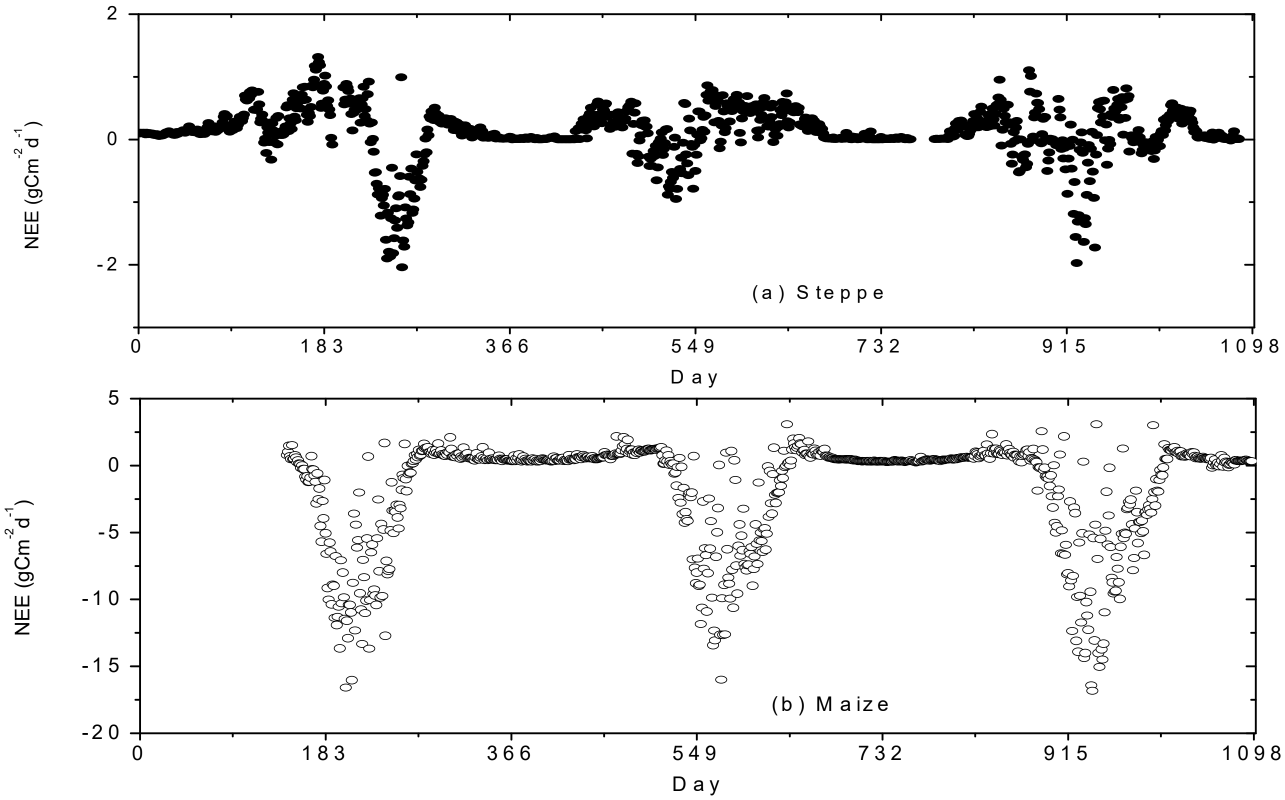

Effects of land use practices on LE, H and NEE

Rainfed maize

Carbon sequestration would slight increase
LE would obviously increase
However, H would be obviously decrease
WUE would decrease obviously

Shortage of water resources

Paddy rice

Reed

WUE changes insignificantly
Carbon sequestration would slight increase
LE would increase obviously
H would decrease significantly

Cooling effect on the climate

2.3 Carbon budget evaluation

(1) Meteorology-based flux simulation

(2) Process-based flux simulation

(3) Satellite-based canopy GPP model

(1) Meteorology-based flux simulation

Profile method

$$\begin{cases} \dfrac{\kappa(z-d)}{u_*}\dfrac{\partial u}{\partial z} = \varphi_M(\xi) \\ \dfrac{\kappa(z-d)}{\theta_*}\dfrac{\partial \theta}{\partial z} = \varphi_H(\xi) \\ \dfrac{\kappa(z-d)}{q_*}\dfrac{\partial q}{\partial z} = \varphi_W(\xi) \end{cases}$$

$$H = H_0 \cdot F_H$$

$$\lambda E = \lambda E_0 \cdot F_W$$

where: $F_H = (\varphi_M \varphi_H)^{-1}$ $F_W = (\varphi_M \varphi_W)^{-1}$

are the functions of sensible and latent heat fluxes affected by stability; H_o and λE_o are sensible and latent heat fluxes under neutral conditions

Bowen Ratio Energy Balance Method(BREB)

$$B = \frac{c_p \Delta\theta}{\lambda \Delta q}$$

$$R_n - G = H + Q$$

$$B = H/Q$$

$$\Rightarrow Q = \frac{R_n - G}{1 + B}$$

B---the defined Bowen ratio

- Shortcomings
  - computationally unstable
  - spurious large values around –1 of B

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- **Variational technique(VT):** based on full information provided by the boundary layer observation, the **surface energy budget**, and **Monin-obukhov similarity** theory.

$$u(z) = \frac{u_*}{\kappa}\left[\ln\left(\frac{z}{z_0}\right) - \psi_m\left(\frac{z}{L}\right) + \psi_m\left(\frac{z_0}{L}\right)\right] \qquad L = \frac{u_*^2\bar{\theta}}{\kappa g \theta_*} \quad \text{Monin-Obukhov length}$$

$$\Delta\theta = \theta(z_2) - \theta(z_1) = \frac{\theta_*}{\kappa}\left[\ln\left(\frac{z_2}{z_1}\right) - \psi_h\left(\frac{z_2}{L}\right) + \psi_h\left(\frac{z_1}{L}\right)\right] \qquad \bar{\theta} = [\theta(z_1) + \theta(z_2)]/2$$

$$\Delta q = q(z_2) - q(z_1) = \frac{q_*}{\kappa}\left[\ln\left(\frac{z_2}{z_1}\right) - \psi_q\left(\frac{z_2}{L}\right) + \psi_q\left(\frac{z_1}{L}\right)\right]$$

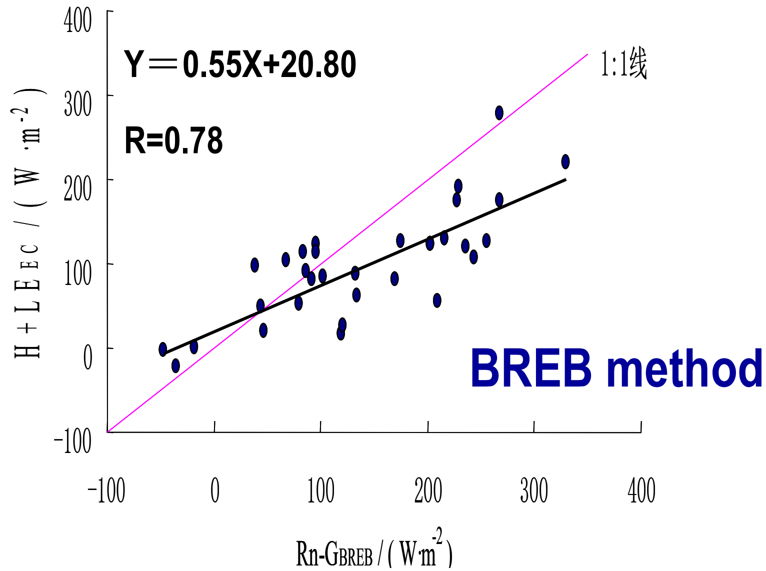
The cost function $J = \frac{1}{2}[w_u(u - u_{ob})^2 + w_\theta(\Delta\theta - \Delta\theta_{ob})^2 + w_q(\Delta q - \Delta q_{ob})^2 + w_r\delta^2]$

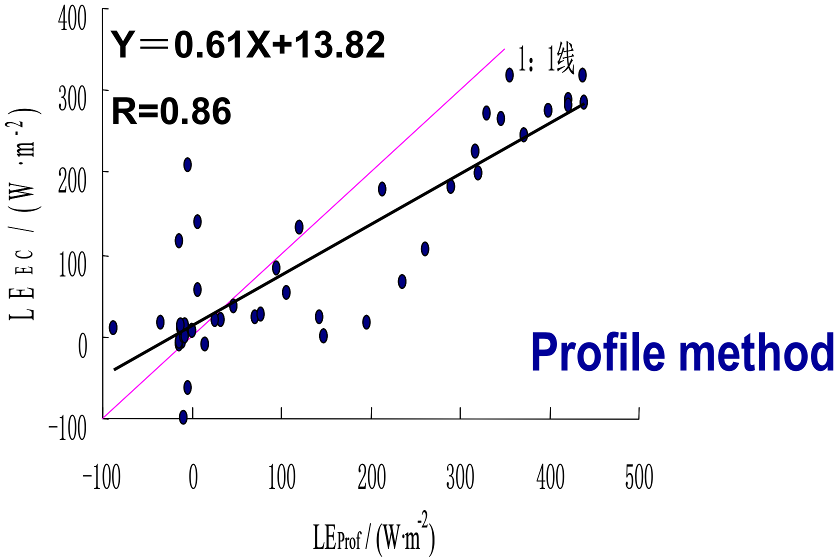
$$\delta = R_n - G - H - Q$$

$$\frac{\partial J}{\partial u_*} = \frac{\partial J}{\partial \theta_*} = \frac{\partial J}{\partial q_*} = 0$$

