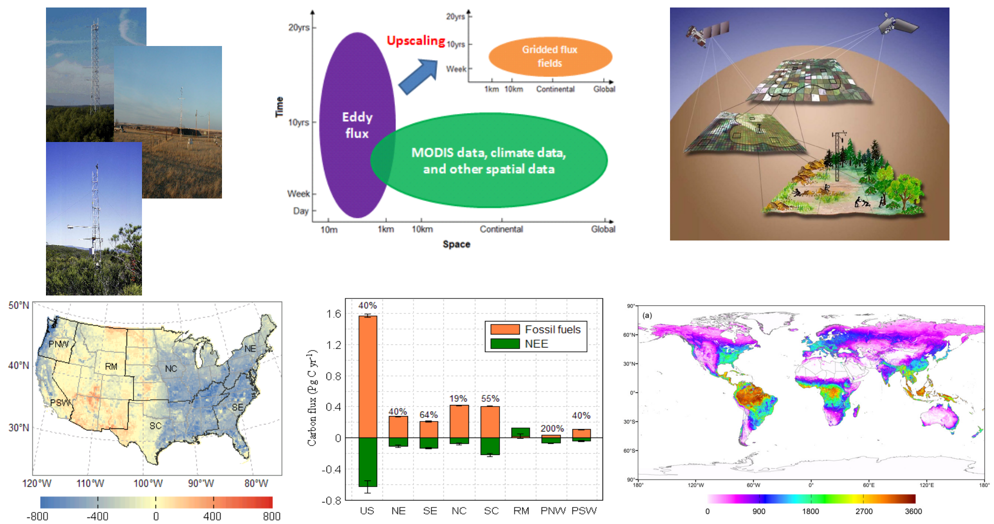
Land-atmosphere carbon and water exchange derived from flux observations, satellite data, and modeling



肖劲锋

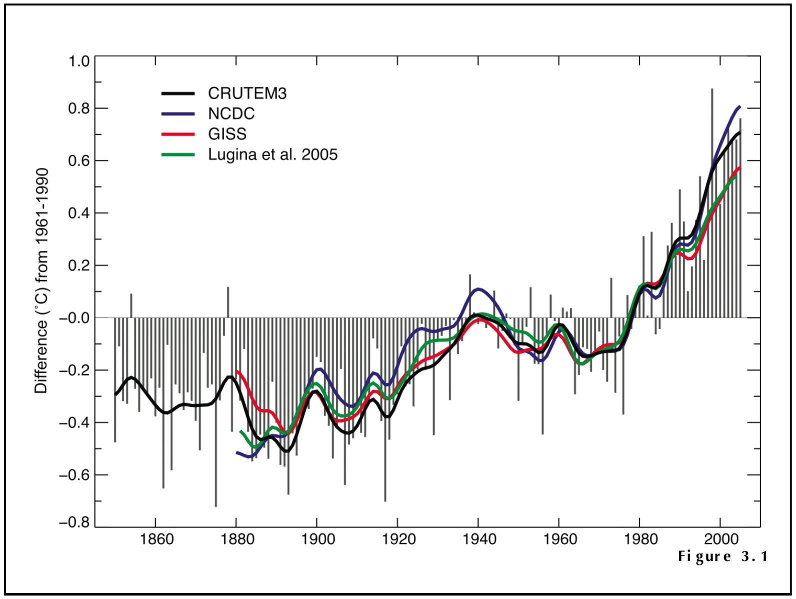
[1]Earth Systems Research Center, University of New Hampshire

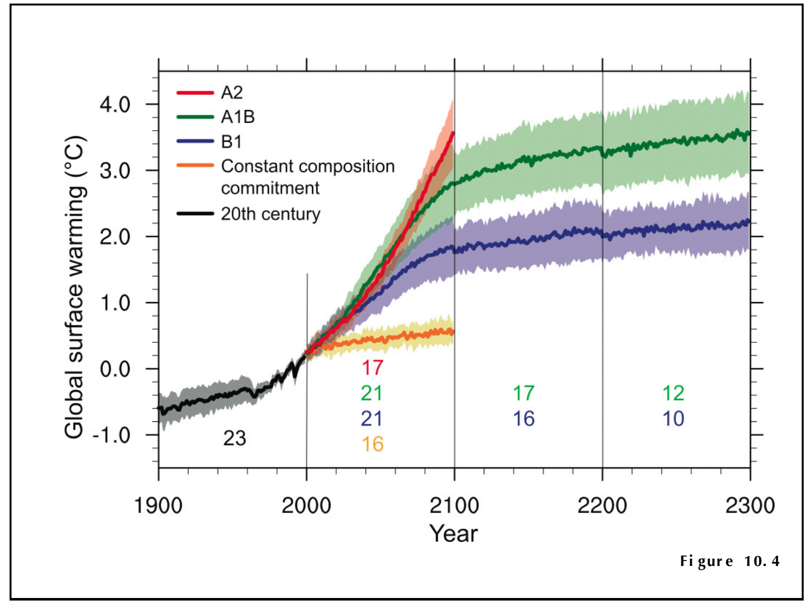
[2]International Center for Ecology, Meteorology, and Environment, NUIST

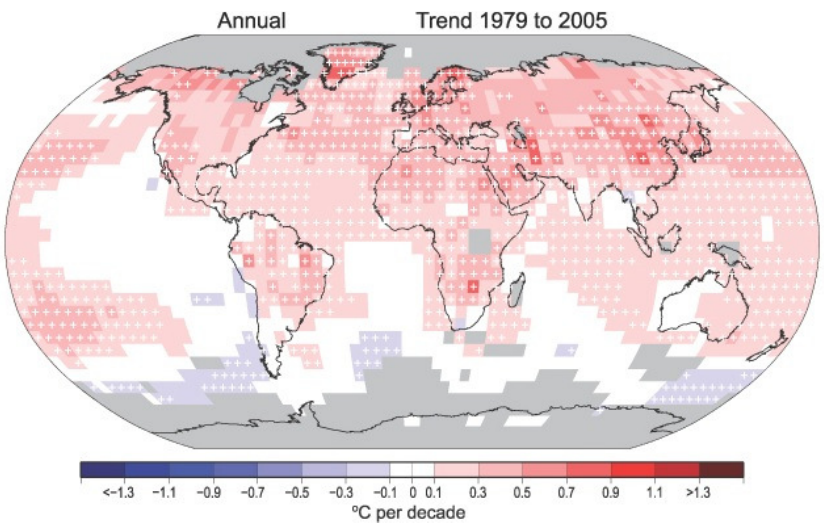
Yale-NUIST Center on Atmospheric Environment

