南京信息工程大学

Uncertainties in carbon simulation & disturbance effects on Carbon sinks and sources

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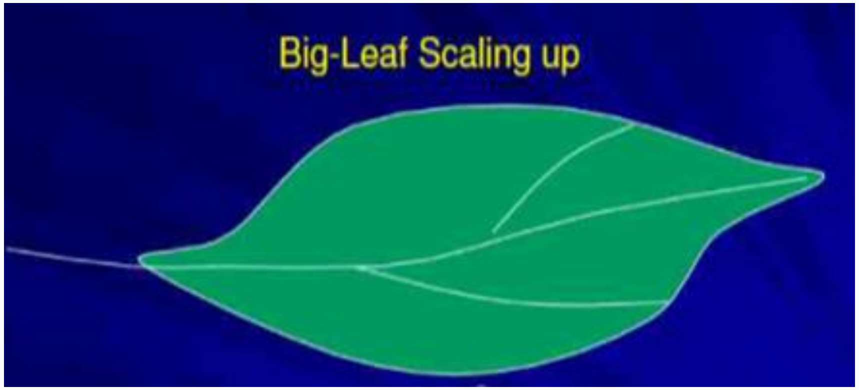
2019.7.27

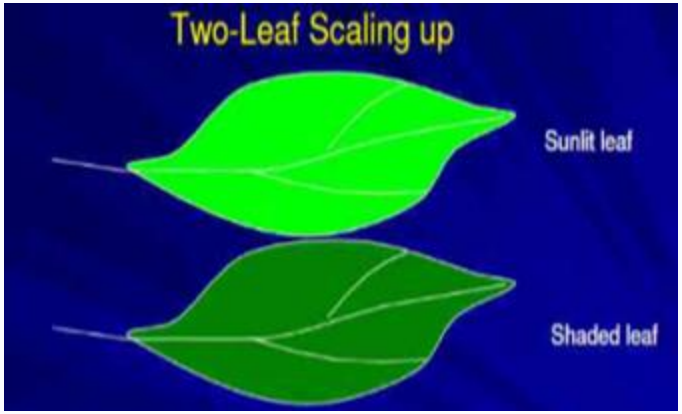
Part I:
Uncertainties in carbon simulation

-Gross Primary Productivity (GPP)

- Group I: an empirical relationship is used to quantify GPP as a function of light use efficiency (LUE) and environmental conditions, such as CASA (Potter et al., 1993), and the MODIS algorithm (Zhao & Running, 2010).

- Goup II: models using mechanistic description of the photosynthetic biochemical processes occurring at leaf level (Farquhar et al., 1980), eg. BEPS.





eg, LUE model (MODIS)

eg, BEPS model

Is GPP distorted using big-leaf Models?

Objective

- To verify any systematic biases exist with the big-leaf LUE modeling approach in generating the spatial and temporal distribution patterns of GPP

- To investigate the underlying reasons for these biases using the process-based model (BEPS)

Methods

LUE model------the MODIS algorithm

Process-based model----BEPS

BEPS principles

(1) Leaf photosynthesis

(2) Sunlit and shaded LAI stratification

(3) Sunlit and shaded leaf irradiance

(4) Stomatal conductance

(5) Soil moisture scalar

Chen et al., Ju et al., Zhang et al., 1999-2015

Leaf photosynthesis

Rubisco activities

$$W_c = \begin{cases} V_m \dfrac{C_i - \Gamma}{C_i + k_{co}} & \text{, for } C_3 \\ V_m & \text{, for } C_4 \end{cases}$$

Electron transport

$$W_j = \begin{cases} J \dfrac{C_i - \Gamma}{4.5C_i + 10.5\Gamma} & \text{, for } C_3 \\ J & \text{, for } C_4 \end{cases}$$

Irradiance dependence of electron transport

$$\theta_1 J^2 - (I_{le} + J_m)J + I_{le}J_m = 0$$

$$A = \min(W_c,\ W_j, W_e) - R_d$$

The FvCB photosynthesis model

Sunlit and shaded LAI stratification

$$L_{sun} = 2\cos\theta(1\text{-}\exp(-0.5L\Omega/\cos\theta))$$

$$L_{shade} = L - L_{sun}$$

Sunlit and shaded leaf irradiance

$$S_{sunlit} = S_{dir}\cos\alpha / \cos\theta + S_{shaded}$$

$$S_{shaded} = (S_{dif} - S_{dif,under}) / LAI + C$$

$$C = 0.07\Omega S_{dir}(1.1 - 0.1LAI)\exp(-\cos\theta)$$

$$S_{dif,under} = S_{dif}\exp(-0.5\Omega LAI / \cos\bar{\theta})$$

$$\cos\bar{\theta} = 0.537 + 0.025LAI$$

Stomatal conductance

$$A = (C_a - C_i)g$$

$$g = m\frac{Ah_s}{C_s}p + b$$

$$g = f_w(m\frac{Ah_s}{C_s}p + b)$$

Soil moisture scalar

Soil moisture scalar

The soil water availaility factor $f_{w,i}$ in layer *i* is caculated as:

$$f_{w,i} = \frac{1.0}{f_i(\psi_i)\, f_i(T_{s,i})}$$

a function of matrix suction (Zierl, 2011).

The effect of soil temperature

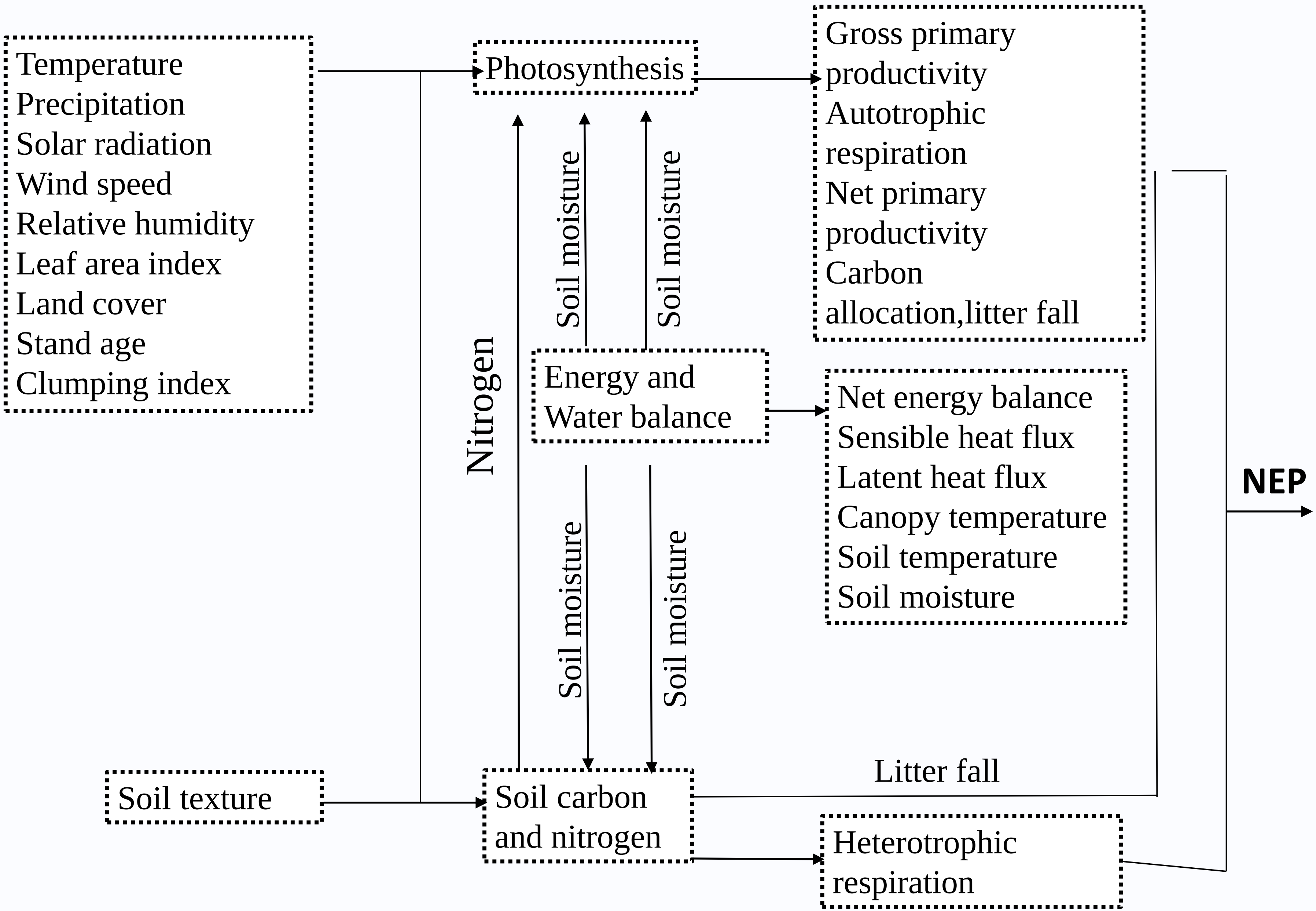
$$f_i(T_{s,i}) = \begin{cases} \dfrac{1.0}{1 - \exp(t_1 T_{s,i}^{t_2})} & T_{s,i} > 0°C \\ \infty & else \end{cases}$$