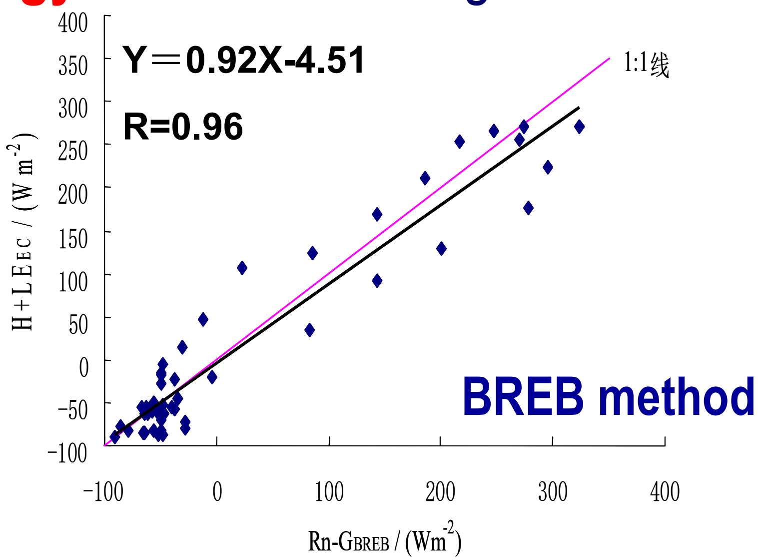
The quasi-Newton algorithm can be used to find the minimum of J and the optimal estimates of (u_*, θ_*, q_*)

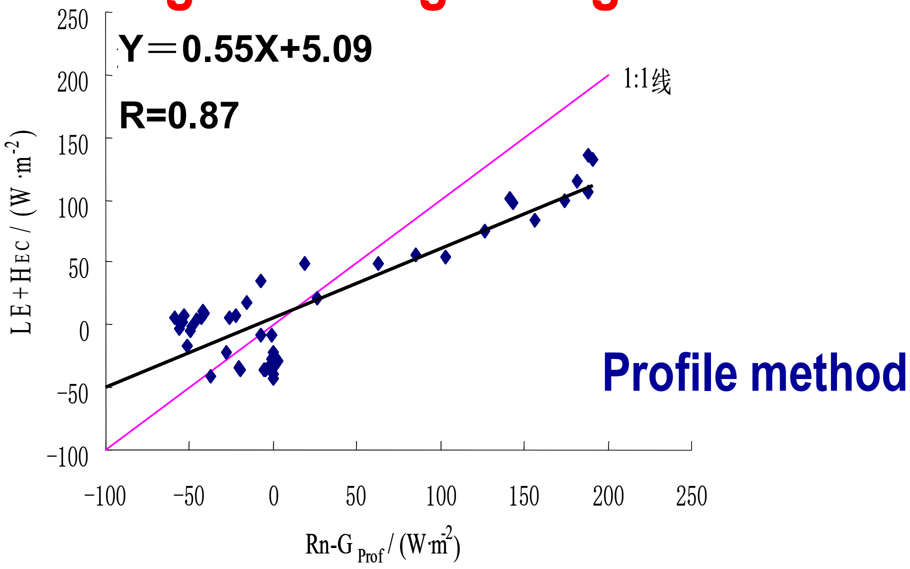
Energy closure of *Phragmites* swamp during the growing season





Energy closure of *Phragmites* swamp during the non-growing season





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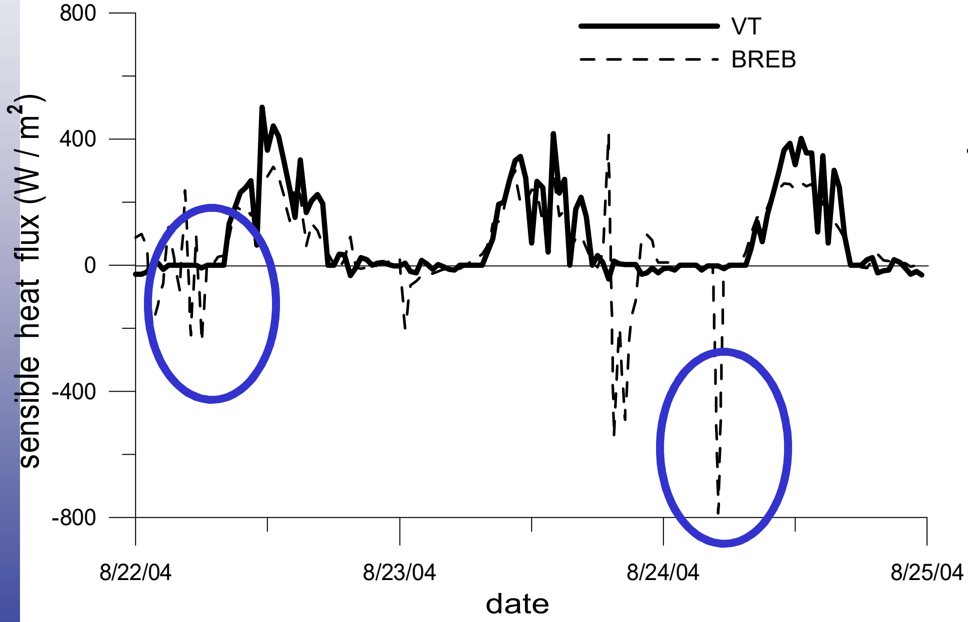
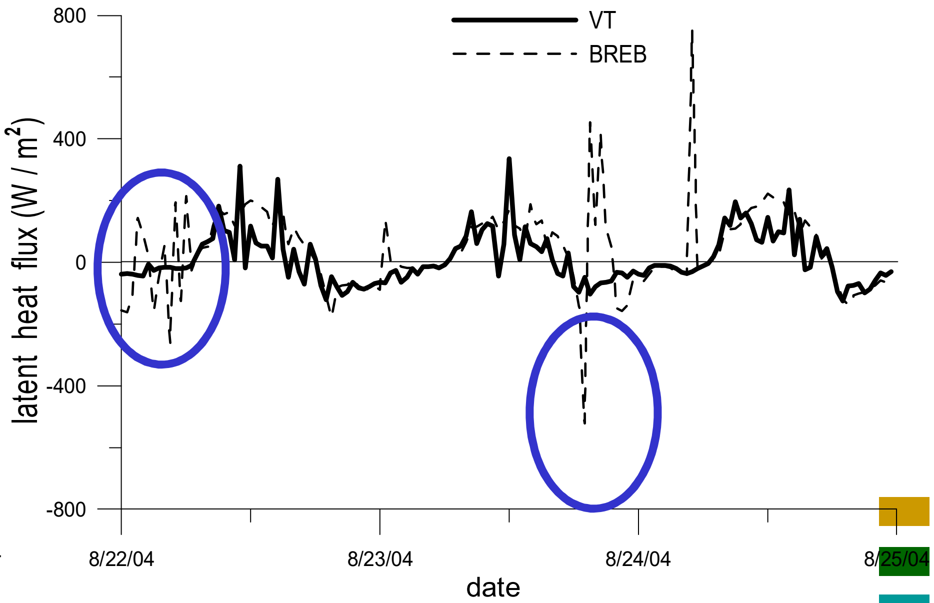
- Variational technique could solve the problems
  - Conventional BREB method produces computationally unstable
  - BREB method results in spurious large values when B is around -1.