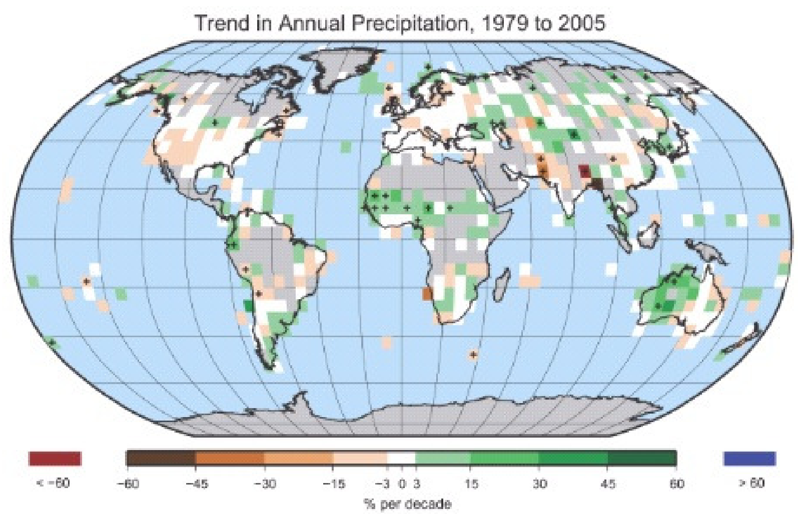
May 23, 2013

Global climate change









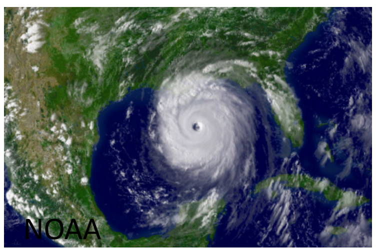
Source: IPCC, AR4, Nov 2007

Consequences

- Drought and wildfire

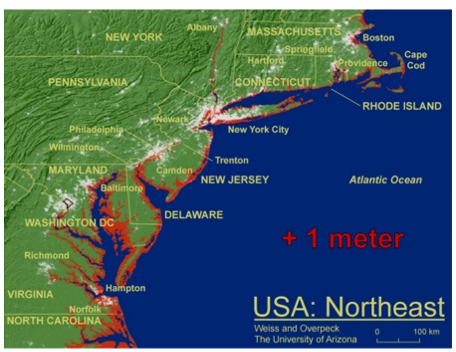

- Heat waves and disease

- Extreme weather events

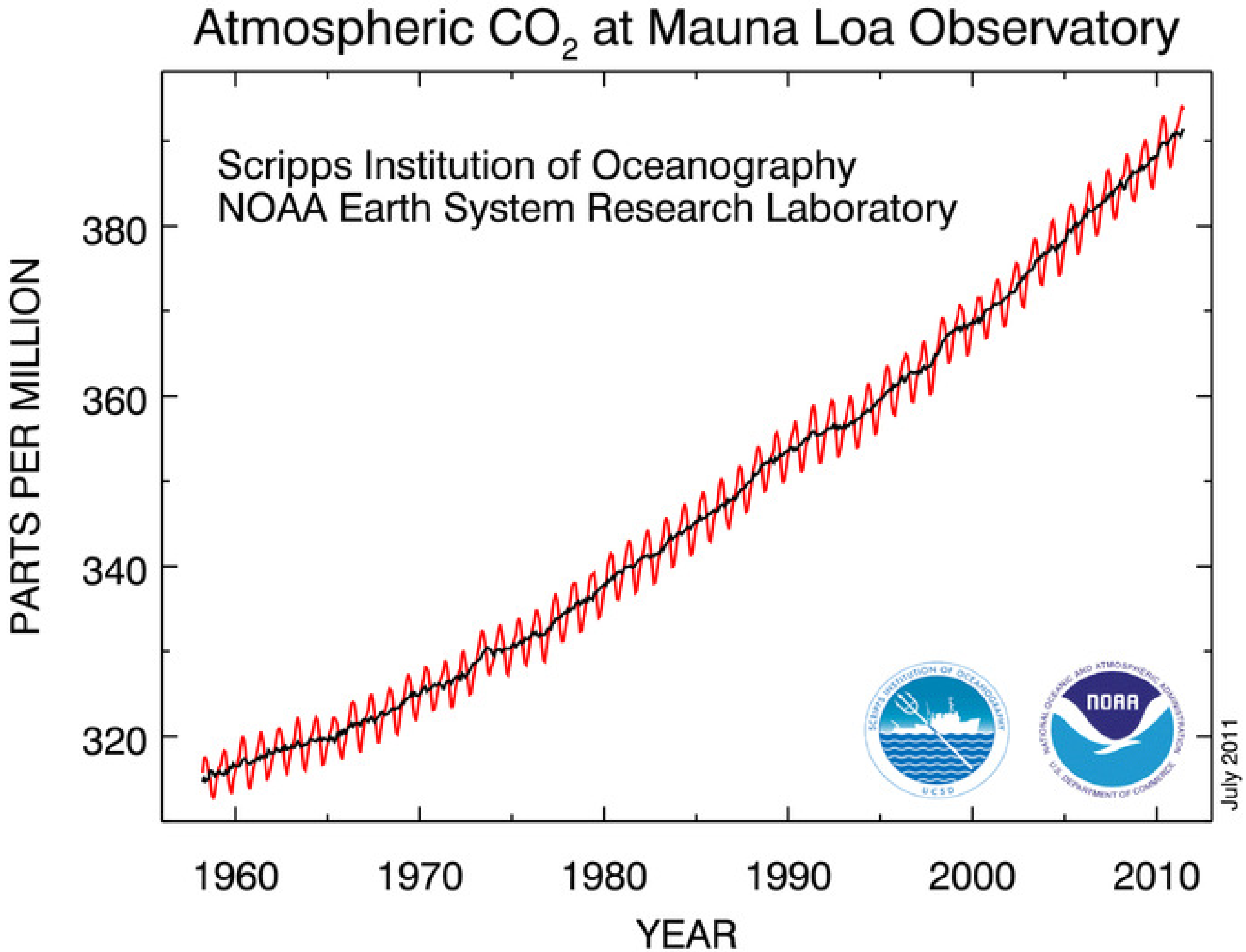


- Melting of ice cap and glacier

- Sea level rise

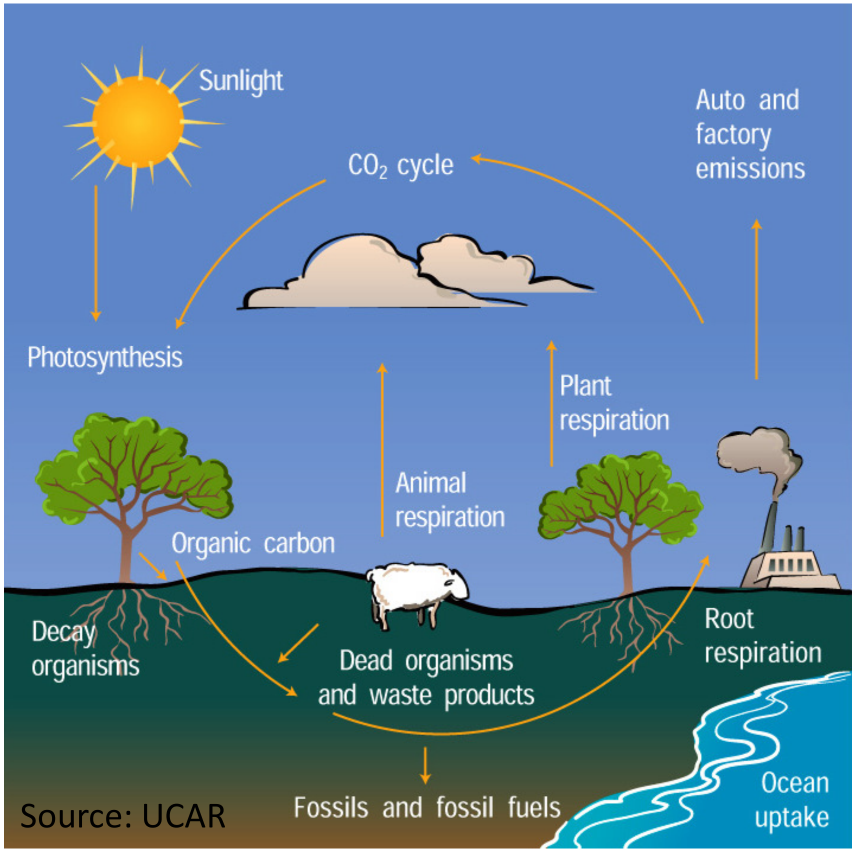


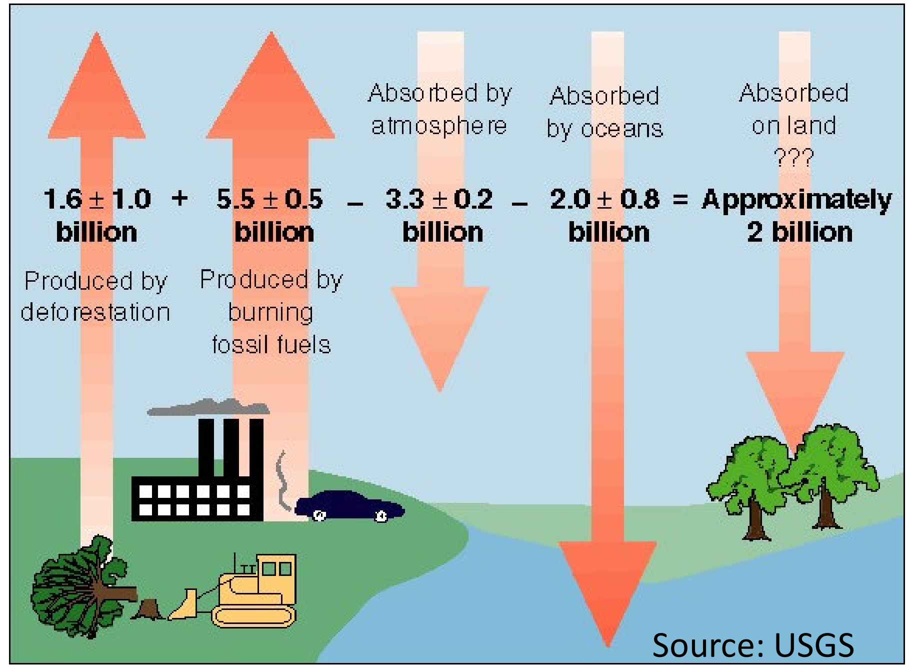
- Ecosystem shifts and species die-off



http://www.esrl.noaa.gov/gmd/ccgg/trends/

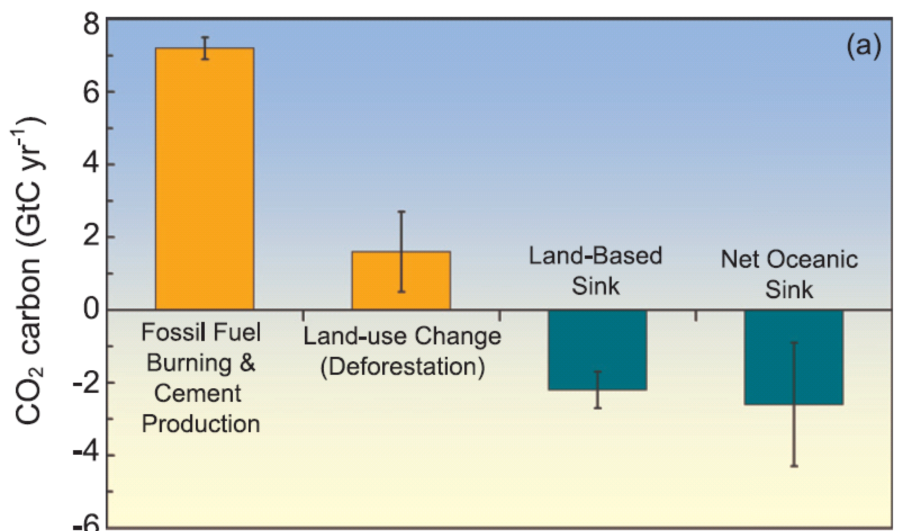
Residual (Missing) carbon sink



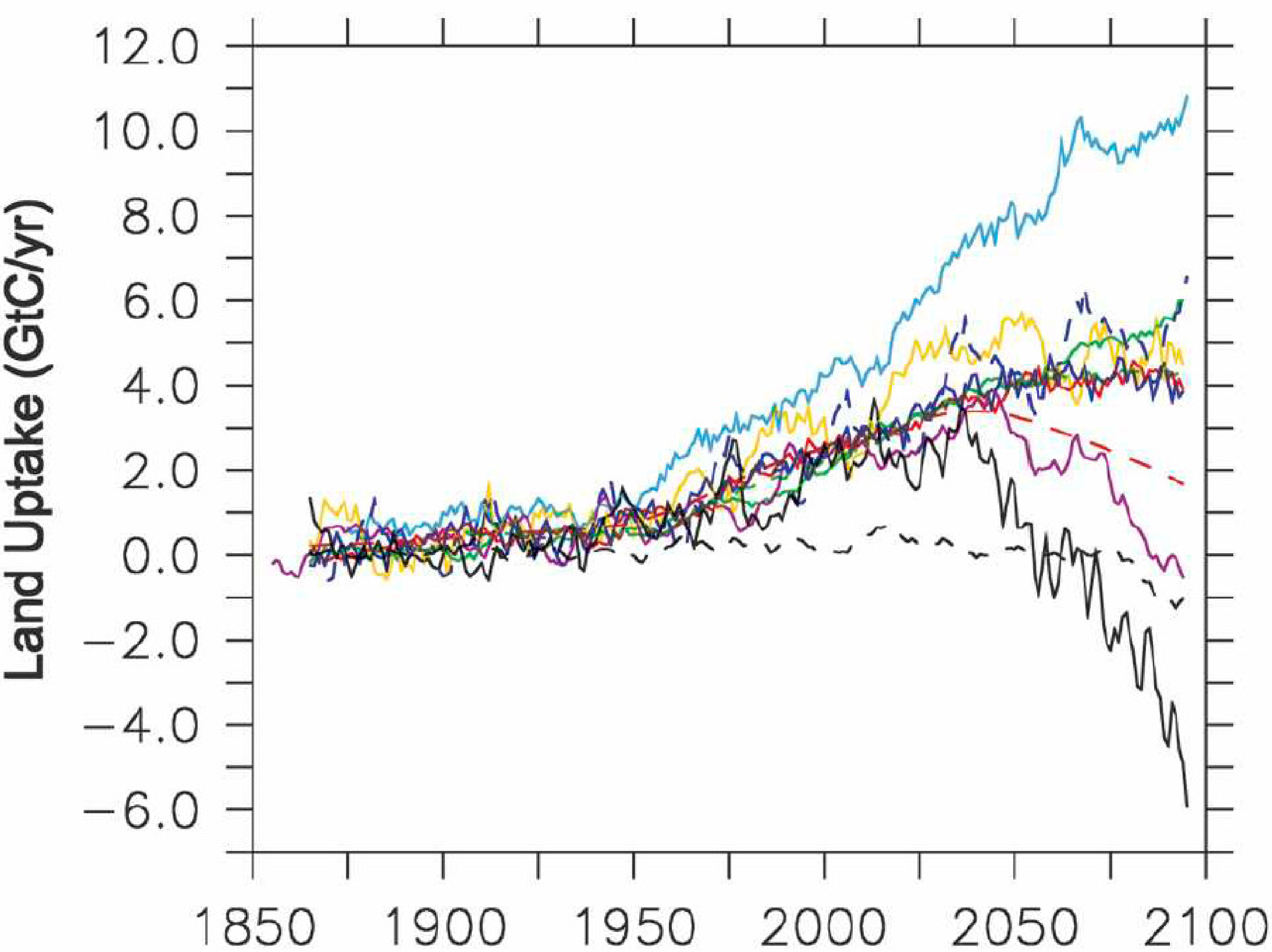


1 Petagrams (Pg) = 1×10^{15} grams

= 1 Gt (1×10^{9} tons) (or 1 billion tons)



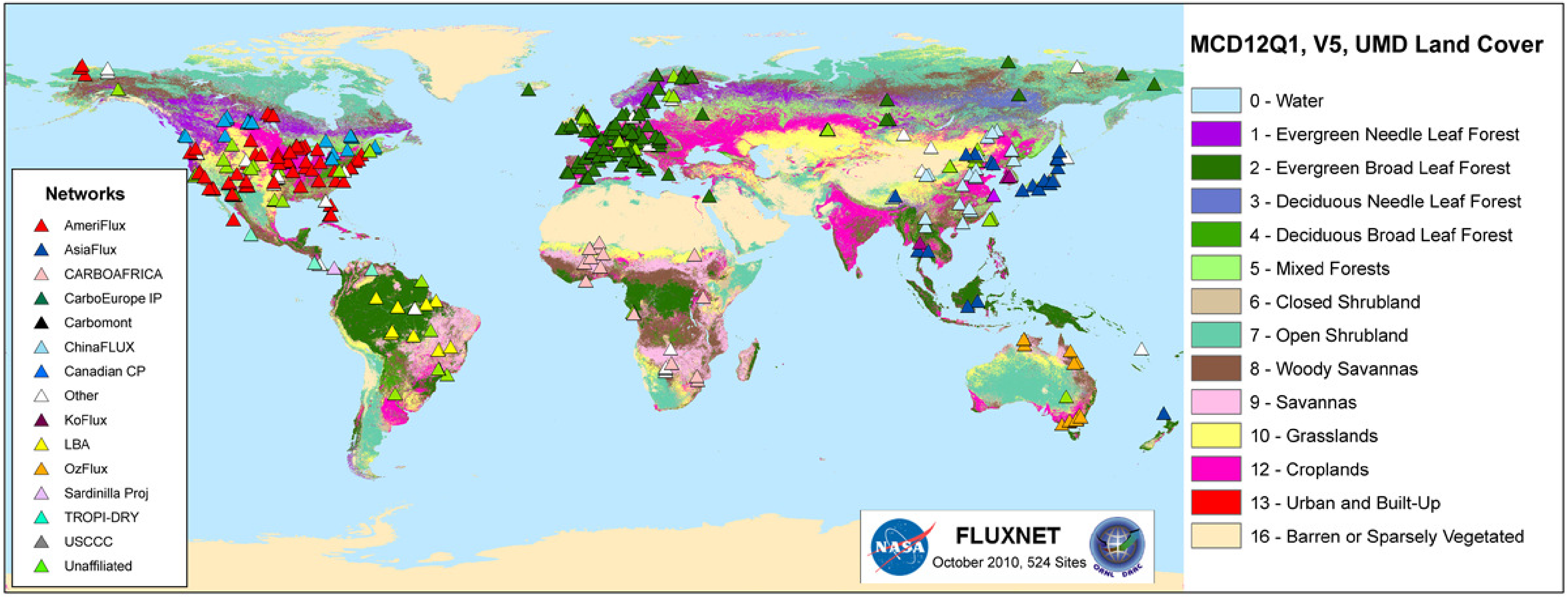
Source: IPCC, AR4, Nov 2007



Friedlingstein et al. 2006

- **Flux observations**
- **Satellite remote sensing**
- **Process-based modeling**

AmeriFlux, other regional flux networks, and FLUXNET

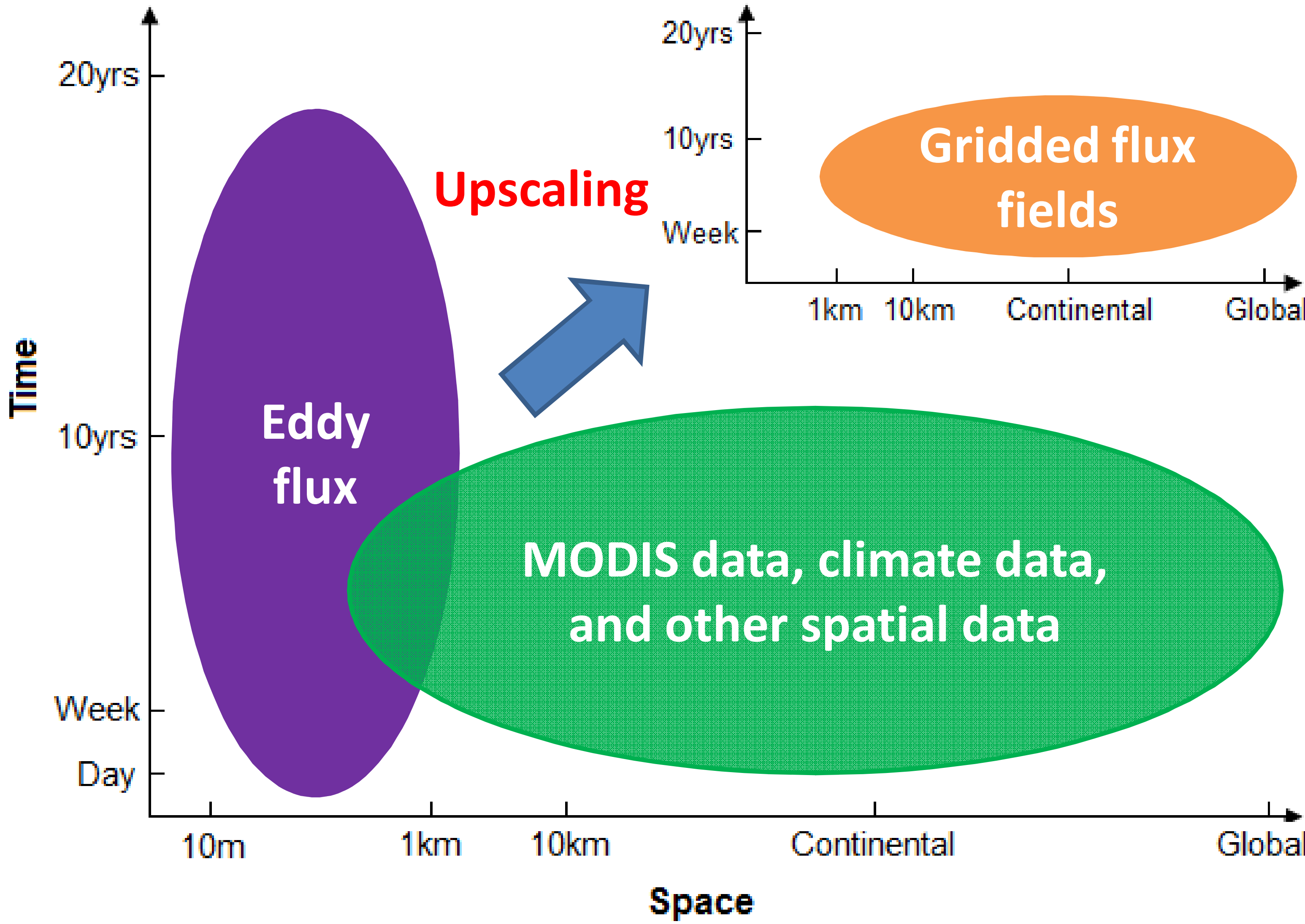


UMBS (MI)

Fort Peck (MT)

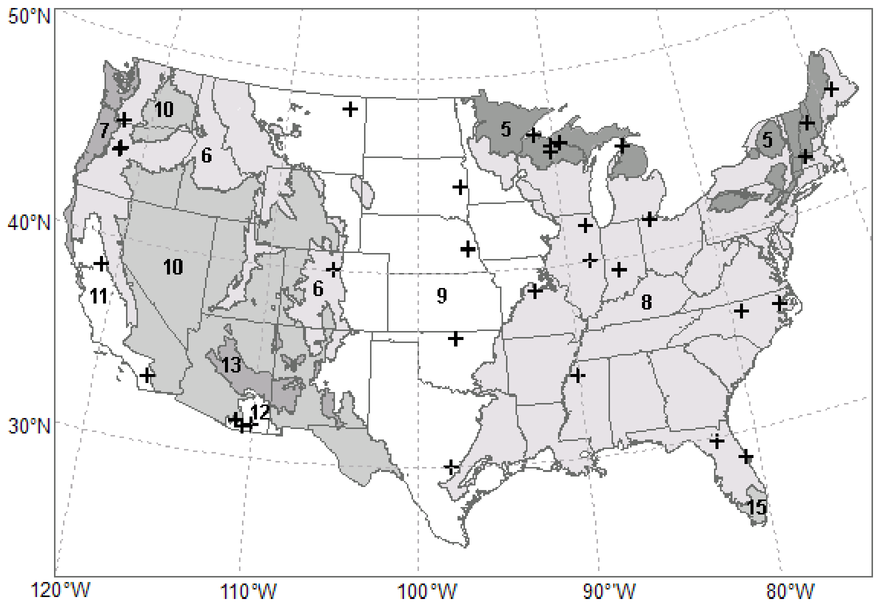
SOO (CA)

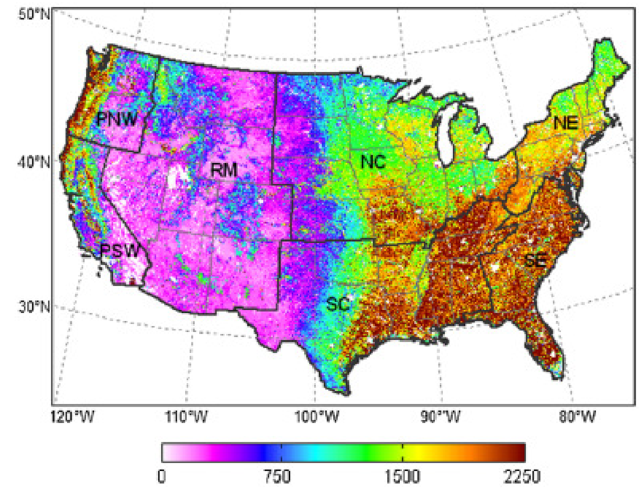
Mead Rotation (NE)