The weight of each layer to f_w

$$w_i = \frac{R_i f_{w,i}}{\sum_{i=1}^{n} R_i f_{w,i}}$$

$$f_w = \sum_{i=1}^{n} f_{w,i} w_i$$

Inputs Model Outputs



MODIS GPP algorithm

$$\mathrm{GPP} = \mathrm{LUE} \times \mathrm{fPAR} \times \mathrm{PAR}$$

$$\mathrm{LUE} = \mathrm{LUE}_{\mathrm{max}} \times f(VPD) \times g(T_{\mathrm{min}})$$

$$\mathrm{fPAR} = 1 - e^{-k \times LAI}$$

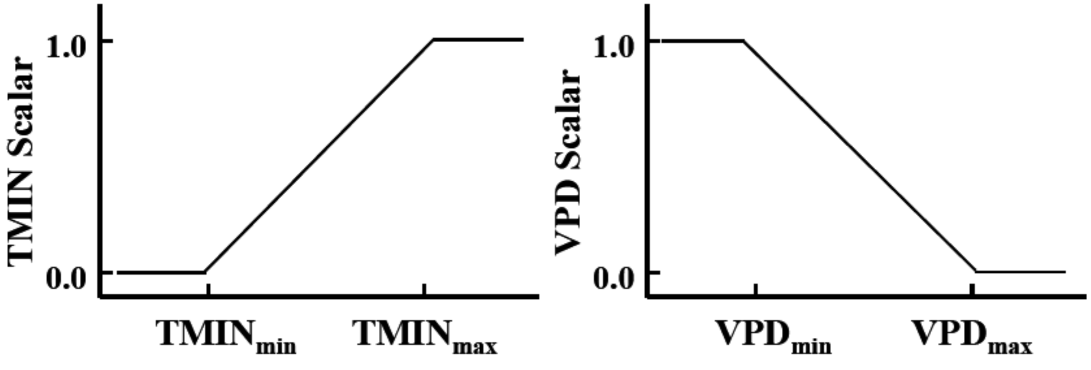
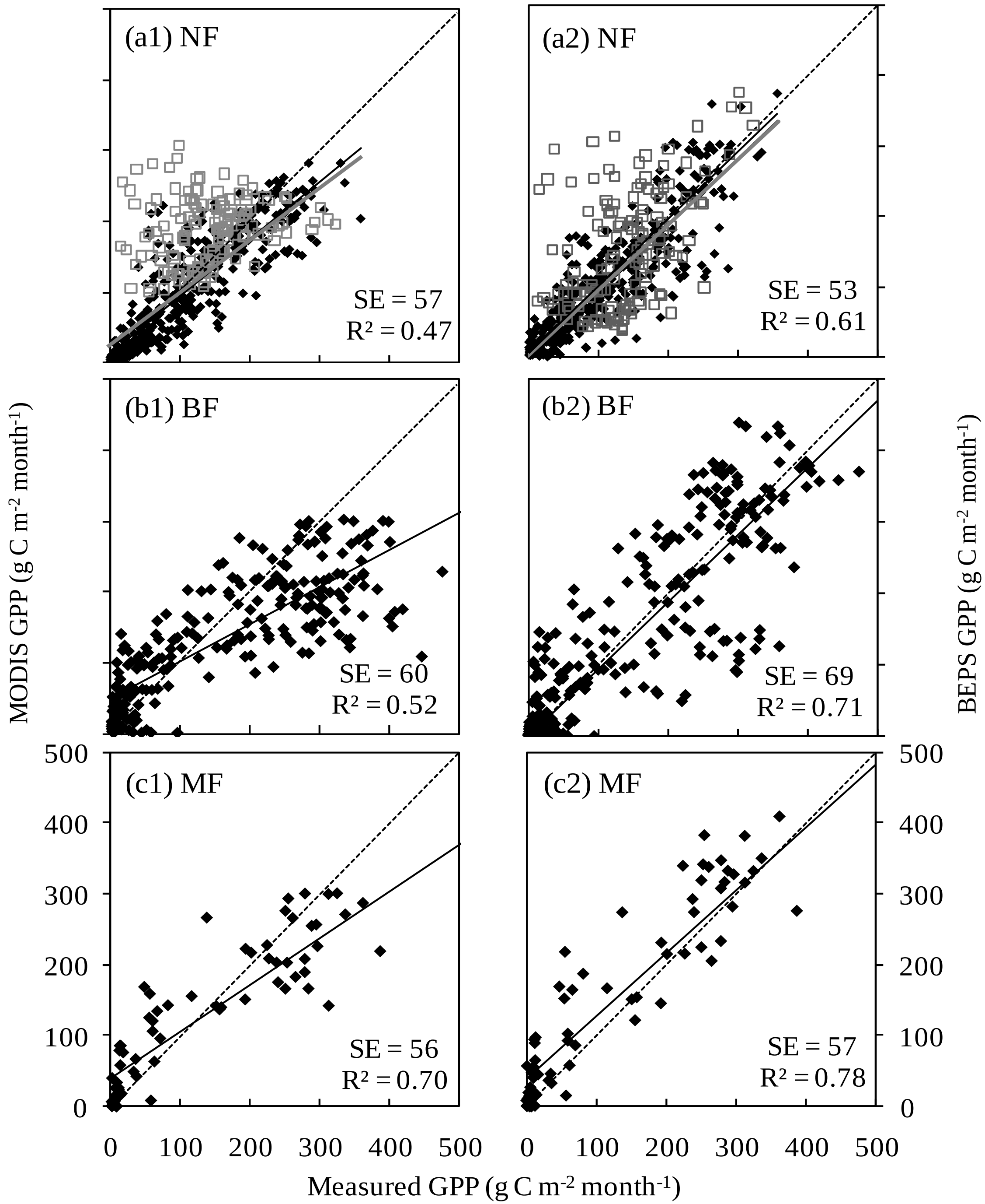
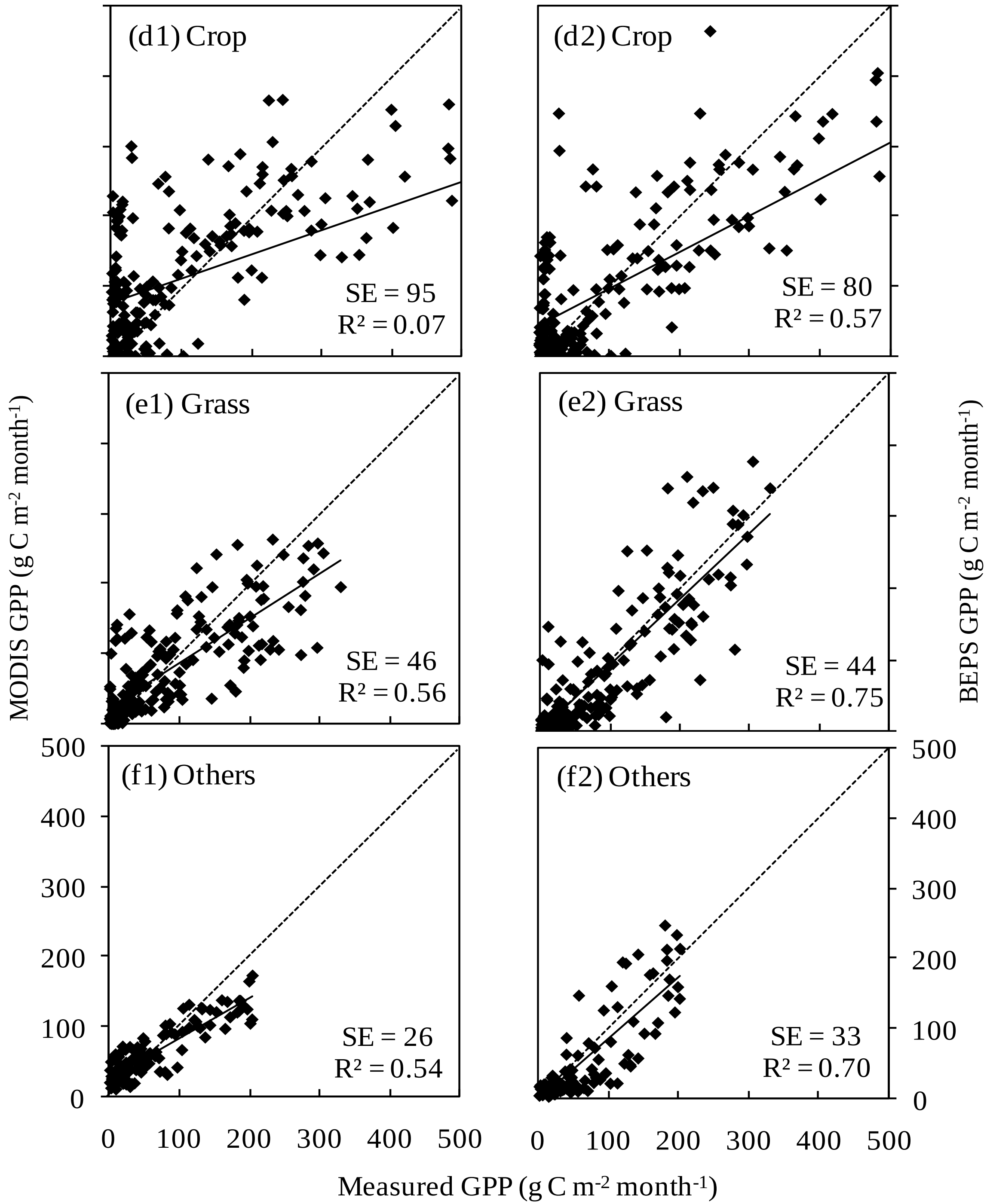