Typical steppe ecosystem in Inner Mongolia

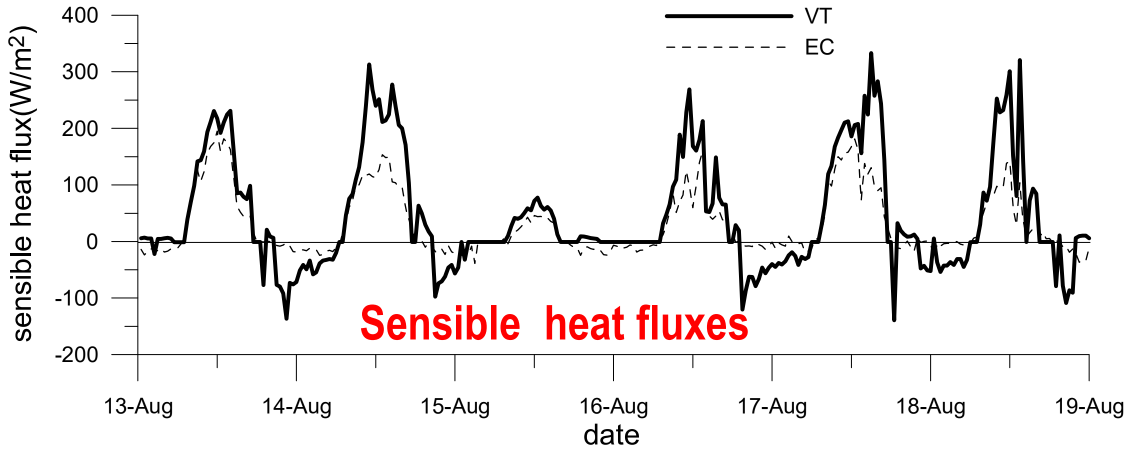


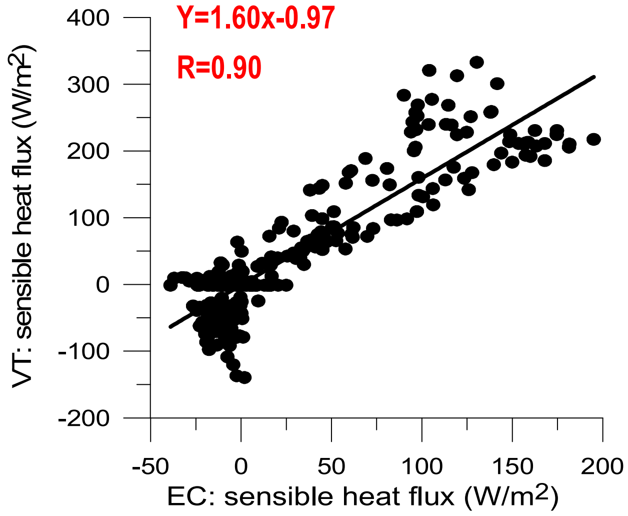


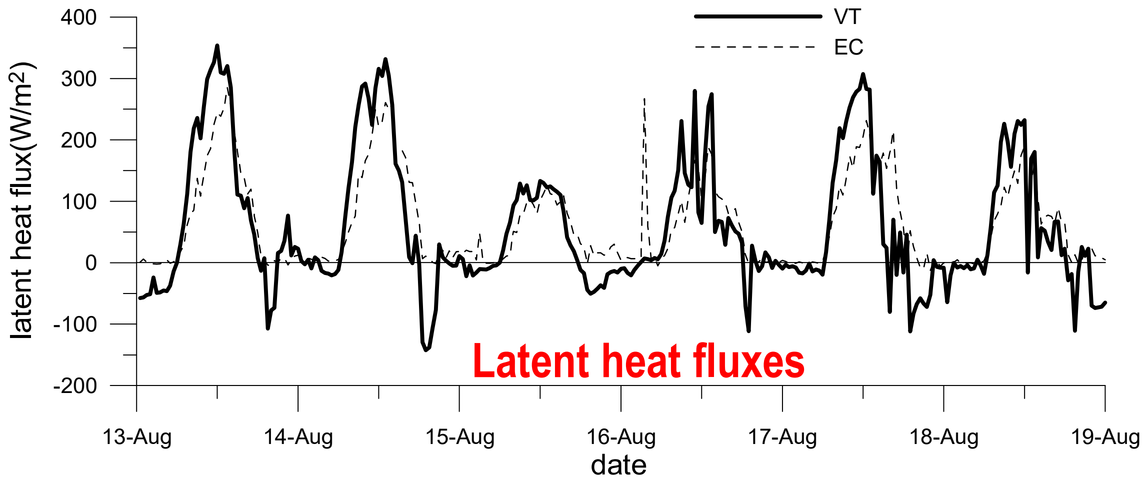
Sensible and latent heat fluxes obtained from BREB and VT from August 22 - 24,2004

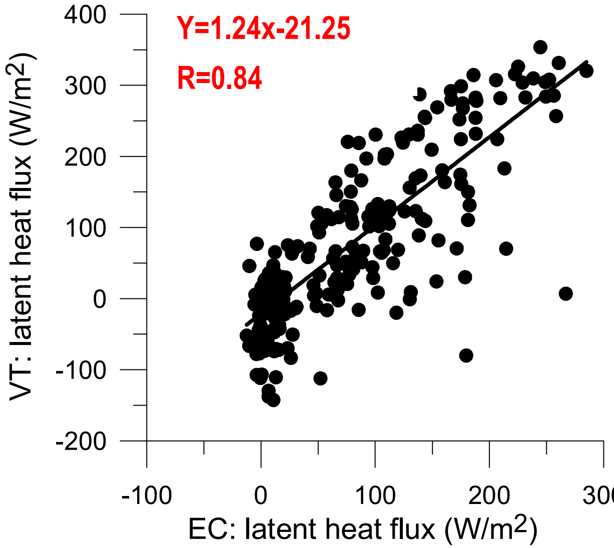
VT method could give better simulations for sensible and latent heat fluxes.