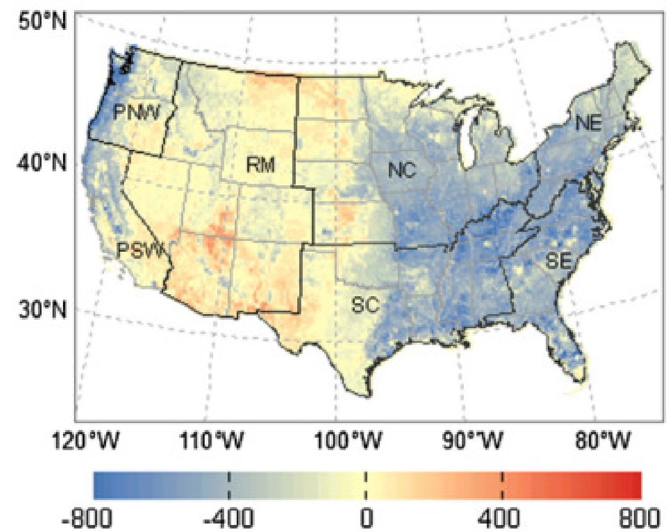


Conceptual framework for upscaling of fluxes from towers to broad regions

Upscaling AmeriFlux data to the national scale







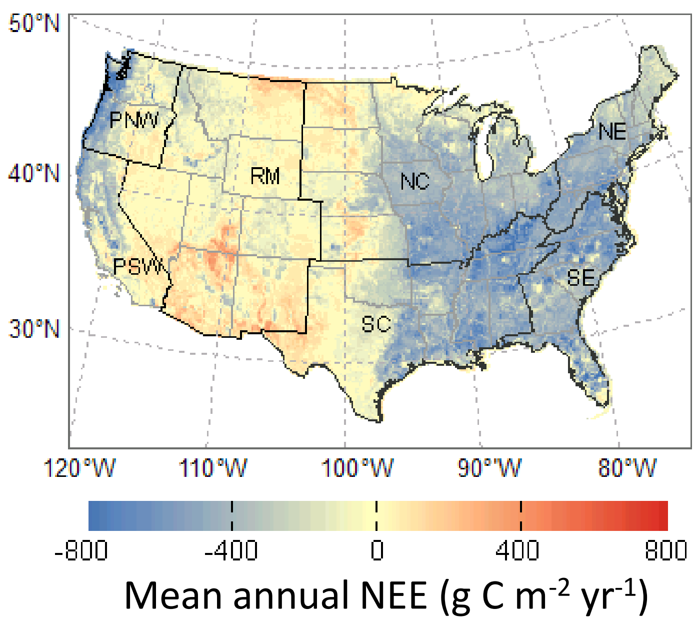
- Observations from 42 towers
- Data-driven approach
- MODIS data streams
- Gridded EC-MOD flux dataset

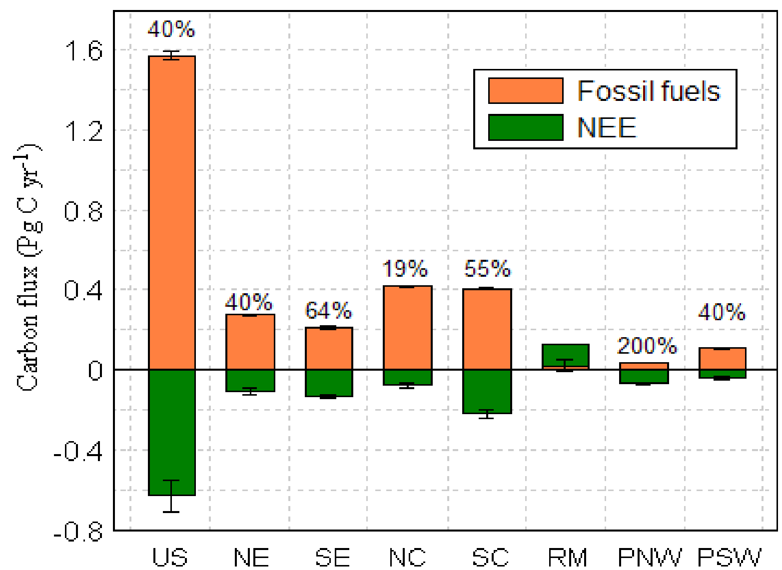
Xiao et al., Agri. For. Met., 2008; Remote Sens. Environ., 2010; Agri. For. Met., 2011

Carbon sinks/sources: an alternative, independent estimate

	Xiao et al.	Pacala et al. 2001	Deng et al. 2007	SOCCR 2007
Carbon sink ($Pg\ C\ yr^{-1}$)	0.63 (0.57)	0.3-0.58	~0.63	0.49

US fire emissions: ~0.06 $Pg\ C\ yr^{-1}$ (Wiedinmyer and Neff, *Carbon Balance Manag., 2007)*





Xiao et al., Agri. For. Met., 2011

Impacts of drought and disturbance

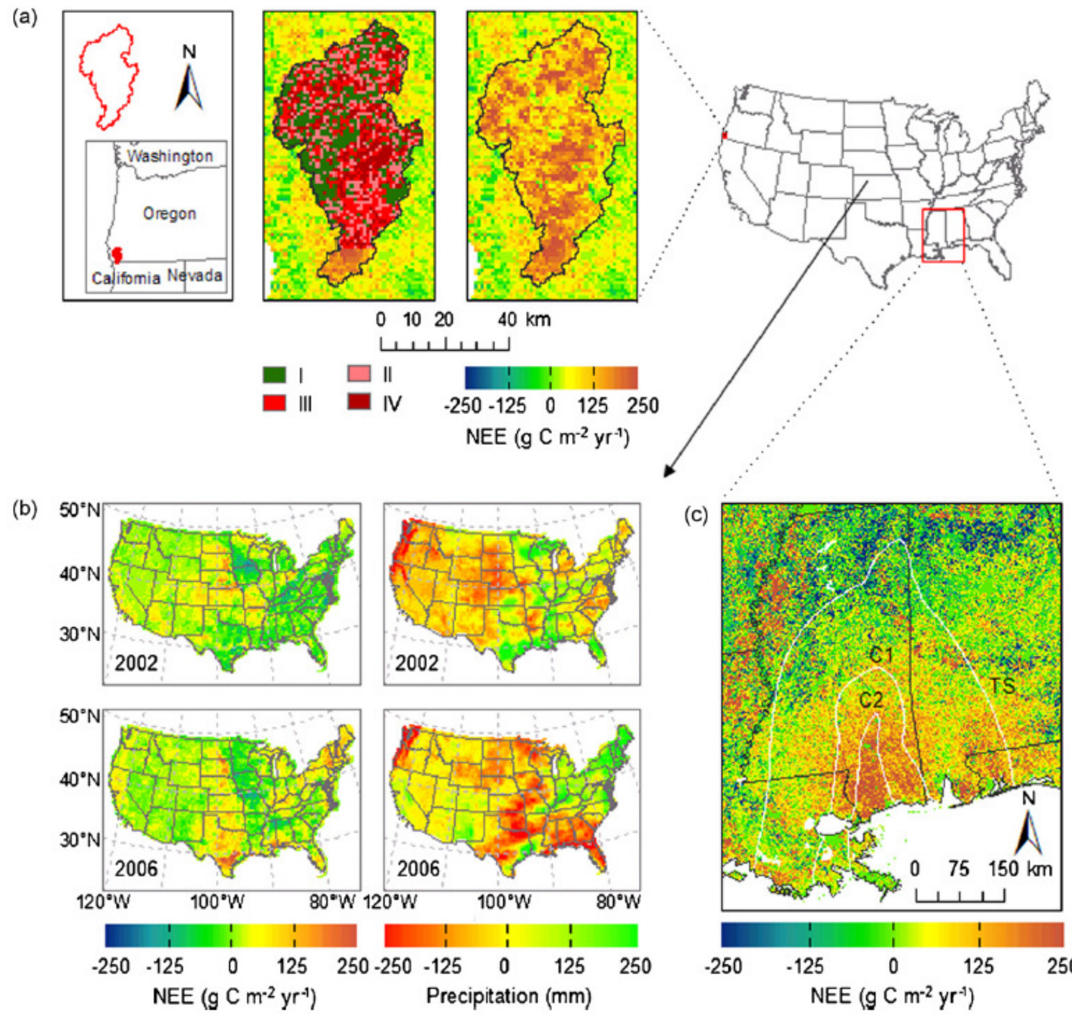
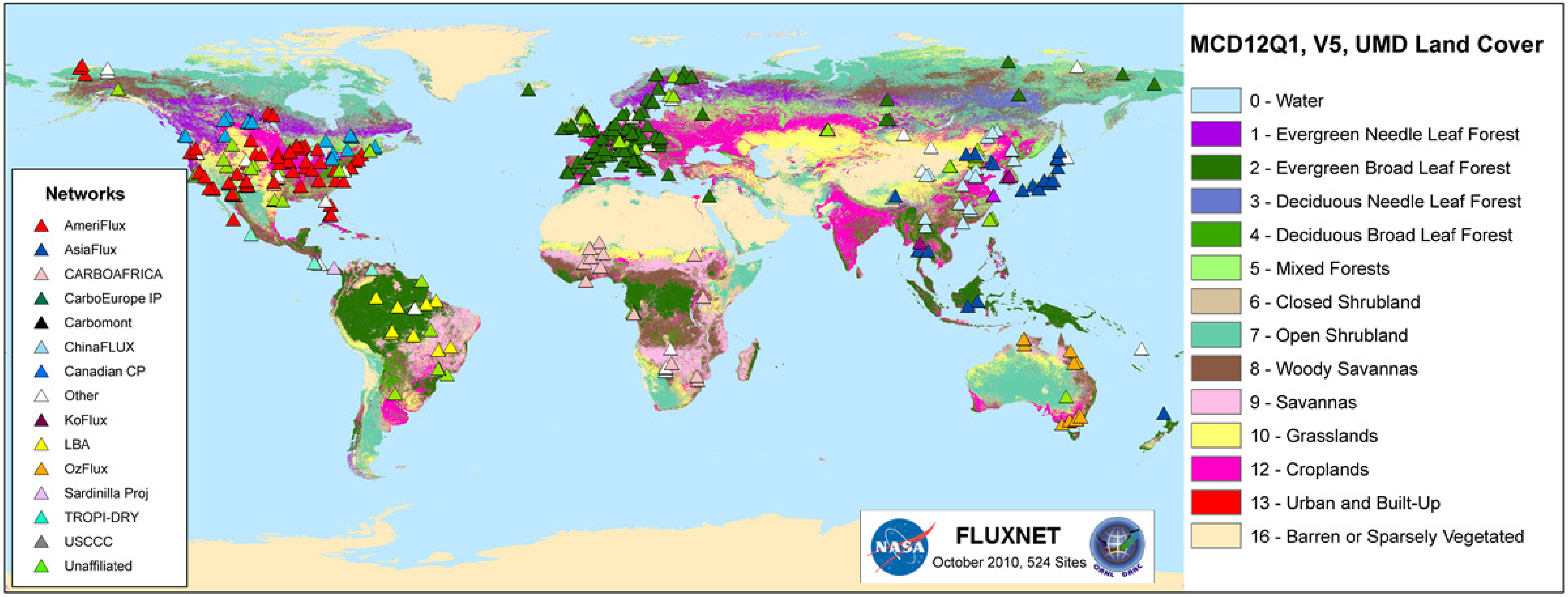


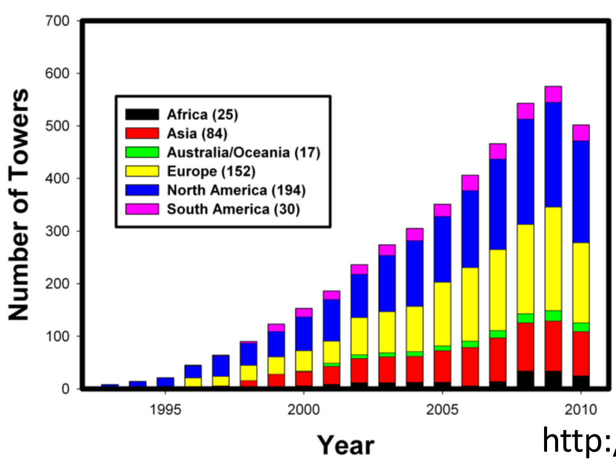
Fig. 9. Effects of extreme climate events and disturbances on annual NEE. (a) Impact of the Biscuit Fire on annual NEE: burned area, fire severity, and anomalies of annual NEE in 2003. Fire severity was based on the difference normalized burn ratio (dNBR) from Landsat Thematic Mapper (TM) data acquired before and immediately after the fire: little or no change (I), green and dead mixed (II), dead trees with needles (III), and dead trees without needles (IV). (b) Anomalies of annual NEE relative to the 6-year period 2001–2006 and anomalies of annual precipitation relative to the 30-year period 1970–1999 taken from the PRISM climate database in 2002 and 2006. (c) Impact of hurricane Katrina on annual NEE in 2006. The white lines indicate the isotachs, including tropical storm, hurricane category 1, and hurricane category 2.

Xiao et al., Agri. For. Met., 2011

AmeriFlux, other regional flux networks, and FLUXNET

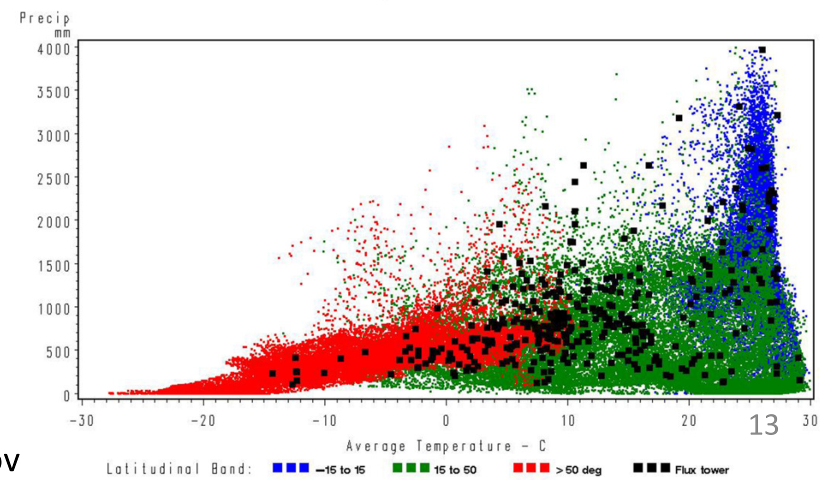


Growth of FLUXNET
502 Towers as of March 1, 2010

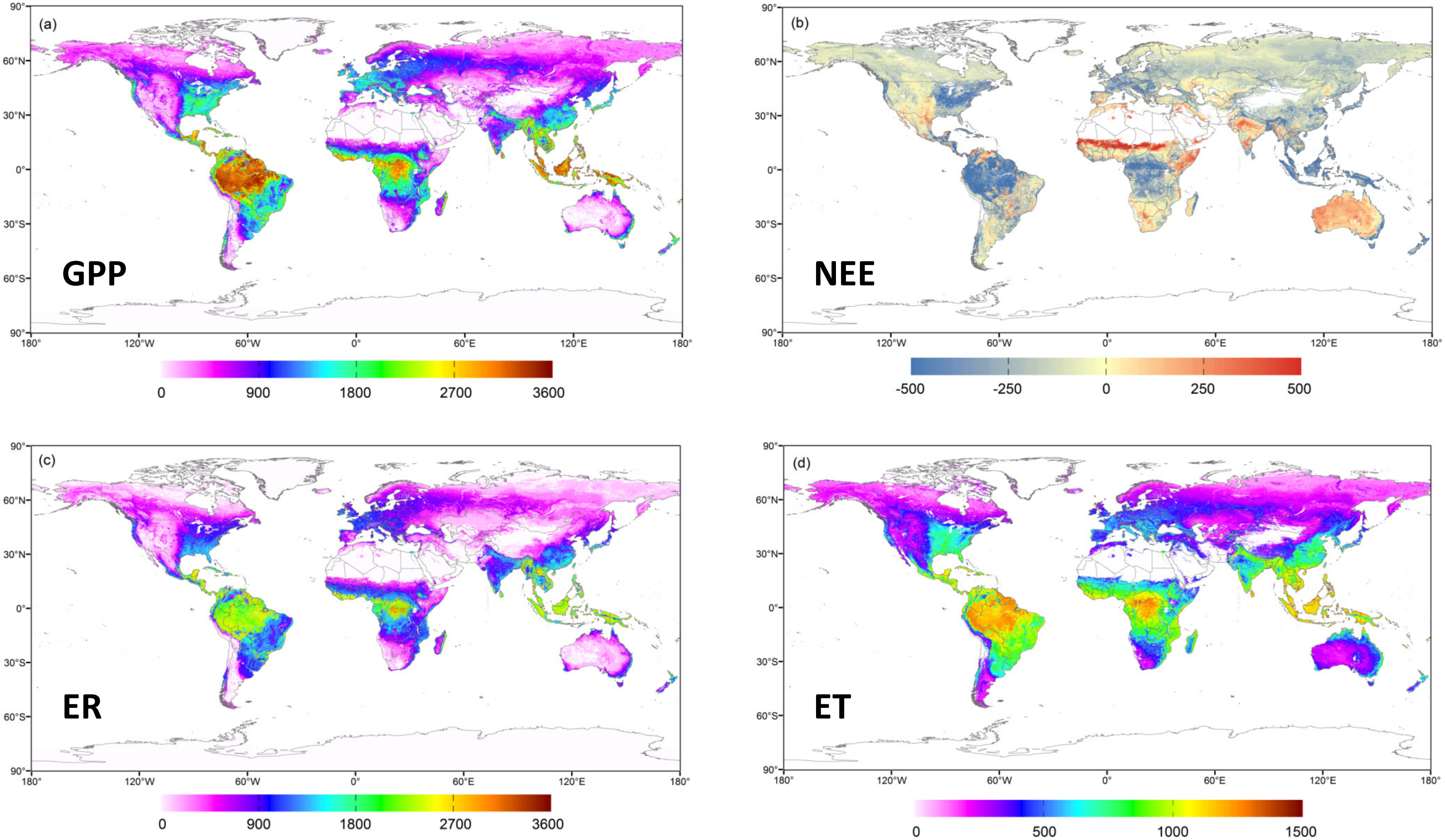


http://www.fluxnet.ornl.gov

Flux Tower Climate Relative to Global Climate (Cramer et al)
April 2009



Global flux fields – EC-MOD (2000-2010)



Mean annual fluxes over the period 2001-2010: (a) GPP; (b) NEE; (c) ER; (d) ET. The units of carbon fluxes are g C m^{-2} yr^{-1}, and the units of ET are mm yr^{-1}.