Figure 1.2. The TMIN and VPD attenuation scalars are simple linear ramp functions of daily TMIN and VPD.

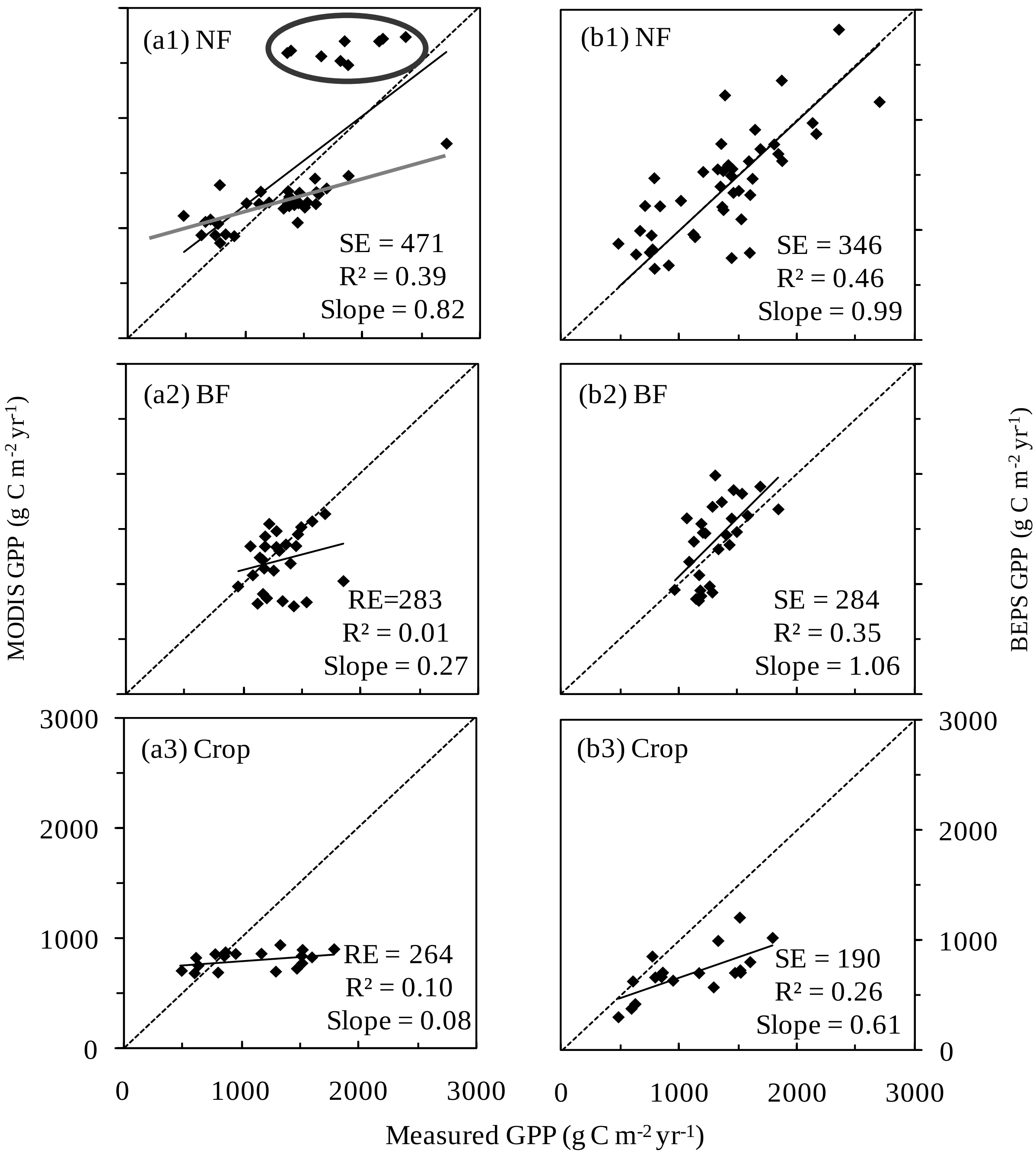