Typical steppe ecosystem in Inner Mongolia



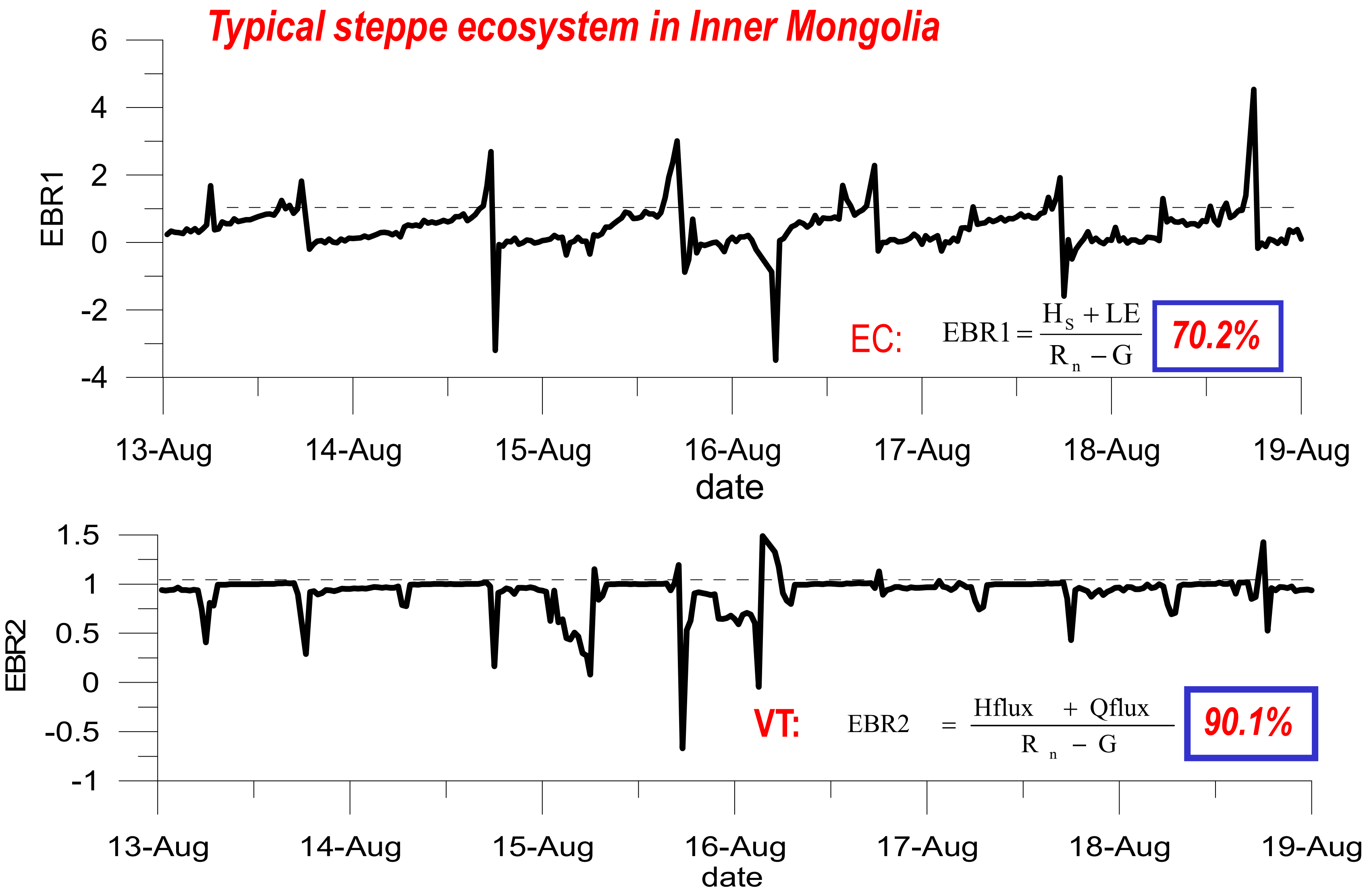






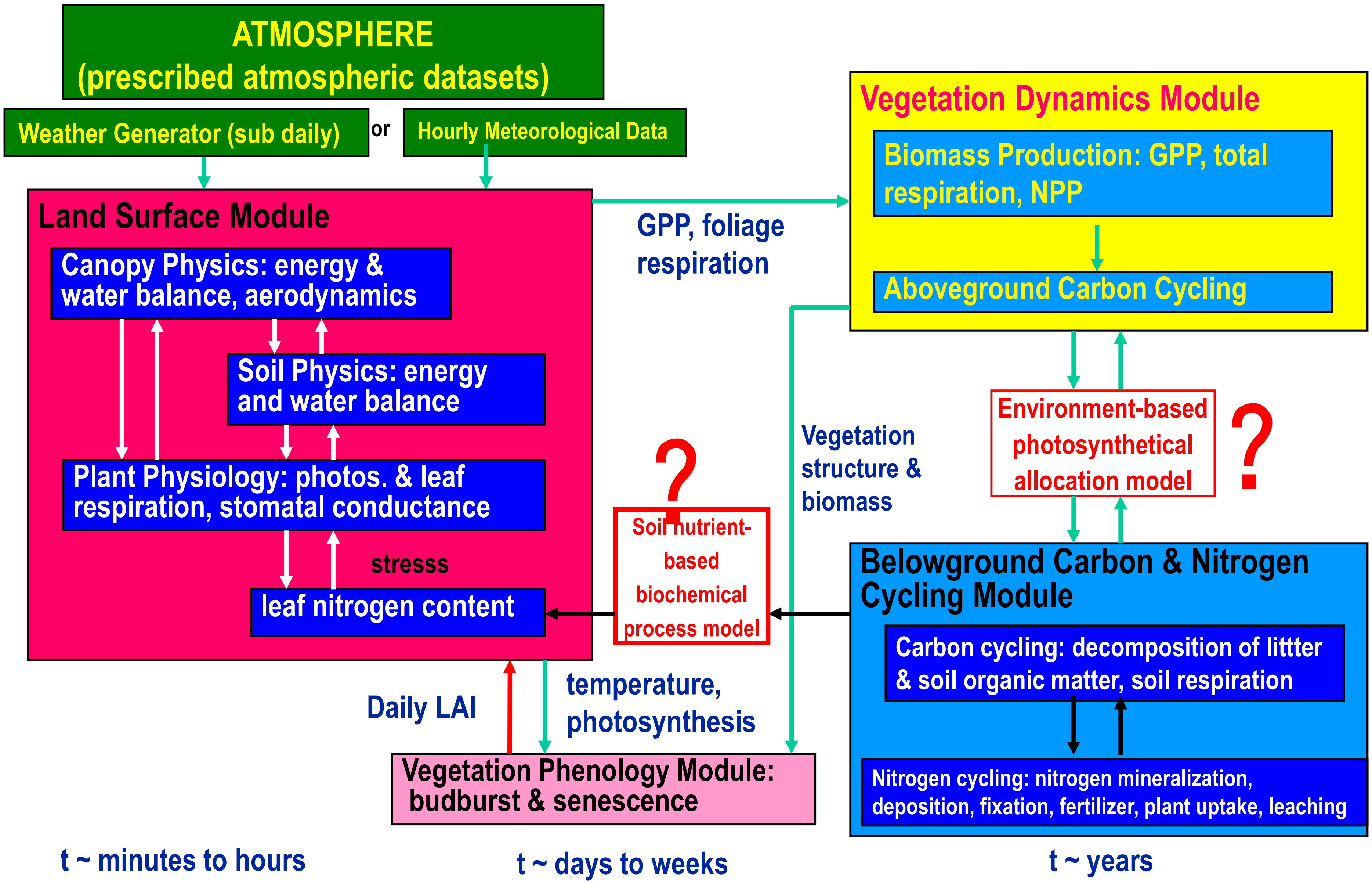
Sensible and latent heat fluxes from 13-18 August, 2004 by EC data and VT method

VT has better energy closure than EC method.



(2) Process-based flux simulation

A case study: Grassland Ecosystem Dynamic Model(GEDM)



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Soil nutrient-based biochemical process model

Biochemical process: $An=\min\{Wc,Wj,Wp\}-Rd$

$$W_c = \frac{V_{c\max}(C_i - \Gamma)}{C_i + K_c(1 + O/K_o)} \qquad V_{cmax} = V_{cmax15} \bullet \exp\{3000 \bullet [\frac{1}{288.16} - \frac{1}{T_l + 273.16}]\}$$

$$V_{cmax15} = \frac{(Amax + Rd)[Ci + Kc \bullet (1 + O/Ko)]}{Ci - \Gamma} \qquad A_{max} = \frac{190 \bullet N}{360 + N} \qquad N = N_T \bullet \frac{I}{I_0}$$

$$N_T = \frac{\exp[u_1 - u_3/(0.00831 T_r)]}{1 + \exp[(u_2 \bullet Tr - 205.9)/(0.00831 T_r)]} \bullet K_T(T_r)$$

$$K_T(T_r) = \{1 + [15 - (T_r - 273.16)]/30\} \bullet (1 + S_C - 13000/10000)$$

$$u_3 = 97.412 - 2.504 \ln(N_p)$$

$$N_p = 120 \bullet Min\{Sn/600, 1\} \bullet \exp(-8 * 10^{-5} \bullet Sc)$$

Soil Nitrogen

Soil Carbon

Root allocation rate

$$root = 0.9 \bullet \frac{L}{L + 2 \bullet \min(W, L)}$$

Shoot allocation rate

$$leaf = 1 - root$$

$$L = \exp(-kLAI)$$

$$W = \frac{SW - WP}{FC - WP}$$

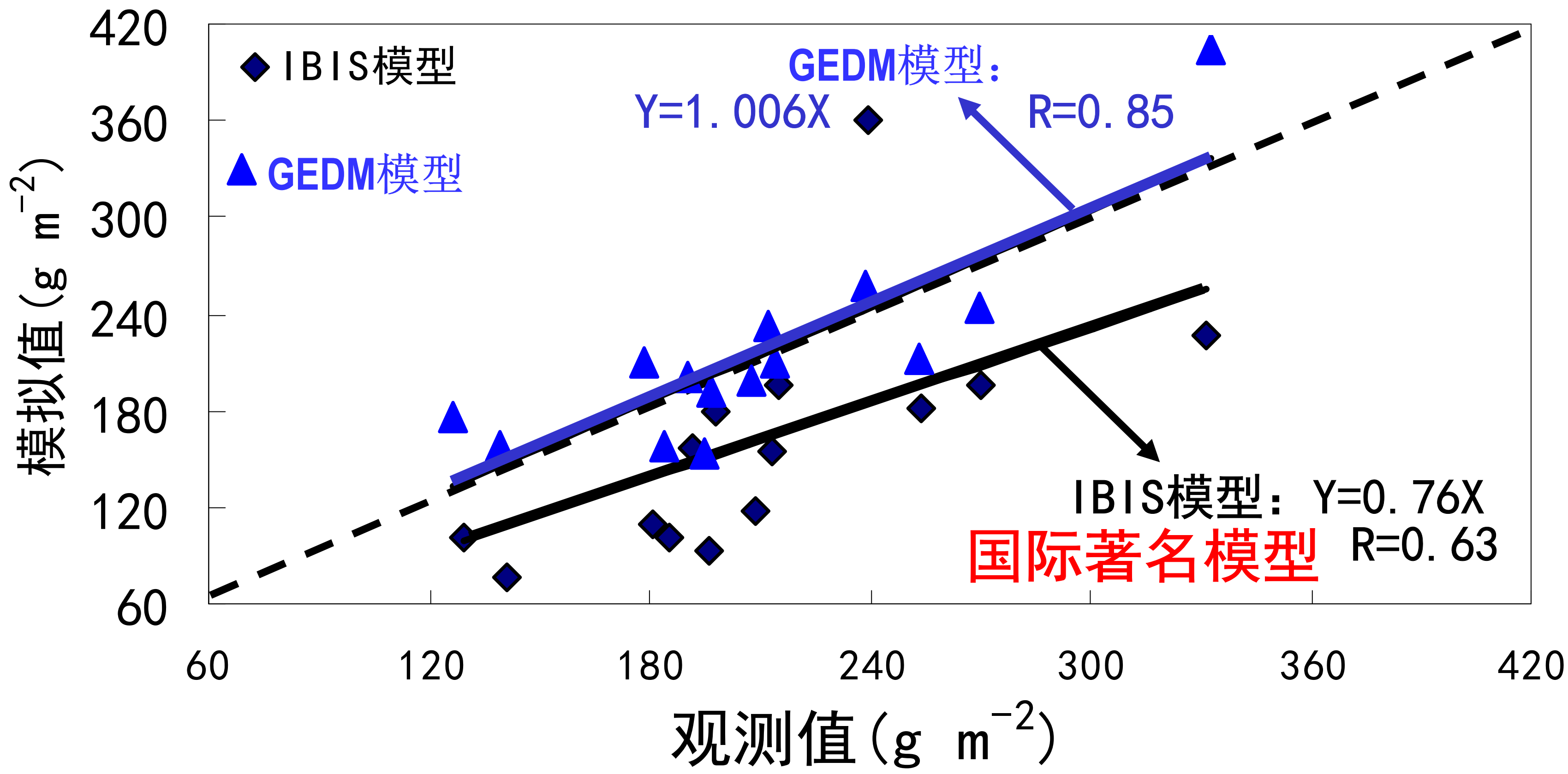
Available water

Available radiation

Environment-based photosynthetical allocation model

Model validation:above-ground biomass

Typical steppe grassland(Inner Mongolia typical steppe grassland ecosystem research station:14 year's observation data)