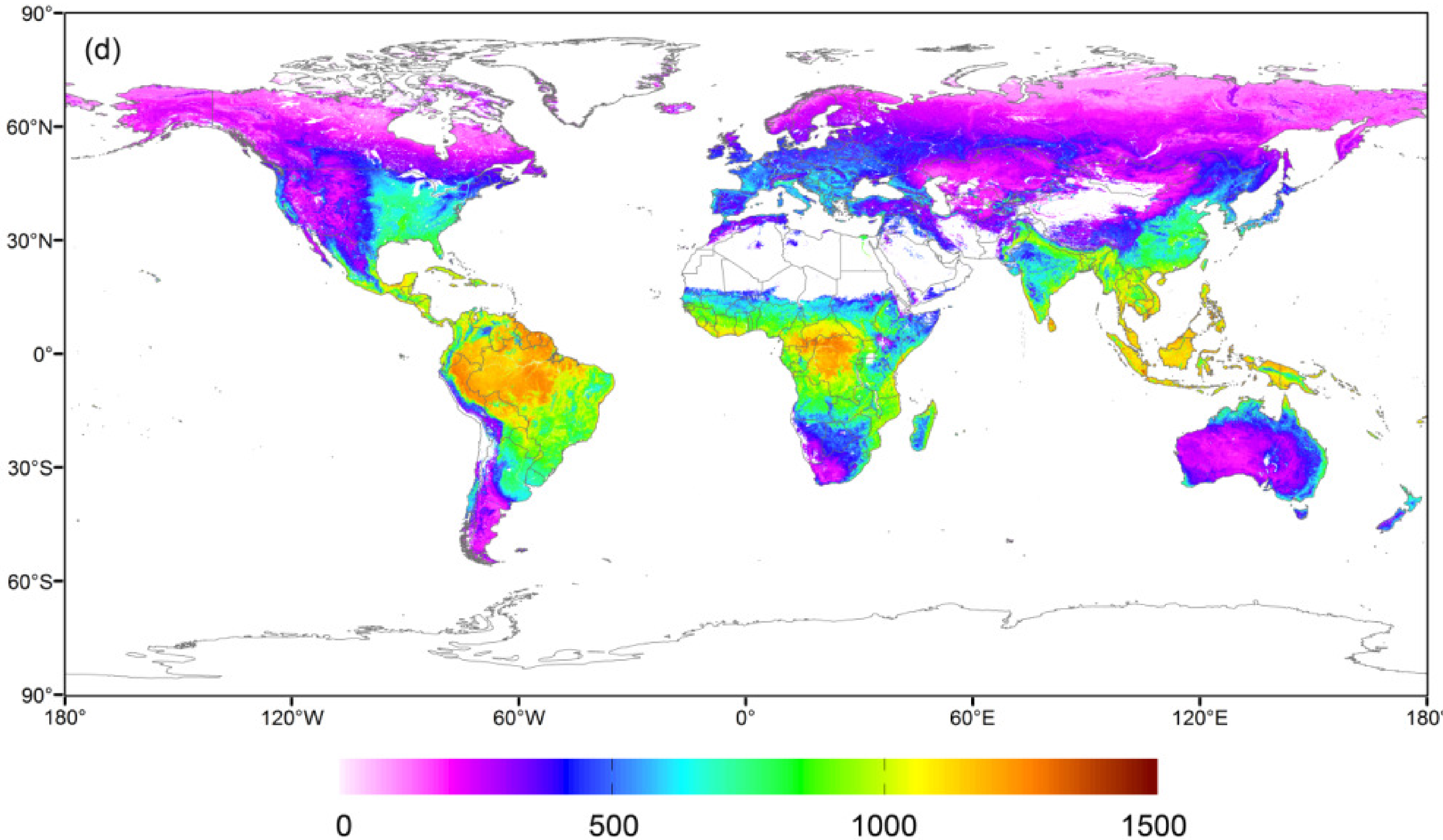
Xiao et al. unpublished

GPP	North America	Eurasia	S. America	Africa	Oceania	Global
Evergreen forests	4.52±0.08	12.69±0.31	22.19±0.65	7.74±0.26	2.29±0.09	49.80±1.33
Deciduous forests	0.92±0.02	1.31±0.04	0.47±0.03	0.16±0.00	0.00±0.00	2.86±0.04
Mixed forests	2.15±0.04	6.17±0.14	0.04±0.00	0.00±0.00	0.00±0.00	8.39±0.14
Shrublands	2.49±0.06	4.12±0.10	0.75±0.05	1.39±0.08	1.11±0.16	9.93±0.32
Savannas	1.31±0.03	2.53±0.08	7.79±0.33	13.89±0.62	1.15±0.10	26.69±1.06
Grasslands	1.09±0.08	2.85±0.09	1.12±0.09	1.09±0.06	0.08±0.01	6.24±0.16
Croplands	4.47±0.11	12.90±0.37	1.68±0.09	0.93±0.04	0.33±0.06	20.34±0.43
Total	16.96±0.30	42.58±0.80	34.04±1.14	25.20±0.95	4.96±0.34	124.25±2.86

NEE	North America	Eurasia	S. America	Africa	Oceania	Global
Evergreen forests	-0.65±0.06	-1.67±0.16	-3.78±0.57	-1.10±0.11	-0.50±0.03	-7.75±0.79
Deciduous forests	-0.24±0.02	-0.43±0.03	-0.08±0.02	-0.03±0.00	0.00±0.00	-0.78±0.03
Mixed forests	-0.36±0.02	-0.93±0.05	-0.01±0.00	0.00±0.00	0.00±0.00	-1.30±0.06
Shrublands	-0.51±0.03	-0.83±0.05	-0.17±0.02	0.59±0.03	0.84±0.06	-0.09±0.12
Savannas	-0.12±0.01	-0.26±0.01	-0.31±0.12	-1.07±0.07	-0.06±0.02	-1.82±0.17
Grasslands	-0.02±0.03	-0.73±0.05	-0.04±0.02	0.71±0.03	0.004±0.003	-0.08±0.05
Croplands	-0.86±0.05	-1.81±0.15	-0.15±0.04	0.13±0.03	0.07±0.02	-2.62±0.17
Total	-2.77±0.14	-6.66±0.18	-4.54±0.70	-0.77±0.12	0.36±0.09	-14.44±0.81

ER	North America	Eurasia	S.America	Africa	Oceania	Global
Evergreen forests	3.79±0.07	10.61±0.30	17.08±0.65	6.76±0.23	1.80±0.06	40.34±1.22
Deciduous forests	0.66±0.01	0.87±0.02	0.42±0.02	0.14±0.00	0.00±0.00	2.08±0.04
Mixed forests	1.64±0.02	4.75±0.11	0.04±0.00	0.00±0.00	0.00±0.00	6.45±0.12
Shrublands	1.42±0.05	2.36±0.06	0.47±0.03	1.41±0.07	1.18±0.14	6.90±0.26
Savannas	1.01±0.03	1.91±0.06	5.98±0.23	10.95±0.46	0.93±0.08	20.80±0.77
Grasslands	0.91±0.06	1.88±0.04	0.99±0.07	0.99±0.04	0.07±0.01	4.83±0.13
Croplands	3.16±0.07	10.57±0.27	1.46±0.06	0.95±0.03	0.34±0.04	16.50±0.36
Total	12.59±0.23	32.95±0.73	26.44±0.96	21.21±0.76	4.32±0.26	97.91±2.58

Mean annual ET (mm yr^{-1}, 2001-2010)



ET (km^3 yr^{-1})

	North America	Eurasia	South America	Africa	Oceania	Global
Evergreen forests	1,805±29.3	4,801±117.8	8,484±273.1	3,226±106.9	826±34.4	19,268±533.0
Deciduous forests	339±12.7	526±19.0	268±15.3	82±2.4	0.2±0.01	1,217±28.2
Mixed forests	776±13.8	2,303±20.8	15±1.0	1.0±0.04	0.1±0.00	3,103±28.0
Shrublands	1,602±39.1	2,700±39.8	746±36.2	1,739±64.2	1,926±143.0	8,746±255.4
Savannas	695±11.6	1,294±32.0	4,275±153.0	8,416±292.4	739±45.2	15,436±482.9
Grasslands	819±39.0	1,946±34.9	654±37.2	1,073±27.1	54±5.3	4,548±84.4
Croplands	2,201±39.1	7,428±154.7	1,025±37.7	585±15.9	213±20.5	11,464±201.1
Total	8,240±141.1	20,999±331.0	15,466±534.6	15,121±487.9	3,758±219.6	63,782±1,477.0

ET ($\times 10^3$ km^3 yr^{-1})

Study	ET	Period	Resolution	Method
This study	63.8	2001-2010	5km	Data-driven
Mu et al. (2011)	62.8	2000-2006	1km	LUE
Ryu et al. (*)	63.0	2001-2003	5km	
Jung et al. (2010)	65.0	1982-2008	0.5 degree	Data-driven
Oki and Kanae (2006)	65.5			
Trenberth et al. (2007)	72.6	1979-2000		

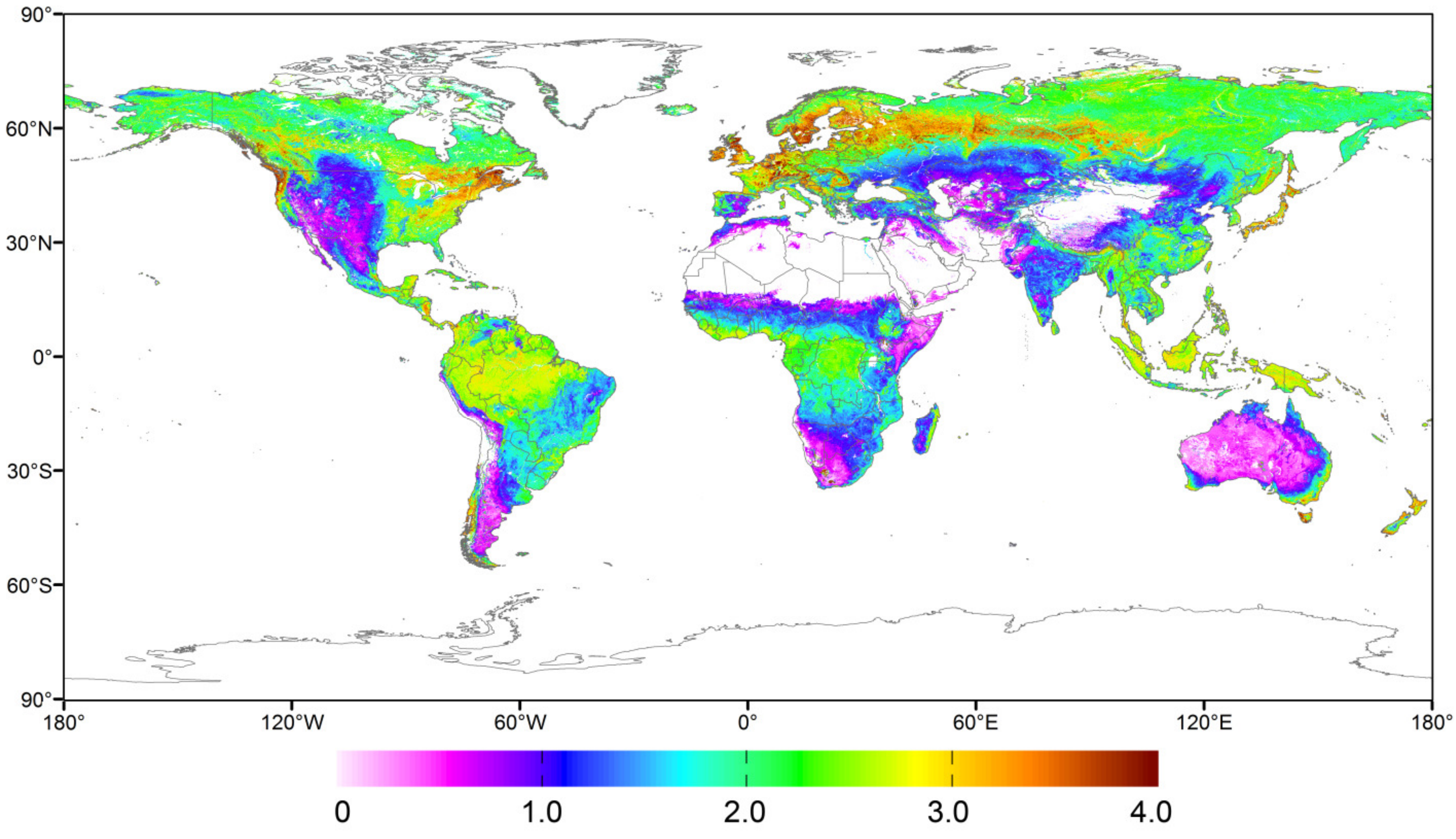
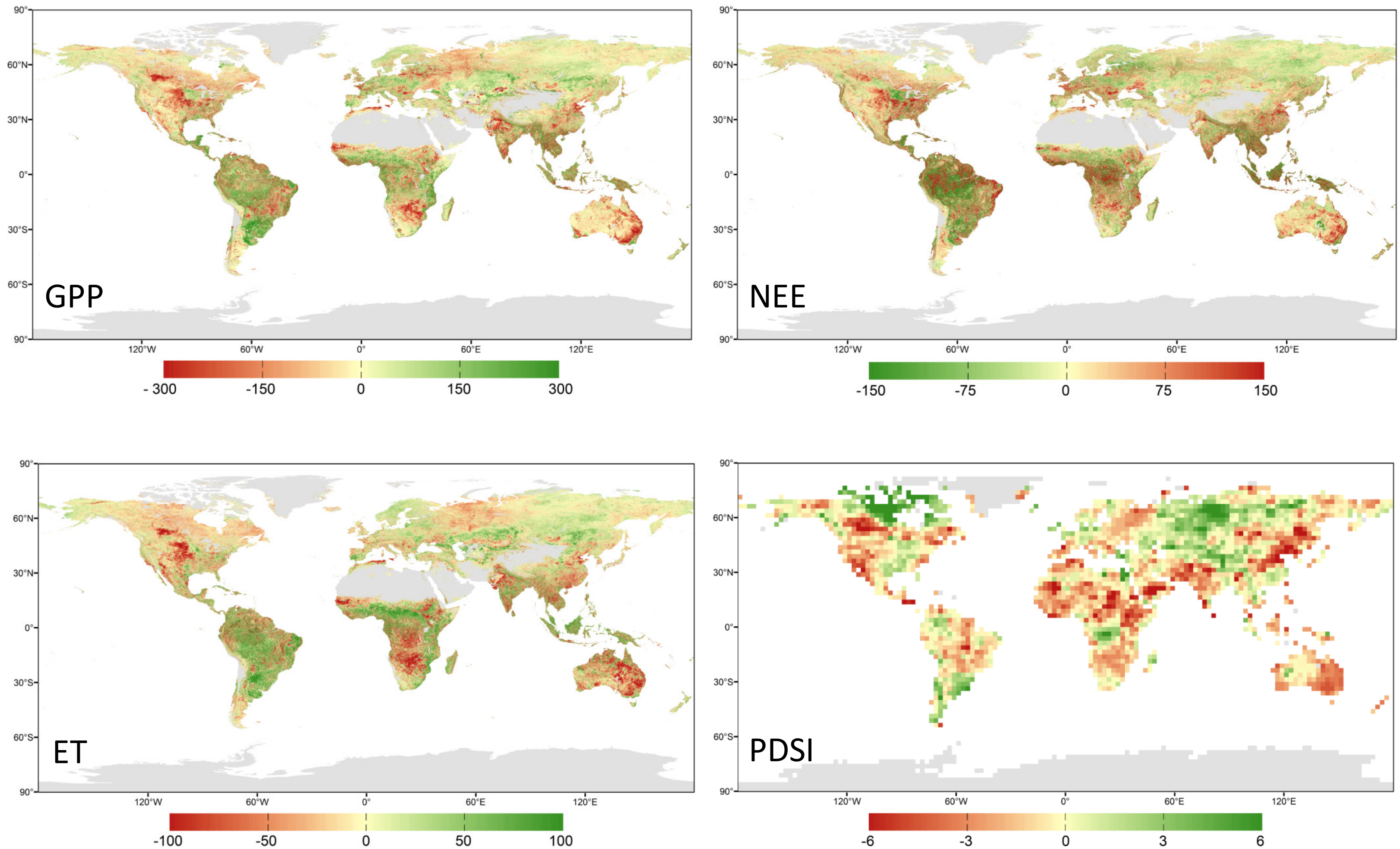


Figure 8. Mean annual **water use efficiency** over the period 2001-2010. The units are g C / kg H_2O.

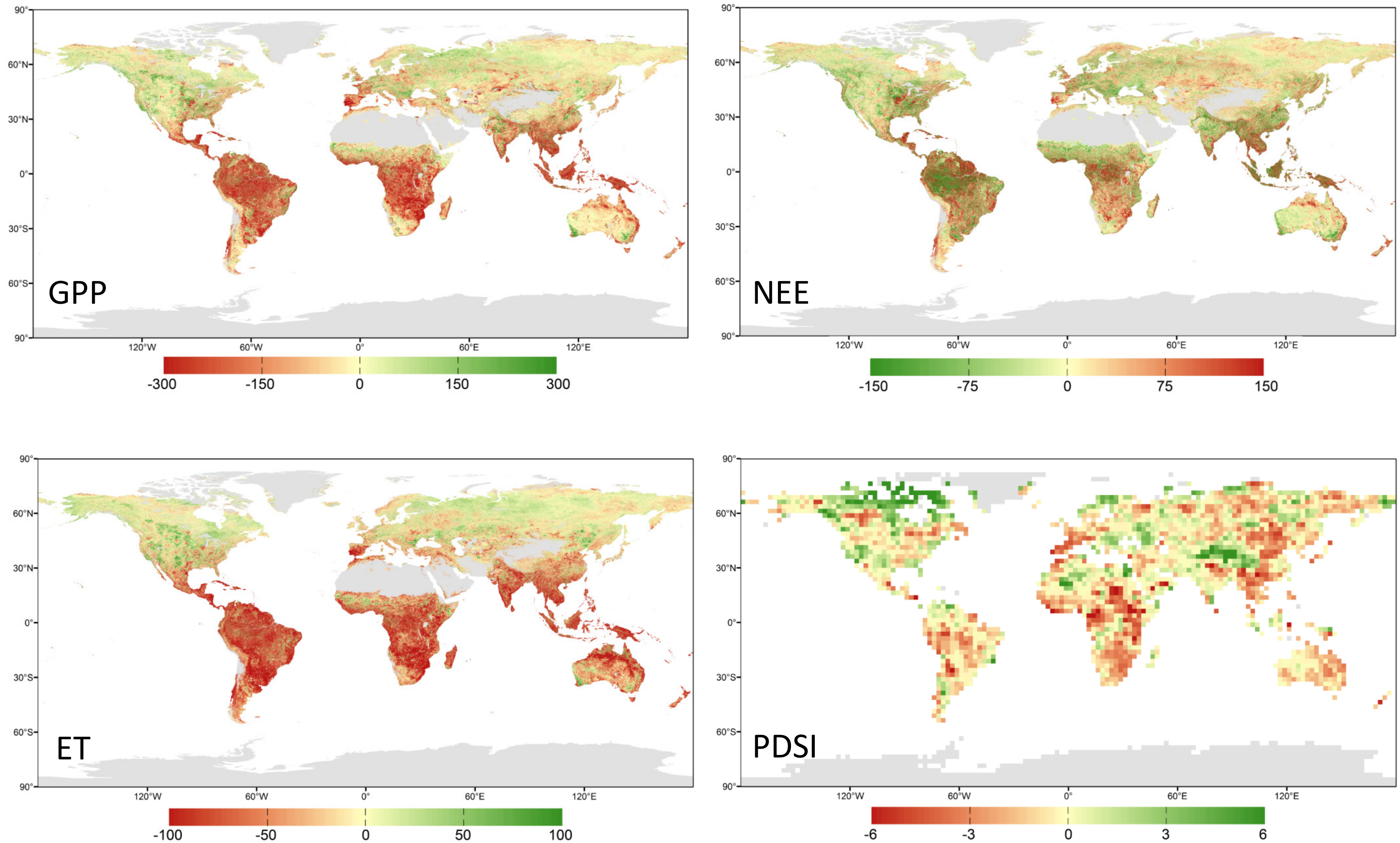
Xiao et al. unpublished

2002



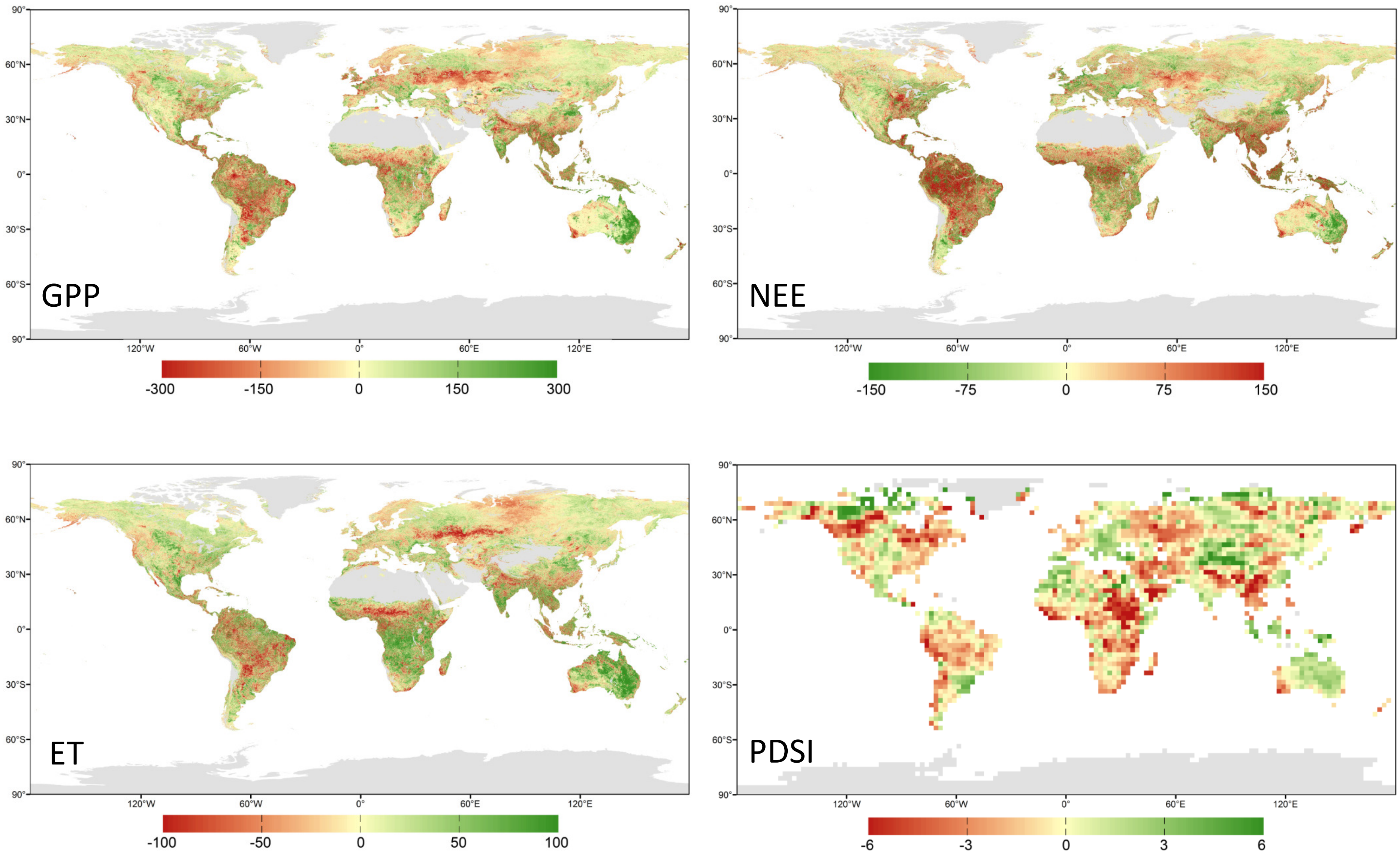
Xiao et al. unpublished

2005

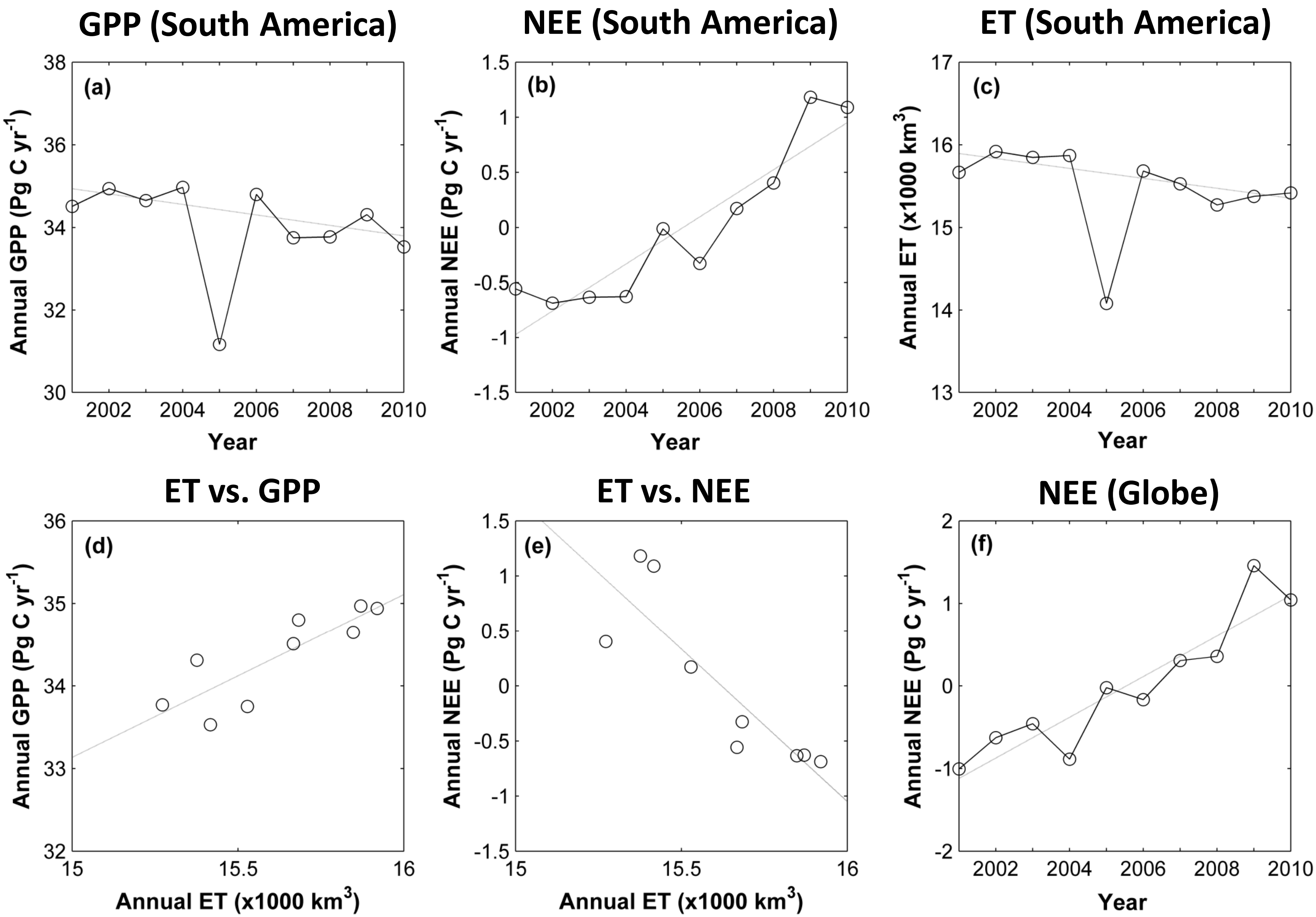


Xiao et al. unpublished

2010



Xiao et al. unpublished



Xiao et al. unpublished

- **Flux observations**
- **Satellite remote sensing**
- **Process-based modeling**

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Environ. Res. Lett. 7 (2012) 045706 (10pp) doi:10.1088/1748-9326/7/4/045706

The 2010 spring drought reduced primary productivity in southwestern China

Li Zhang[1,2], Jingfeng Xiao[3], Jing Li[1], Kun Wang[2], Liping Lei[2] and Huadong Guo[2]

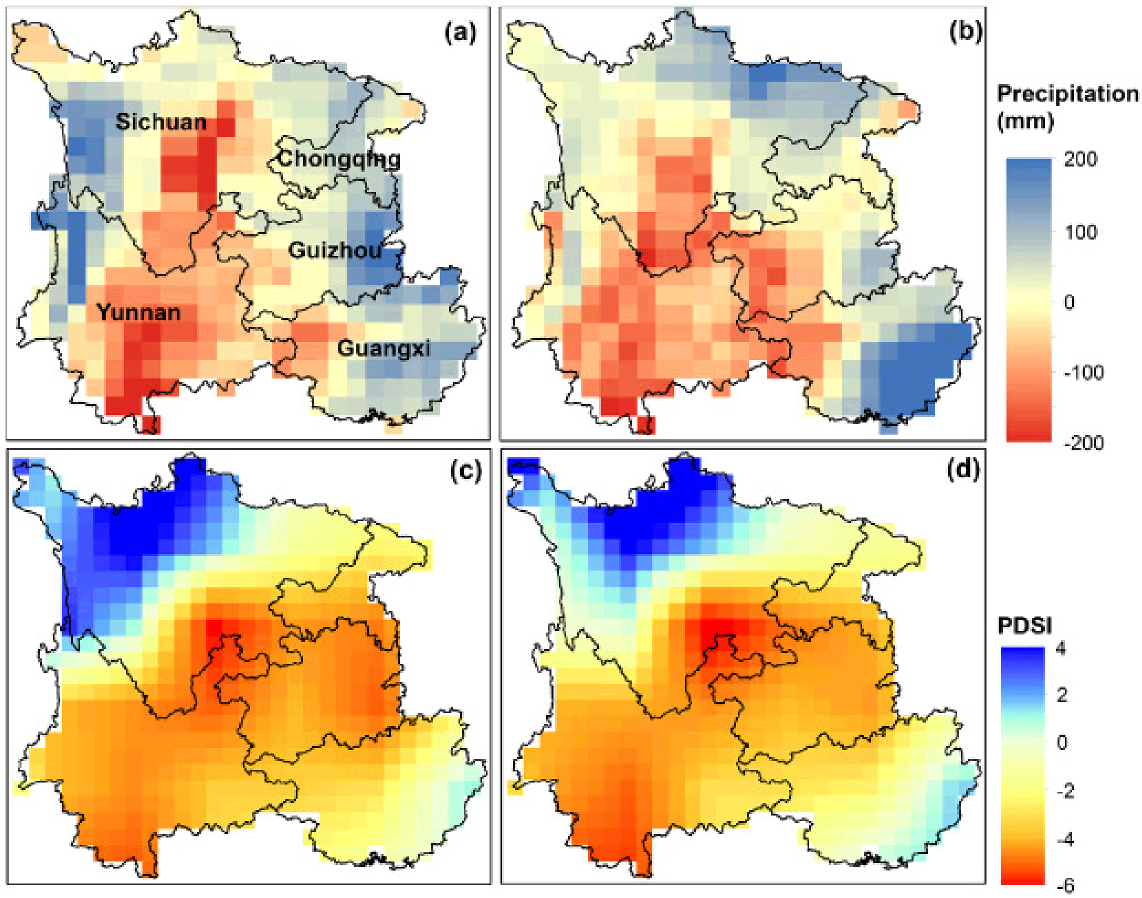


Figure 3. Spatial extent and severity of the 2010 spring drought in southwestern China. (a) Precipitation anomalies for spring (March–May) 2010 relative to the mean over the period 1980–2009, (b) precipitation anomalies for September 2009–May 2010 relative to the mean over the period 1980–2009, (c) mean monthly PDSI for spring (March–May) 2010, (d) mean monthly PDSI for September 2009–May 2010.