Our model could simulate AGB better than IBIS model does

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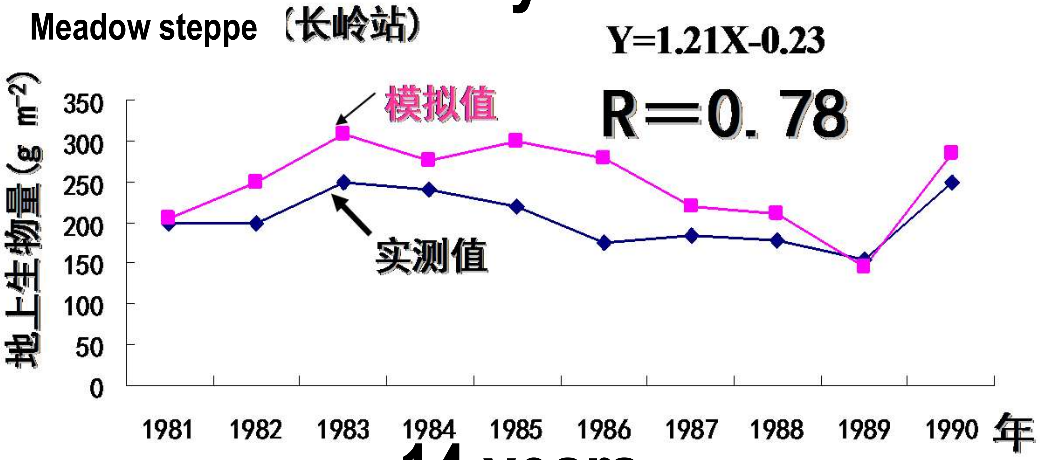
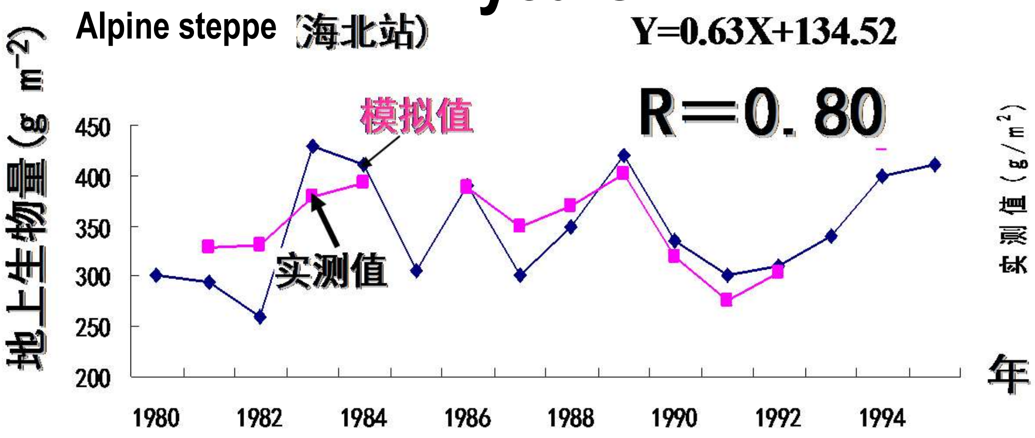
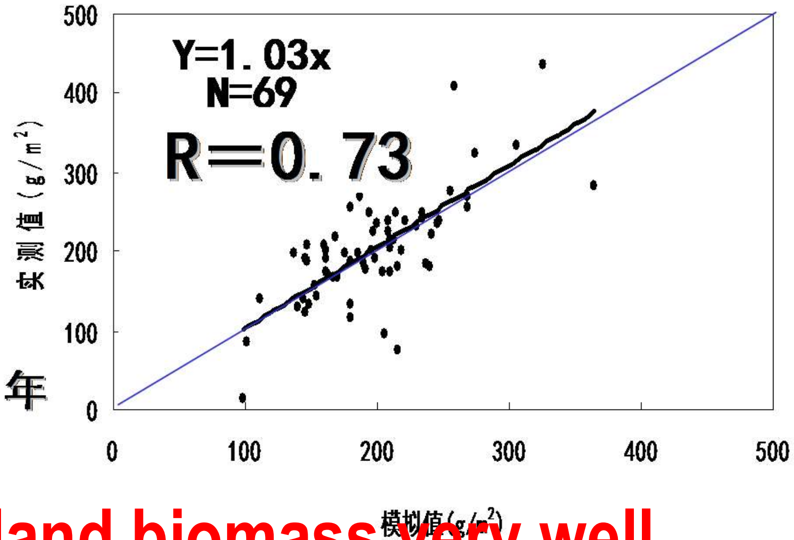
10 years



14 years

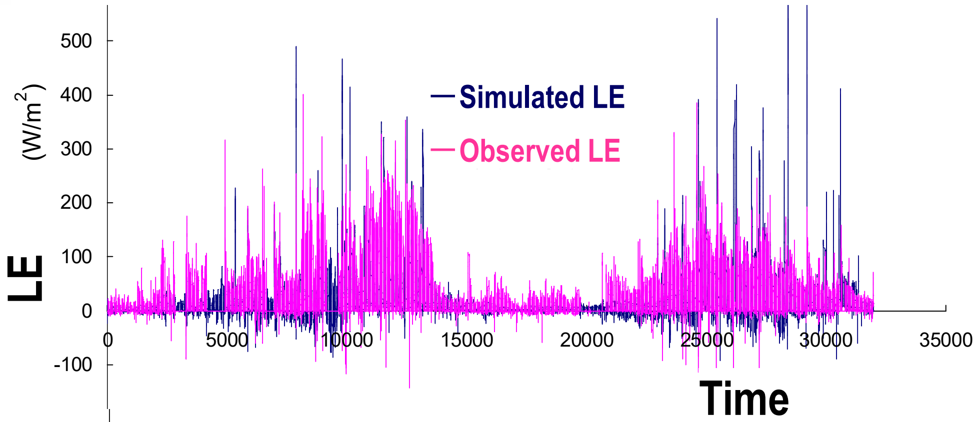


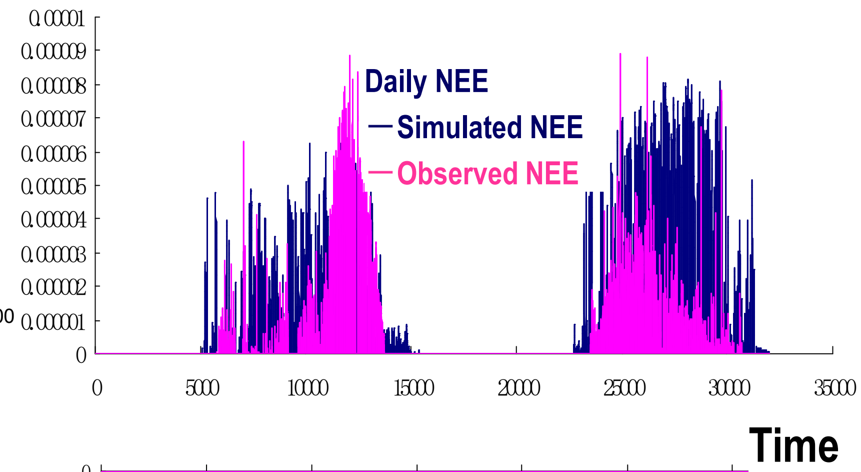


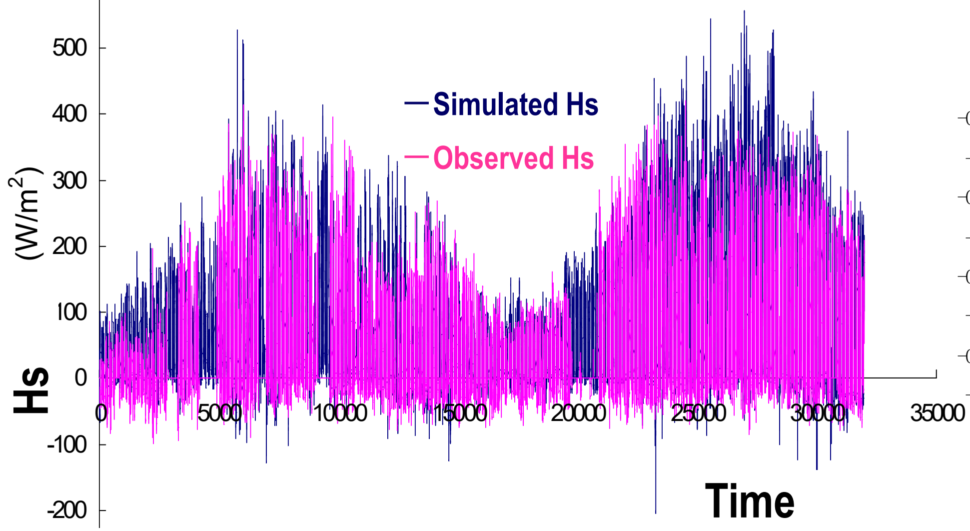
Our model could simulate grassland biomass very well