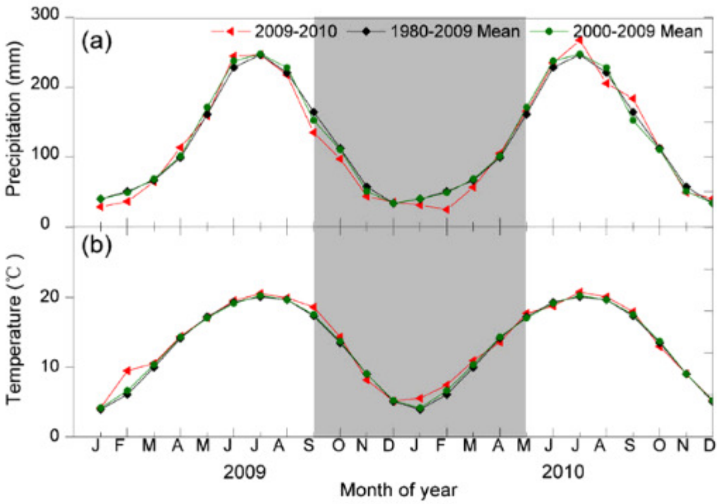


Figure 2. Monthly air temperature and precipitation averaged over southwestern China: (a) monthly total precipitation (mm), (b) monthly mean temperature (°C). The 2010 spring drought can be tracked back to September 2009. The shaded area indicates the entire dry period from September 2009 to May 2010 including the 2010 spring drought event.

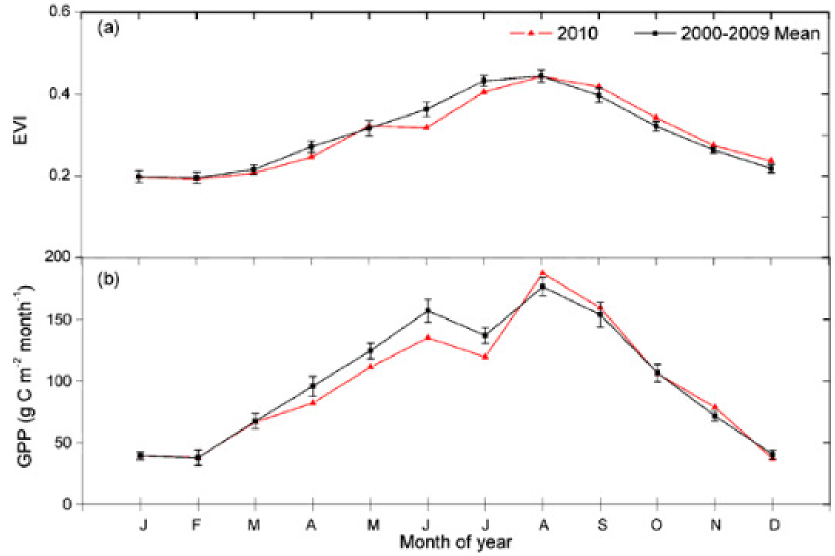


Figure 4. Intra-annual variations of (a) EVI and (b) GPP for 2010 together with the means for 2000–2009. For the 2000–2009 mean, the error bars denote mean ± standard error.

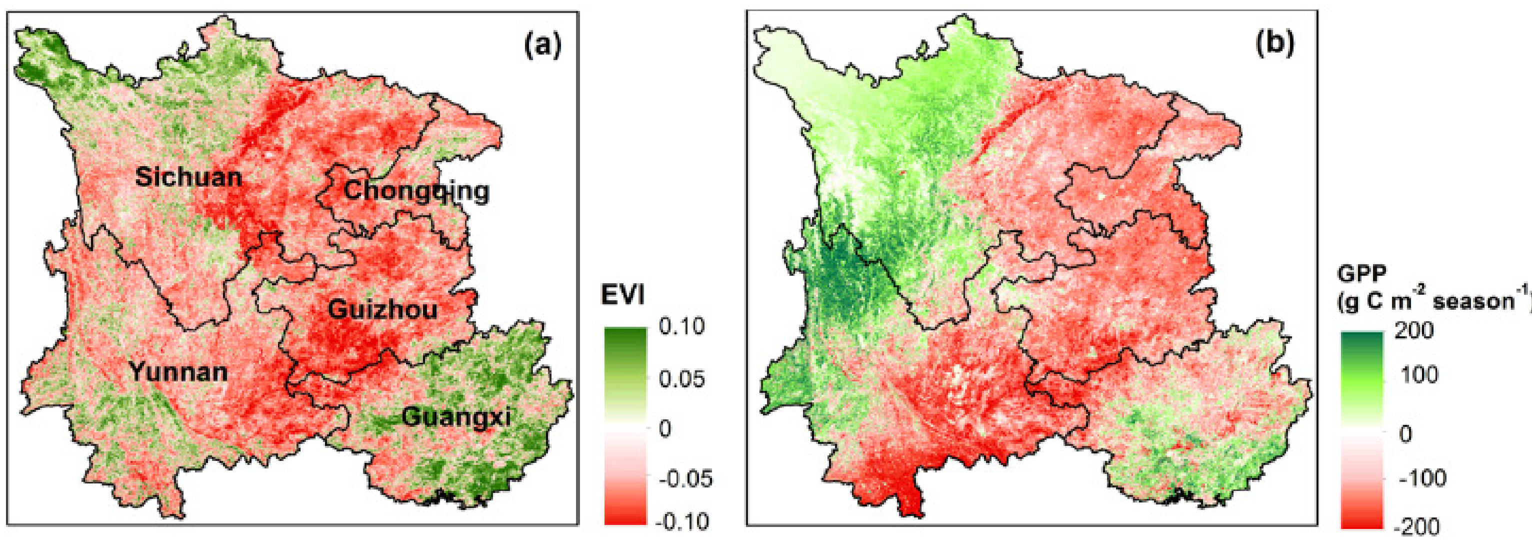


Figure 6. Regional anomalies of (a) EVI and (b) GPP during spring (March–May) 2010 relative to the means over the period 2000–2009.

Zhang et al., ERL, 2012

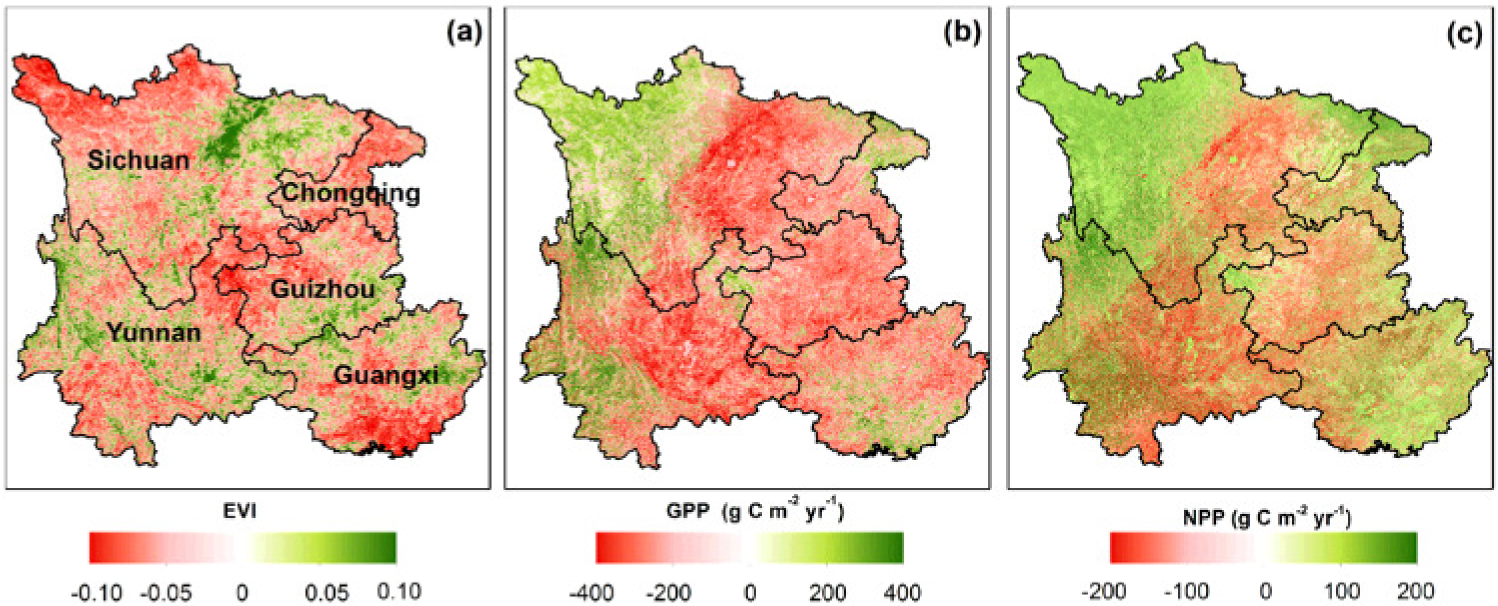


Figure 7. Regional anomalies of annual (a) EVI, (b) GPP and (c) NPP in 2010 relative to the means over the period 2000–2009.

Zhang et al., ERL, 2012

- **Flux observations**
- **Satellite remote sensing**
- **Process-based modeling**

Twentieth-Century Droughts and Their Impacts on Terrestrial Carbon Cycling in China

Earth Interactions • Volume 13 (2009) • Paper No. 10 • Page 8

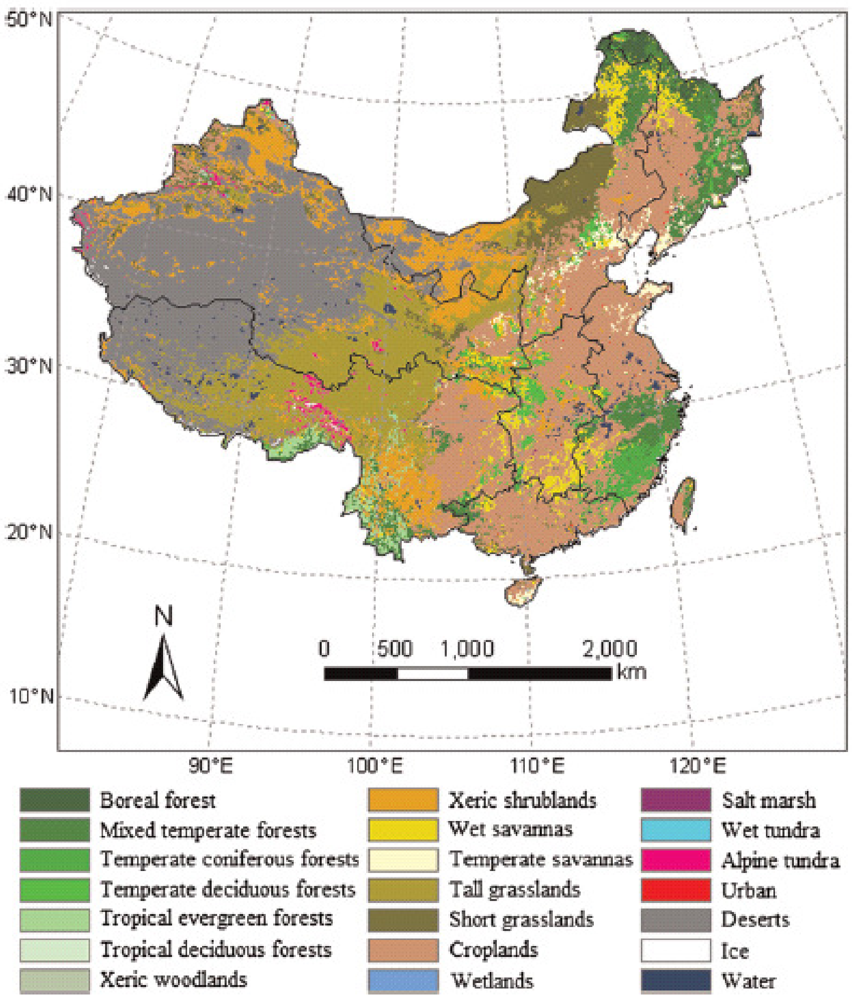


Figure 2. Land-cover map of China (8 km × 8 km) used in the TEM simulations. The map was reclassified and reaggregated from the IGBP DISCover Database (Belward et al. 1999; Loveland et al. 2000).

- A process-based biogeochemical model, the Terrestrial Ecosystem Model (TEM) (Raich et al. 1991; Melillo et al. 1993; McGuire et al. 2001; Zhuang et al. 2003)
- TEM is a global biogeochemistry model that simulates the cycling of carbon, nitrogen, and water among vegetation, soils, and the atmosphere at monthly time steps.

Xiao et al., Earth Interactions, 2009

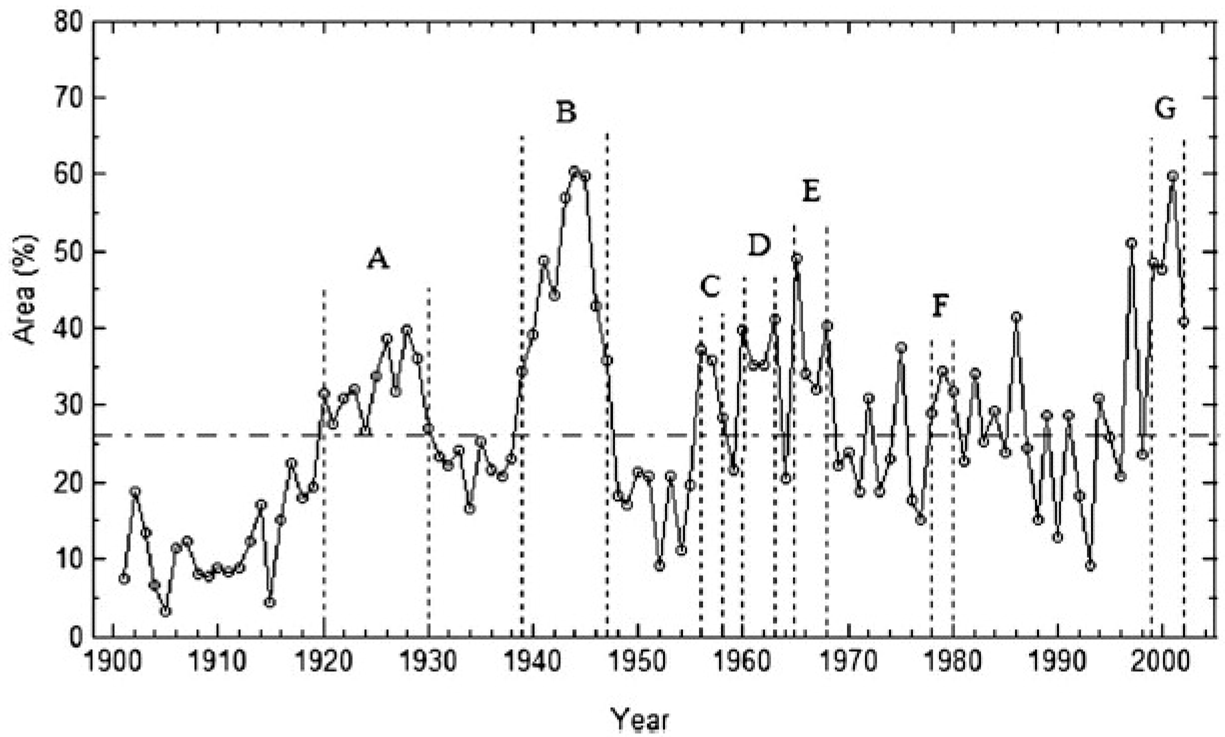


Figure 5. Severe extended drought periods identified using the percentage area experiencing drought (PDSI < −1.0) across the country: 1920–30 (A), 1939–47 (B), 1956–58 (C), 1960–63 (D), 1965–68 (E), 1978–80 (F), and 1999–2002 (G). The horizontal line stands for the average percentage area experiencing drought (PDSI < −1.0) over the study period (1901–2002).

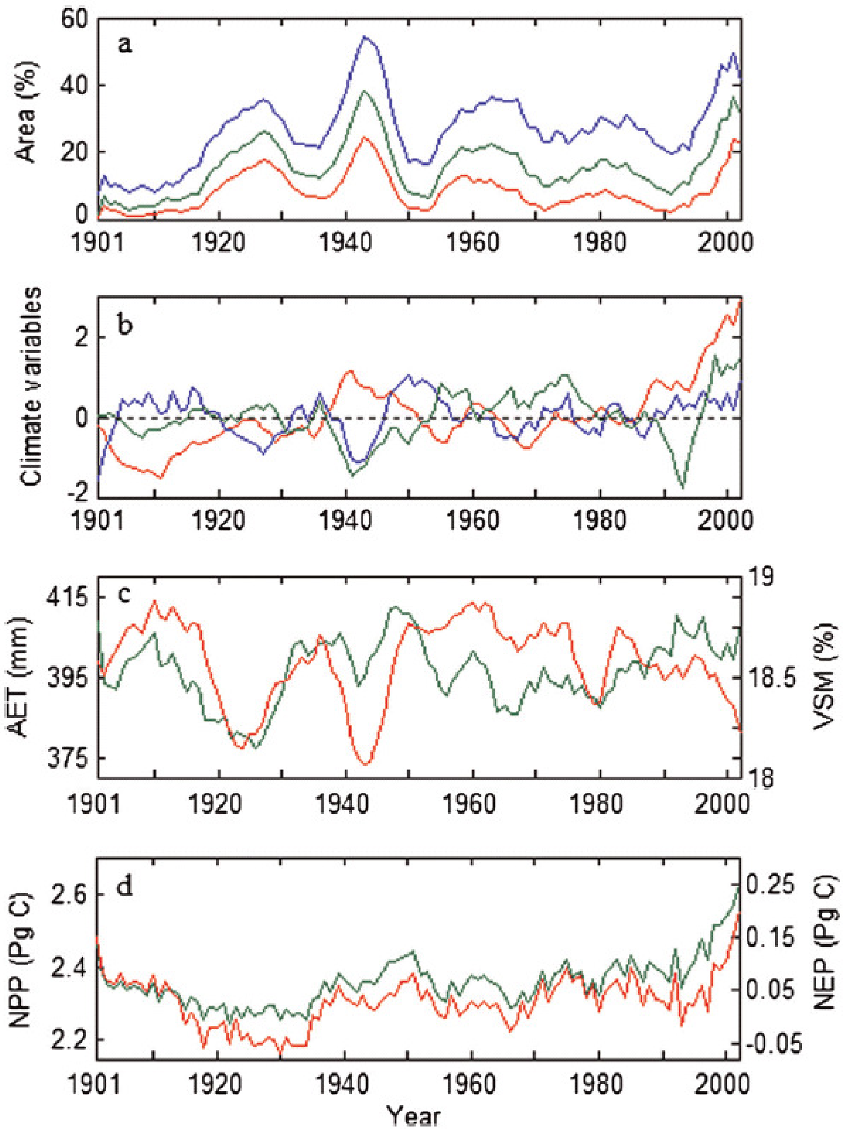


Figure 6. Time series of PDSI, climate variables, AET, VSM, NPP, and NEP averaged over the entire country during 1901–2002. (a) Annual percentage areas in drought conditions: dry areas with PDSI < −1.0 (blue line), PDSI < −2.0 (green line), and PDSI < −3.0 (red line). (b) Standardized temperature (red line), precipitation (blue line), and cloudiness (green line). (c) Simulated AET (green line) and VSM (red line). (d) Simulated annual NPP (Pg C yr^{-1}, green line) and NEP (Pg C yr^{-1}, red line). Each time series was smoothed using a 5-point moving filter.

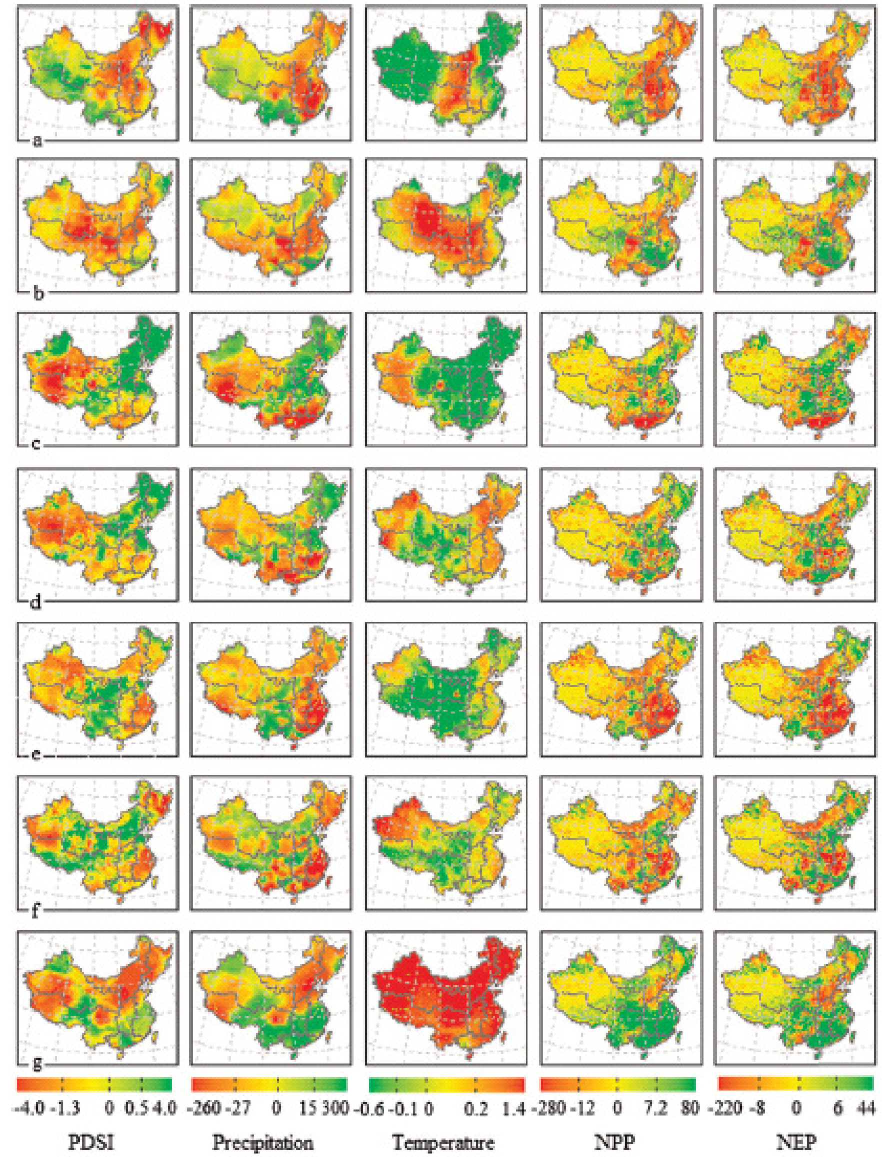


Figure 8. Average annual PDSI over each severe extended drought period and anomalies of average annual precipitation, temperature, NPP, and NEP during the drought period relative to the means over the entire century: (a) 1920–30, (b) 1939–47, (c) 1956–58, (d) 1960–63, (e) 1965–68, (f) 1978–80, and (g) 1999–2002.

Table 2. Countrywide annual NPP, R_H, and NEP (Tg C yr^{-1}) during each severe extended drought period and the entire century.

	Forests			Shrublands			Savannas			Grasslands			Croplands			Total		
Period	NPP	R_H	NEP	NPP	R_H	NEP	NPP	R_H	NEP	NPP	R_H	NEP	NPP	R_H	NEP	NPP	R_H	NEP
1920–30	688.2	689.5	−1.3	139.9	142.3	−2.5	159.1	163.4	−4.3	297.0	299.1	−2.1	960.7	997.6	−36.9	2269.5	2316.2	−46.8
1939–47	722.3	715.4	6.8	139.2	139.0	0.2	167.7	164.7	3.0	307.5	300.4	7.0	996.5	986.8	9.6	2357.6	2331.3	26.2
1956–58	724.7	713.4	11.3	142.0	137.4	4.6	166.8	164.0	2.8	291.5	292.2	−0.6	984.4	973.7	10.7	2333.0	2304.9	28.0
1960–63	727.3	722.9	4.4	135.7	139.4	−3.7	169.6	168.4	1.2	294.2	295.9	−1.8	1017.8	998.2	19.6	2367.5	2348.9	18.4
1965–68	697.2	707.8	−10.6	135.5	139.0	−3.5	162.2	165.0	−2.7	281.3	291.3	−10.1	961.3	981.6	−20.3	2259.1	2308.4	−49.5
1978–80	713.8	701.3	12.5	131.5	138.9	−7.4	164.9	163.7	1.2	289.0	292.0	−3.0	971.9	974.4	−2.4	2294.2	2294.2	−0.1
1999–2002	772.6	747.5	25.2	151.9	145.7	6.2	173.8	170.7	3.2	317.9	304.8	13.1	1058.8	1024.1	34.7	2500.9	2417.6	83.2
1901–2002	725.2	714.7	10.5	142.3	140.0	2.3	167.7	165.3	2.4	298.2	295.8	2.4	1000.0	990.5	9.5	2357.9	2330.5	27.2

- Most droughts generally reduced NPP and NEP in large parts of drought-affected areas.
- Out of the seven droughts, three (1920–30, 1965–68, and 1978–80) caused the countrywide terrestrial ecosystems to switch from a carbon sink to a source, and one (1960–63) substantially reduced the magnitude of the countrywide terrestrial carbon sink.
- Strong decreases in NPP were mainly responsible for the anomalies in annual NEP during these drought periods.

A process-based ecosystem model – PnET-CN

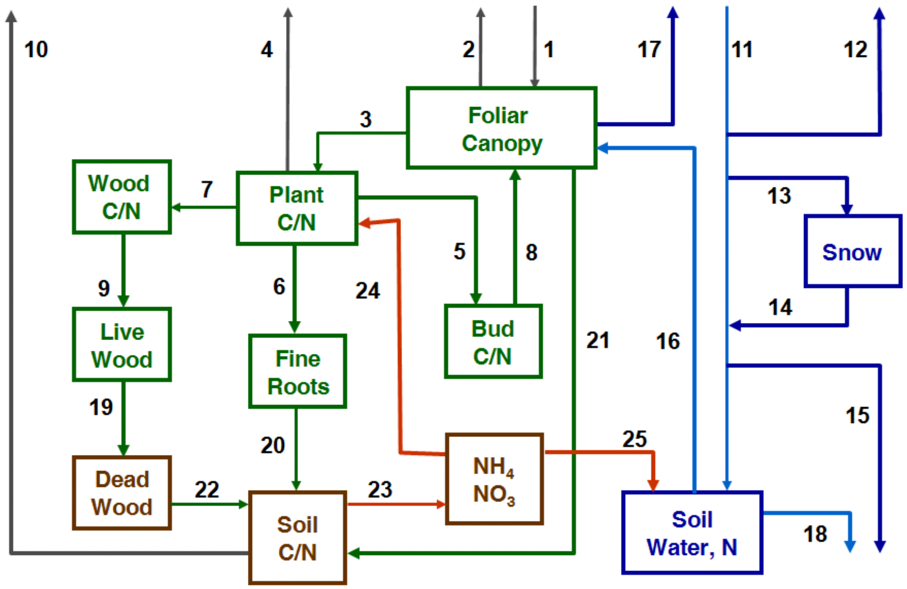


Figure 5. Structure of the PnET-CN model. Boxes represent pools and numbered arrows represent fluxes: (1) Gross photosynthesis & ozone uptake (2) Foliar respiration (3) Transfer to mobile pools (4) Growth and maintenance respiration (5) Allocation to buds (6) Allocation to fine roots (7) Allocation to wood (8) Foliar production (9) Wood production (10) Soil respiration (11) Precipitation & N Deposition (12) Canopy interception & evaporation (13) Snow-rain partitioning (14) Snowmelt (15) Macro-pore flow (16) Plant uptake (17) Transpiration (18) H2O Drainage (19) Woody litter (20) Root litter decay (21) Foliar litterfall (22) Wood decay (23) N Mineralization & Nitrification (24) Plant N uptake (25) N transfer to soil solution.

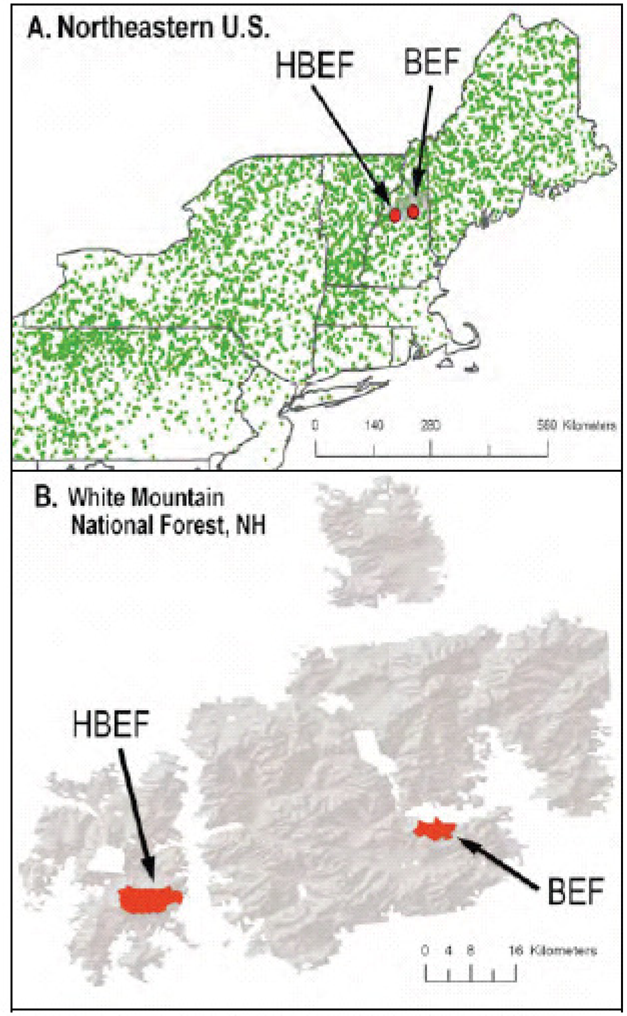


Figure 2. (A) BEF and HBEF locator map, with shading density illustrating the relative importance of maple-beech-birch stands in terms of county-level forest composition, as derived from Forest Service FIA data. (B) Location of BEF and HBEF within the White Mountain National Forest.