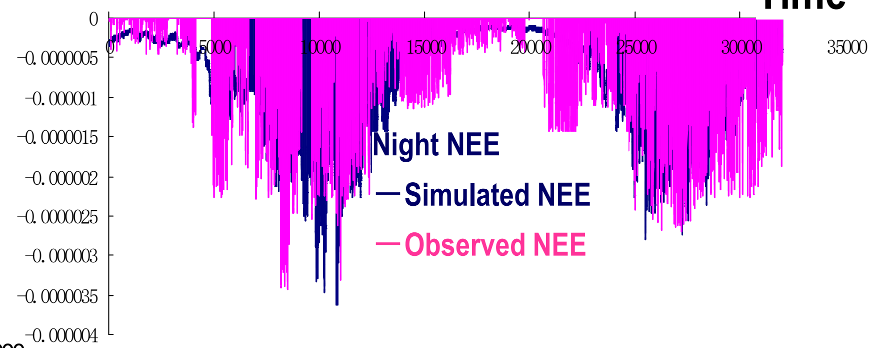
Model validation: fluxes

Typical steppe (Inner Mongolia station): 2004. 7—2005. 12









Our model could simulate fluxes of water, heat and carbon very well

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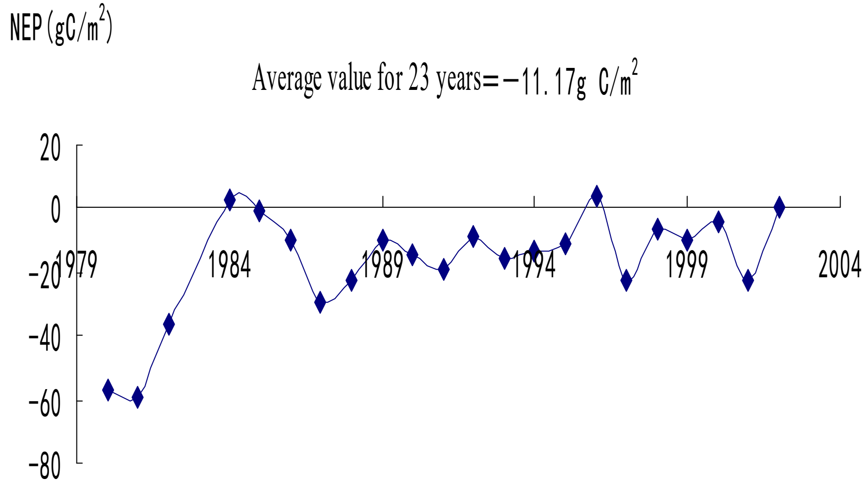
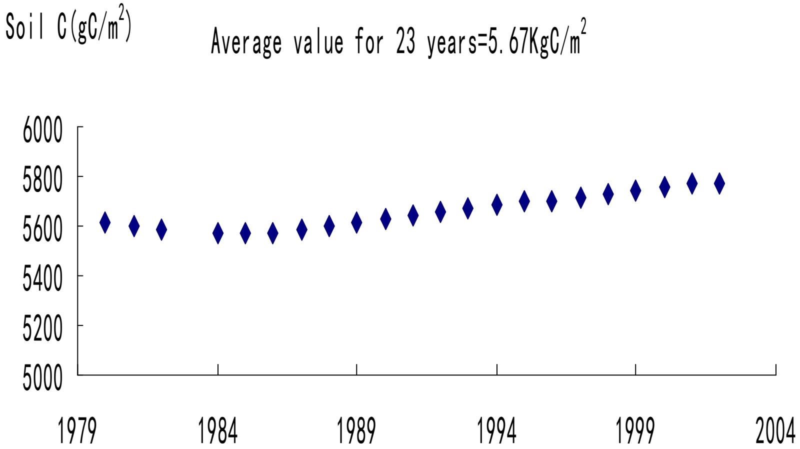
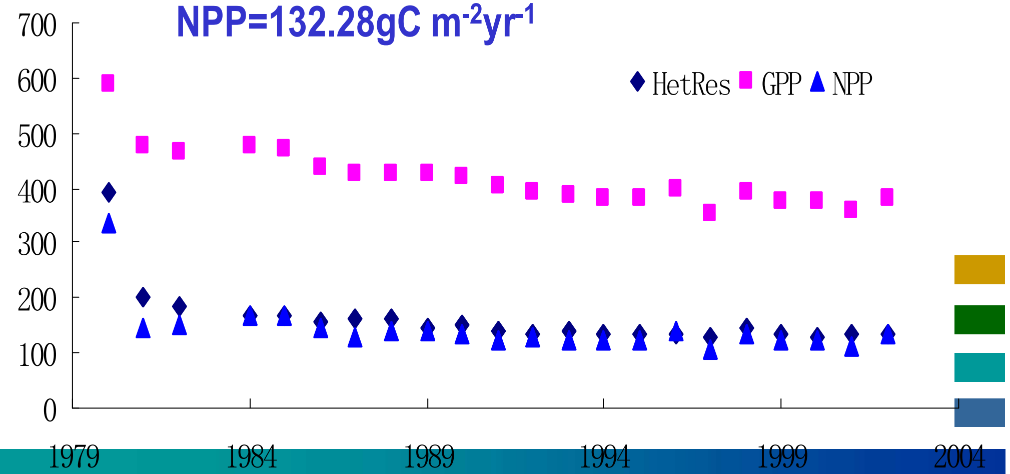
- Chinese grassland carbon budget
- Results
  - Chinese grassland was a slight carbon source (0.044Pg C) from 1980 to 2002(1 Pg = 10^{15} g).
  - NEE is about 11.17g C/m^2.





HetRes=143.45gC m^{-2}yr^{-1}
GPP=403.06gC m^{-2}yr^{-1}
NPP=132.28gC m^{-2}yr^{-1}



(3) Satellite-based canopy GPP model

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- Evaluating the gross primary productivity (GPP) of terrestrial ecosystems based on remote sensing has been a major challenge in quantifying the global carbon cycle.

$$GPP = fPAR \bullet PAR \bullet LUE$$

$$LUE = \varepsilon_{max} \bullet f$$

PAR is the incident photosynthetically active radiation per day or month

fPAR is the fraction of PAR absorbed by the vegetation canopy

LUE is light use efficiency

ε_{max} is the potential LUE without environment stress

f represents the environmental stress on potential LUE, varying from 0 to 1

- The key issue to estimate GPP is to calibrate LUE rigorously.
- Eddy covariance (EC) measurements recorded by the increasing number of EC towers offer the best opportunity for estimating GPP and calibrating LUE.
- The objective of this study is to calibrate LUE for evaluating daily GPP across biomes based on EC flux data

ε_{max} and T_{opt} are calibrated based on EC data

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Key parameters to estimate GPP is ε_{max} and T_{opt}

W_s:Moisture availability on plant photosynthesis

$$W_s = \frac{LE}{LE+H}$$

LE is latent heat flux

H is sensible heat flux

$$GPP = fPAR \bullet PAR \bullet LUE$$

$$LUE \rightarrow \varepsilon = \varepsilon_{max} \times \min(T_s, W_s)$$

$$fPAR = a \bullet NDVI + b$$

$$T_s = \frac{(T-T_{min})(T-T_{max})}{[(T-T_{min})(T-T_{max})]-(T-T_{opt})^2}$$

a = 1.24, b = 0.168 (Sims et al., 2005)

NDVI is obtained directly from 1-km MODIS data

T_{min}=0°C, T_{max}=40°C

T_{opt} is the optimum air temperature for photosynthetic activity,and determined by nonlinear optimization

- Calibration data for ε_{max} and T_{opt}
  - Remote sensing data is MODIS NDVI 16-day composites at 1-km spatial resolution from the AmeriFlux web site
  - EC flux data were downloaded from the AmeriFlux site (http://public.ornl.gov/ameriflux; AmeriFlux, 2001) and EuroFlux site (http://www.fluxnet.ornl.gov/fluxnet/index.cfm; Valentini, 2003)
    - 44 EC tower sites including 5 major terrestrial biomes: deciduous broadleaf forest, mixed forest, evergreen needle leaf forest, grassland and savanna
- ε_{max} = 2.14 g C m^{-2} MJ^{-1} APAR
- T_{opt} = 20.33°C

28 EC sites for calibrating parameters

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Name, location, annual mean temperature (AMT), annual precipitation (AP), and other characteristics of the study sites used for model calibration and validation

Site	Latitude, longitude	Vegetation type	AMT (°C)	AP (mm)	Stand age (year)	Reference
Model calibration sites						
Morgan Monroe	39.32°N, 86.41°W	Deciduous broadleaf forest	12.42	1030.5	60–90	Schmid et al. (2000)
Sarrebourg	48.67°N, 7.08°E	Deciduous broadleaf forest	9.20	820	30	Granier et al. (2000)
Duke Hardwood	35.97°N, 79.10°W	Deciduous broadleaf forest	14.35	1154	80–100	Pataki and Oren (2003)
Donaldson	29.75°N, 82.16°W	Evergreen needleleaf forest	21.70	1330	11–13	Gholz and Clark (2002)
Metolius Young	44.44°N, 121.57°W	Evergreen needleleaf forest	7.68	403	15	Law et al. (2000a)
Metolius	44.49°N, 121.62°W	Evergreen needleleaf forest	8.37	577	250 and 50	Law et al. (2000b)
Howland Forest	45.20°N, 68.74°W	Evergreen needleleaf forest	6.65	523–1032	95–140	Hollinger et al. (1999, 2004)
Tharandt	50.97°N, 13.63°E	Evergreen needleleaf forest	7.50	824	140	Kramer et al. (2002)
Boreas NSA	55.87°N, 98.48°W	Evergreen needleleaf forest	−3.55	420	120 and 90	Goulden et al. (1998)
Walnut River	37.52°N, 96.86°W	Grassland	13.10	1045.4		Song et al. (2005)
Sylvania	46.24°N, 89.35°W	Mixed forest	6.14	408	1–350	Desai et al. (2005)
Vaira Ranch	38.41°N, 120.95°W	Grassland	15.90	498		Baldocchi et al. (2004)
Model validation sites						
Goodwin Creek	34.25°N, 89.97°W	Deciduous broadleaf forest	16.10	700–1800		
Willow Creek	45.91°N, 90.08°W	Deciduous broadleaf forest	5.13	703	60–80	Bolstad et al. (2004)
Austin Cary	29.73°N, 82.22°W	Evergreen needleleaf forest	21.70	1330	81	Gholz and Clark (2002)
Blodgett Forest	38.89°N, 120.63°W	Evergreen needleleaf forest	10.40	1290	6–7	Goldstein et al. (2000)
Boreas NSA 1930	55.91°N, 98.52°W	Evergreen needleleaf forest	−2.88	499.82	76	Goulden et al. (2006)
Boreas NSA 1963	55.91°N, 98.38°W	Evergreen needleleaf forest	−2.87	502	43	Goulden et al. (2006)
Boreas NSA 1981	55.86°N, 98.49°W	Evergreen needleleaf forest	−2.86	500.34		Goulden et al. (2006)
Metolius Mid	44.45°N, 121.56°W	Evergreen needleleaf forest	7.00	418	56	Law et al. (2004)
Hyytiala	61.85°N, 24.28°E	Evergreen needleleaf forest	3.50	640	30	Kramer et al. (2002)
Niwot Ridge	40.03°N, 105.55°W	Evergreen needleleaf forest	2.40	800	100	Monson et al. (2002)
Duke Pine	35.98°N, 79.09°W	Evergreen needleleaf forest	14.35	1154	17	Stoy et al. (2006)
Fort Peck	48.31°N, 105.10°W	Grassland	5.13	500		
Duke Grass	35.97°N, 79.09°W	Grassland	14.35	1154		Novick et al. (2004)
Lost Creek	46.08°N, 89.98°W	Mixed forest	5.02	648.5		Davis et al. (2003)
UMBS	45.56°N, 84.71°W	Mixed forest	6.20	750	90	Curtis et al. (2005)
Tonzi Ranch	38.43°N, 120.97°W	Savanna	15.4	494		Baldocchi et al. (2004)