Parameter estimation with multiple constraints

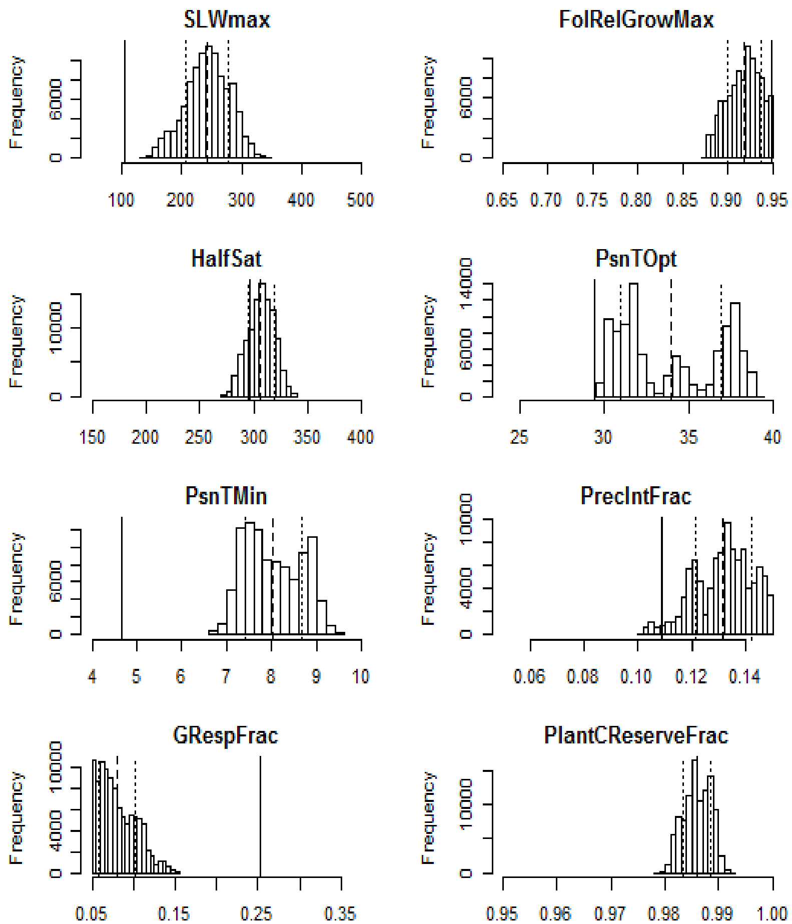
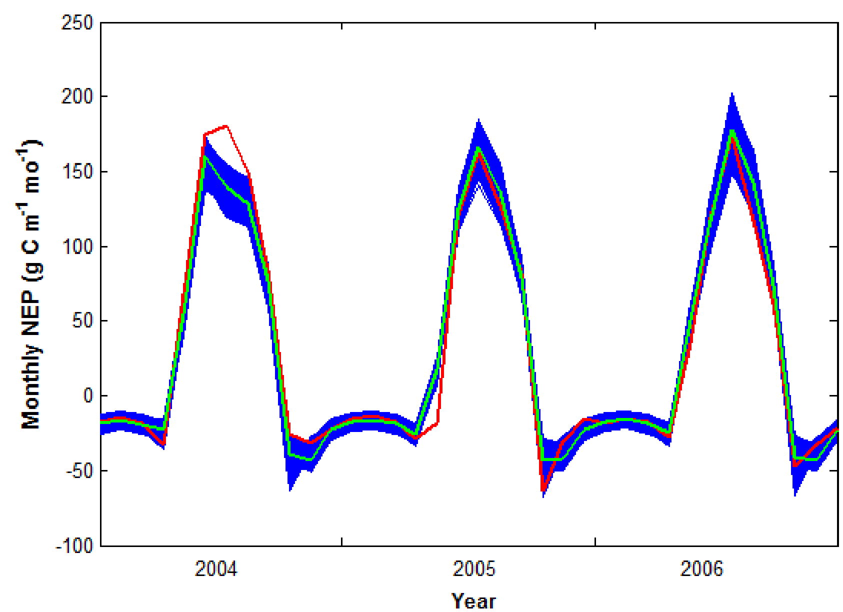


Figure 1. Probability density functions (PDFs) of some key model parameters.

Data constraints

- Carbon fluxes from BER
- ET from BEF
- Runoff from HBEF
- Nitrogen loss from HBEF



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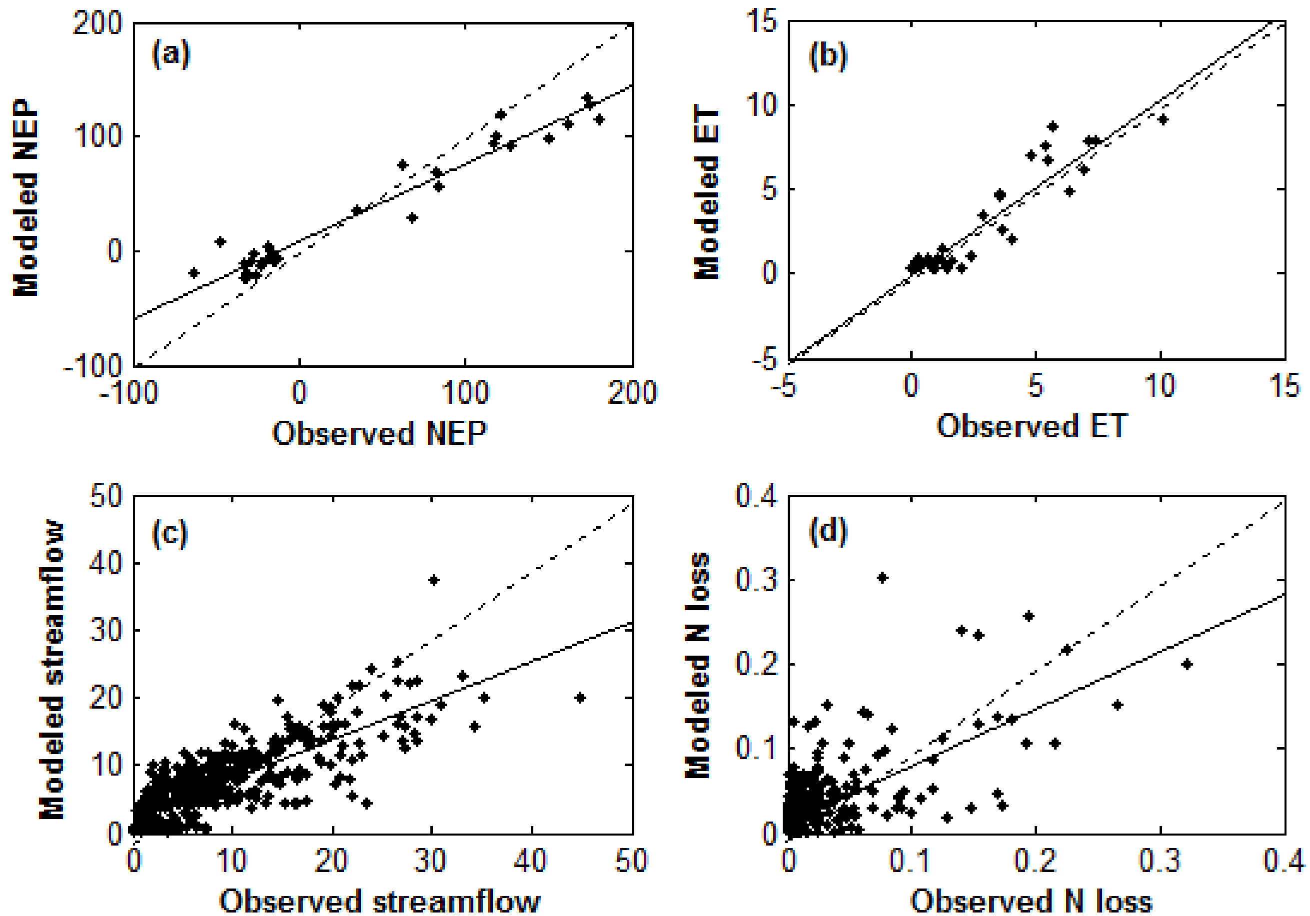
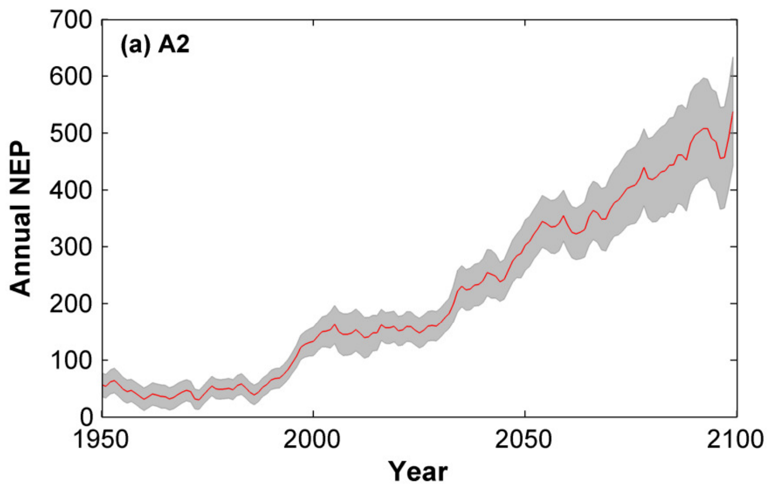
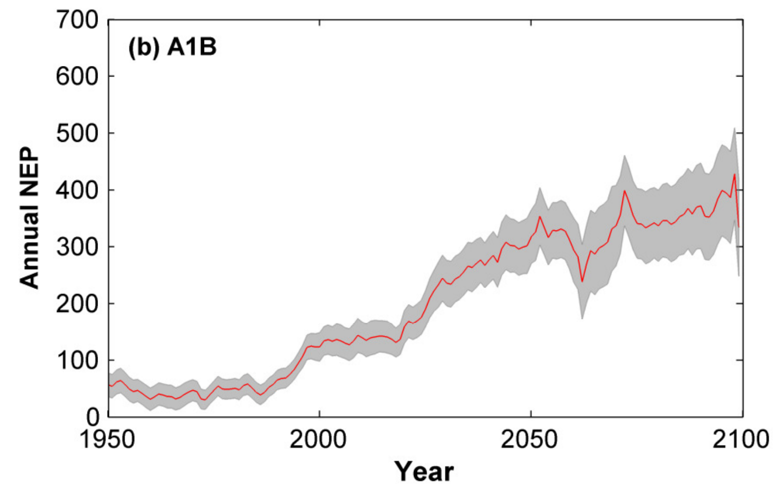


Figure 6. Observed fluxes versus modeled fluxes for **NEP, ET, streamflow, and streamwater chemistry**: (a) monthly ET (mm mo^{-1}); (b) monthly streamflow (mm mo^{-1}); (c) monthly N loss (g N m^{-2} mo^{-1}). Solid lines are the regression lines, and dashed lines are 1:1 lines.

Quantifying uncertainties of flux projections





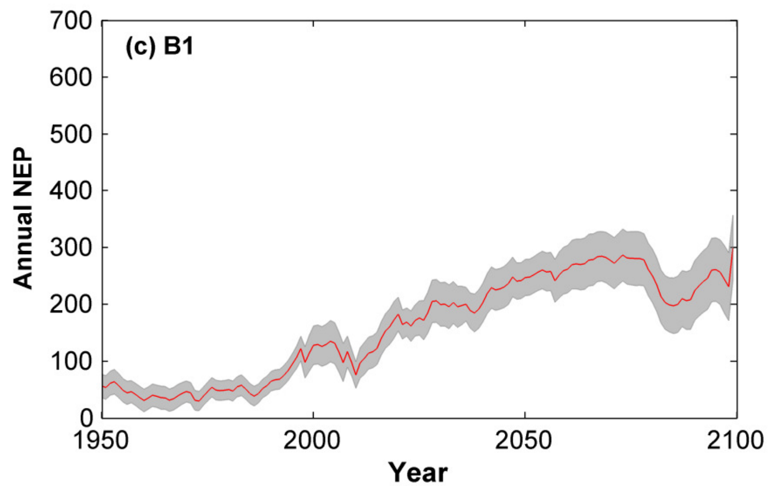
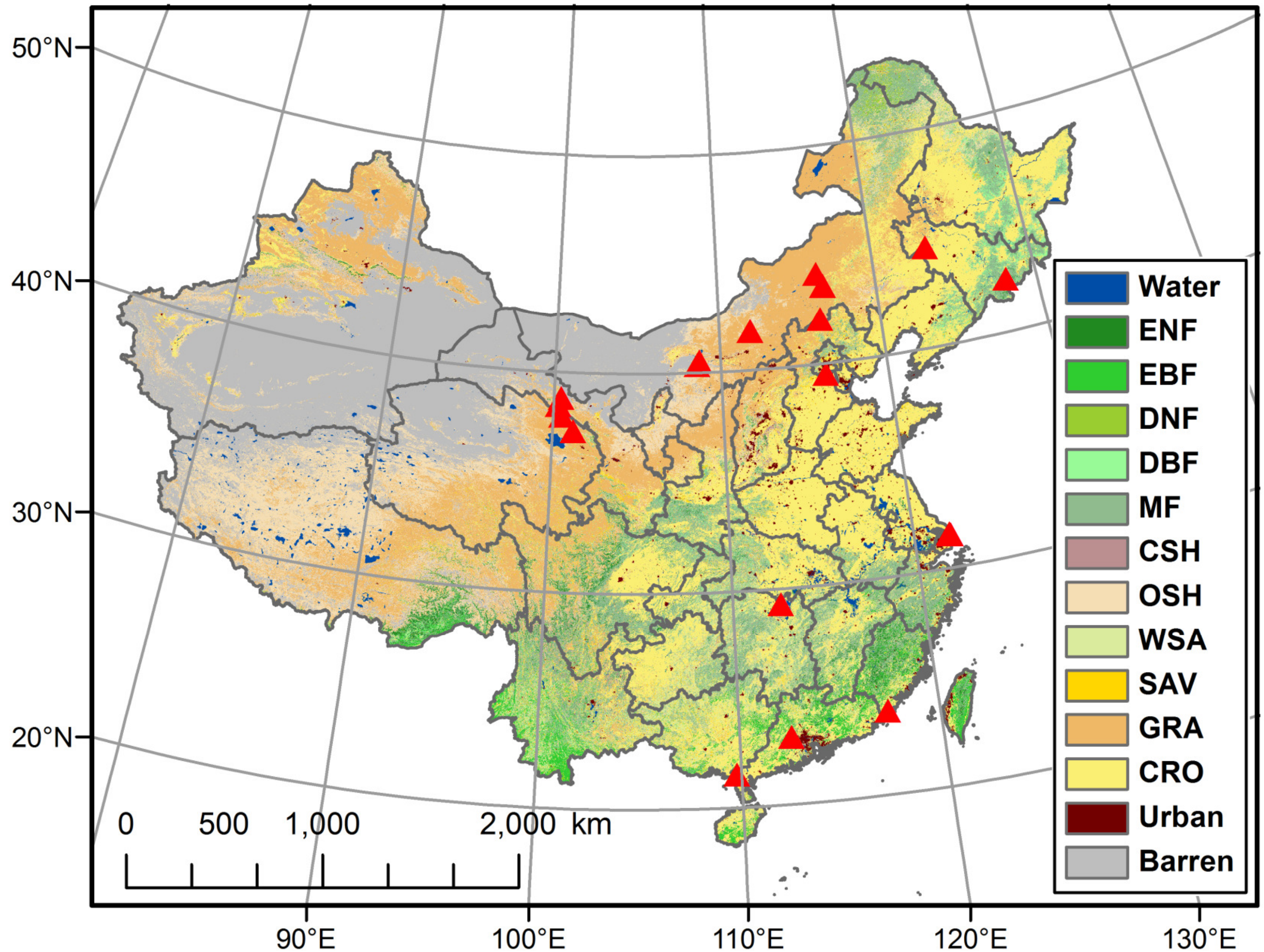


Figure 9. Uncertainty of historical (1950-1999) and projected (2000-2099) annual NEP under different emission scenarios (A2, A1B, and B1) at Bartlett Experimental Forest. For each scenario, the red line stands for the mean of annual NEP simulated with parameter PDFs, and the shade area stands for 2 standard deviations away from the mean.

Xiao et al., unpublished

Ongoing work in China



Special session at AGU

Impacts of Extreme Climate Events and Disturbances on Carbon Dynamics

Convener(s): Jingfeng Xiao (University of New Hampshire) and Shuguang Liu (USGS EROS)

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Scheduled Special Issues

The EU Project SHIVA (Stratospheric Ozone: Halogen Impacts in a Varying Atmosphere) (ACP/BG/OS Inter-Journal SI)

- Guest Editors: W. T. Sturges, J. Williams, G. Roberts, and C. Robinson
- Timeline: 01 Sep 2012 – 31 Dec 2013
- More Information

Impacts of extreme climate events and disturbances on carbon dynamics

- Guest Editors: J. Xiao, S. Liu, and P. Stoy
- Timeline: 01 Aug 2012 – 30 Sep 2013
- More Information

Extreme climate events (e.g., drought, heat and cold waves) and disturbances (e.g., fire, hurricane, and insect outbreaks) substantially affect carbon cycle processes. However, their impacts on terrestrial carbon dynamics over landscapes, regions, and continents are not well understood. We invite submissions that investigate and quantify the impacts of extreme climate events and disturbances on the terrestrial carbon dynamics over various spatial and temporal scales using observations (e.g., eddy covariance flux measurements, and national inventories), remote sensing, state-of-the-art modeling approaches (e.g., ecosystem models, upscaling methods), and model-data fusion techniques.

A special issue focusing on this topic will be timely and valuable to the research communities of carbon and global change. Collectively, we believe that this special issue will play a critical role in our understanding of how extreme climate events and disturbances influence the terrestrial carbon cycle and increase the visibility and influences of Biogeosciences in carbon cycle and climate change.

Impact of atmospheric inputs on an oligotrophic ecosystem - the DUNE experiment

- Guest Editors: C. Guieu, F. Dulac, and E. Marañón
- Timeline: 01 Aug 2012 – 31 Dec 2012
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