Validation(16 sites)

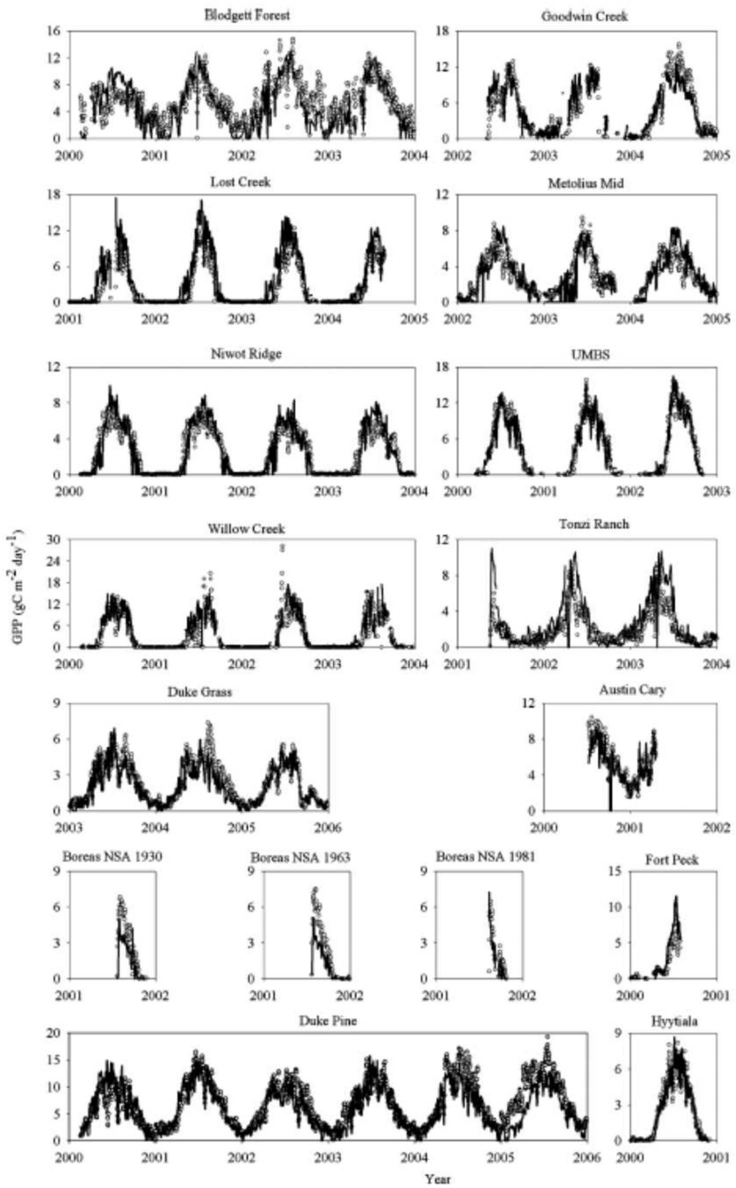
Site	R^2	Pred[a]	Est[b]	PE	RPE (%)	τ	N[c]
Model calibration sites							
Morgan Monroe	0.82	4.11	3.51	0.60	0.17	0.90	777
Sarrebourg	0.83	5.72	6.03	−0.31	−0.05	0.91	239
Duke Hardwood	0.91	5.36	5.31	0.05	0.01	0.95	1845
Donaldson	0.63	6.29	8.36	−2.07	−0.25	0.79	738
Metolius Young	0.81	2.03	2.72	−0.69	−0.25	0.89	1044
Metolius	0.85	3.50	2.87	0.63	0.22	0.92	298
Howland Forest	0.90	3.19	3.75	−0.56	−0.15	0.94	1393
Tharandt	0.89	2.92	4.17	−1.25	−0.30	0.94	368
Boreas NSA	0.83	1.51	1.39	0.12	0.09	0.91	1303
Walnut River	0.93	3.84	3.46	0.38	0.11	0.96	1160
Sylvania	0.89	3.22	3.19	0.03	0.01	0.94	945
Vaira Ranch	0.80	2.93	2.12	0.81	0.38	0.89	1147
Model validation sites							
Goodwin Creek	0.77	4.71	4.54	0.17	0.04	0.88	822
Willow Creek	0.73	3.81	3.47	0.34	0.10	0.85	1161
Austin Cary	0.72	5.08	5.48	−0.41	−0.07	0.84	283
Blodgett Forest	0.60	4.87	5.48	−0.61	−0.11	0.77	1352
Boreas NSA 1930	0.79	1.84	3.04	−1.20	−0.39	0.89	107
Boreas NSA 1963	0.96	0.90	1.62	−0.72	−0.44	0.97	211
Boreas NSA 1981	0.60	1.80	2.35	−0.55	−0.23	0.77	62
Metolius Mid	0.64	2.94	3.03	−0.09	−0.03	0.79	998
Hyytiala	0.94	2.42	2.50	−0.08	−0.03	0.97	328
Niwot Ridge	0.87	2.39	2.39	0.00	0.00	0.93	1429
Duke Pine	0.78	6.00	6.85	−0.85	−0.12	0.88	2168
Fort Peck	0.90	2.93	2.07	0.85	0.41	0.94	159
Duke Grass	0.83	2.11	2.34	−0.23	−0.10	0.91	1108
Lost Creek	0.87	3.55	2.43	1.11	0.46	0.93	1285
UMBS	0.92	5.75	5.72	0.03	0.00	0.96	681
Tonzi Ranch	0.59	2.76	2.10	0.65	0.31	0.77	938

[a] Average predicted GPP (g C m^{-2} day^{-1}).
[b] Average estimated GPP from EC flux tower data (g C m^{-2} day^{-1}).
[c] Total days.

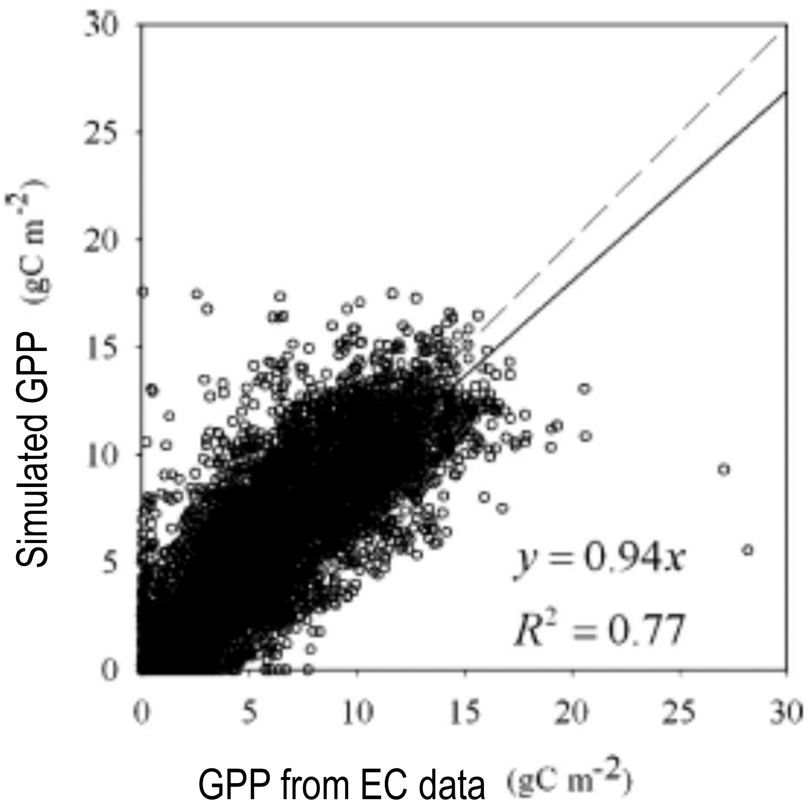
Validation(16 sites)

Black solid lines: the simulated GPP

Open circles: the GPP from EC data



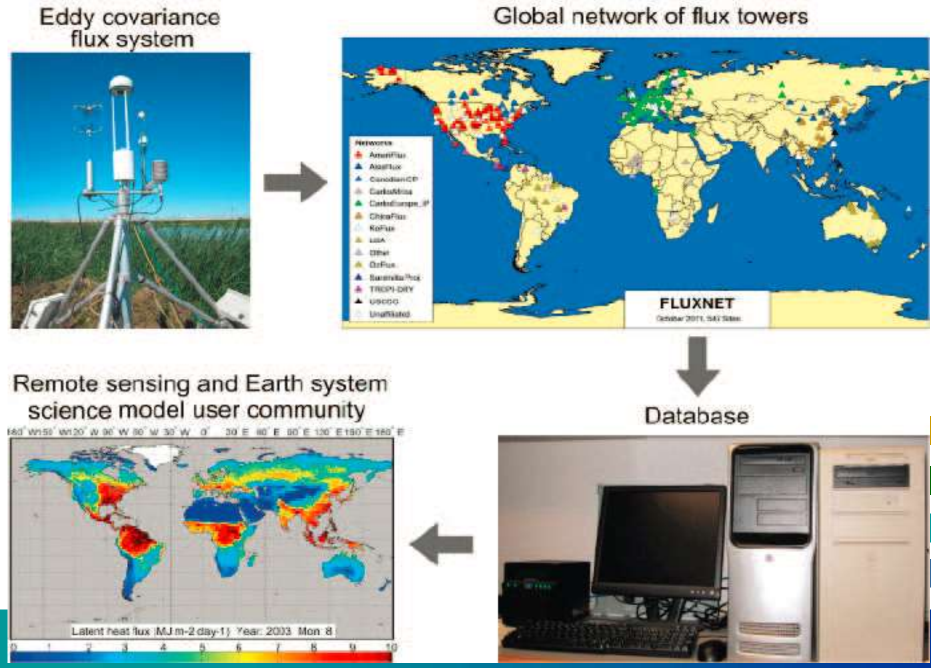
Daily variations of simulated GPP and estimated GPP



Simulated vs. GPP from EC data

3. EC in the world

- The earliest eddy covariance measurements date to the late 1970s and early 1980s, and EC methods were applied during **short-term, field campaigns** (Anderson et al., 1984).
- The application of eddy covariance method started to **grow rapidly** in the early 1990s with the technical development.
- **Global networks of EC sensors** provide continuous EC-flux data and have **revealed a number of new findings.** Overall, EC-based researches have undergone four transformations.



The 1st transformation: Flux observation

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- This stage is featured by the establishment of regional flux networks in North and South America (AmeriFlux, LBA and Fluxnet-Canada), Europe (EuroFlux and CarboEurope), Australia (Oz-Flux), Asia (ChinaFlux and AsiaFlux), and the global network, FLUXNET. These FLUX networks dispersed across most of the world's climatic zones and biomes. Recently, Urban Fluxnets dedicated to urban areas have emerged.
- In this stage, the common for eddy covariance researchers was
  - to publish one year of flux data from an individual site
  - to report the annual sums of net carbon and water exchange
  - to reveal how these fluxes responded to environmental drivers like light, temperature, and soil moisture

The 2nd transformation: Carbon evaluation

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- This stage is characterized by carbon evaluation based on long-term EC data at more than 400 field sites across the globe.
- The groups of flux towers have been adept at addressing specific questions relating how carbon, water, and energy fluxes may vary:

  (1) across climatic or elevational gradients

  (2) by land use

  (3) by vegetation(PFT, length of growing season and phenology)

  (4) by disturbance (drought, fire, logging, thinning and insect infestation)

(5) by management practices

- Agriculture: fertilization, irrigation, tillage, thinning, and cultivation
- Forest: deforestation, afforestation of pastures and deserts
- Grassland: grazing
- Ecological restoration

- Flux networks also provide information on how biophysical variables(e.g., albedo, temperature and evaporation) vary with climate(e.g., seasonal or climatic change) and ecological space(e.g., plant functional type and nutrition).

The 3rd transformation: Heterogeneity

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- This stage is featured by landscape scale, at which ecological properties do not operate at cell, leaf, and plant scales. Eddy flux measurements are adept at discovering scale emergent properties – how the functioning of the whole system differs from the sum of the individual parts. Most notable are the discoveries of how:

  (1) the fraction of diffuse light affects light use efficiency of CO_2 exchange

  (2) soil respiration scales with recent photosynthesis

  (3) the degree to which net carbon exchange varies as a function of time since disturbance

  (4) the response of photosynthesis and respiration to temperature acclimates

  (5) ecosystem photosynthetic capacity adjusts with time of season

  (6) rain events stimulate pulses in soil respiration

The 4th transformation: Model simulation

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- At present, data generated by flux measurement networks are being used
  - to test and improve the land- atmosphere flux algorithms used in climate models [Bonan et al., 2011]
  - in the next generation of data assimilation models
  - to calibrate a spatially distributed groundwater–surface water catchment model (MIKE SHE) coupled to a land surface model component with particular focus on the water and energy fluxes(Morten et al., 2016).
  - to produce new information on feedbacks between carbon and water fluxes and meteorological and soil conditions using transfer entropy methods [Kumar and Ruddell, 2010]

4. EC Future

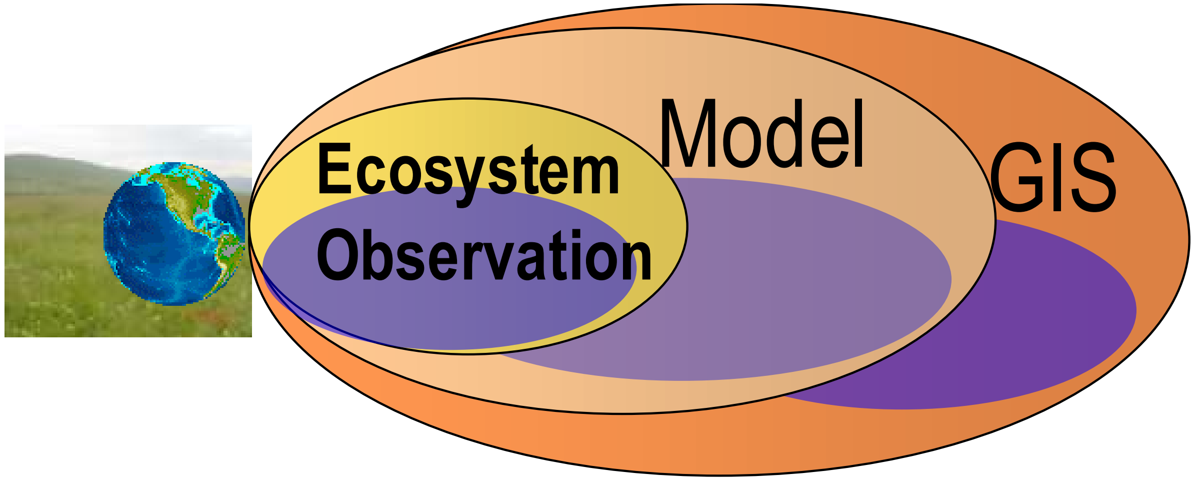
A critical role for a safe and sustainable future

- The IPCC 5th Assessment Report (AR5) in 2013 stated that a warming world was unequivocal, and it is extremely like that most of observed increase in global surface temperature since 1951 is caused by human influence. This statement was based on the use of climate models to investigate what the world's climate would have been like without human emissions of greenhouse gases and land use change.
- In research done in collaboration with the remote sensing and Earth system modeling communities, scientists are finding flux networks to be a critical tool in efforts to produce information on trace gas fluxes that are occurring everywhere, all of the time.

- Terrestrial ecosystems affect climate through exchanges of energy, water, momentum, CO_2, trace gases and mineral aerosols. Changes in community composition and ecosystem structure alter the fluxes and in doing so alter climate.
- It is essential to improve our understanding of the terrestrial biosphere, in terms of not only the possible impacts of climate change, but also the interactive roles that biosphere processes play in the functioning of the earth system as a whole.
- Without doubt, climate change has become a defining problem for the 21th century. EC flux will be able to play a critical for a safe and sustainable future through the nexus of climate science and social science within climate policy framework.

- Therefore, a global challenge research proposal could be suggested:
  - Life Cycle Analysis on GHG/water (resource) footprints for national policy decision on best Environment performance of Ecosystem under present and future climate conditions
  - Focusing on
    - Climate Variability issues: S2S
    - System integration : Process Network Analysis
    - Coupling of Ecosystem to Atmospheric System
    - Synchronization of Mitigation/Adaptation strategies

- **Key subjects**
  - Carbon/Water footprints under present and future climate conditions
  - Assessment on the effects of Ecosystem changes on Carbon/Water footprints under climate projection scenarios
  - Interactive mechanism between Ecosystem/Climate system
  - Modeling ecosystem interactions with the environment, especially related to GHG emissions and climate change, especially extreme climate events (e.g., frost and freezes, drought and heat spells, wind storms, intense rain storms, and floods)
  - (Short-/)Long-term feedback of Ecosystem to Climate system
  - Prediction on long-term orientation of Ecosystem changes and its impact on Climate system
  - Cross-over impact assessments for Adaptation/Mitigation strategies
  - Establishing policy decision-making support system with Life Cycle Analysis for adaptation/mitigation strategies under climate change projections
  - Sustainability Evaluation in terms of Socio-Economic-Policy implications



Thanks for your attention!