Monthly GPP Assessment



Monthly GPP Assessment

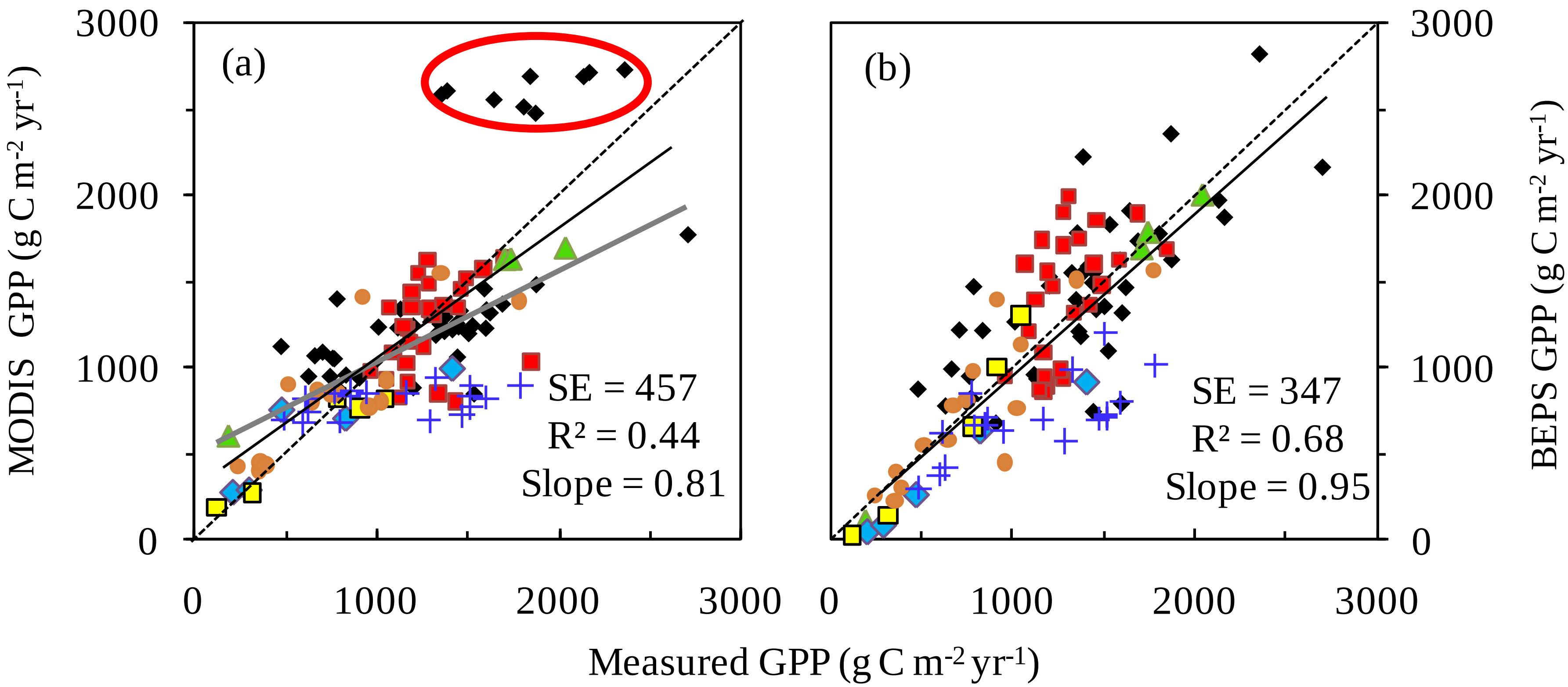


Annual GPP Assessment



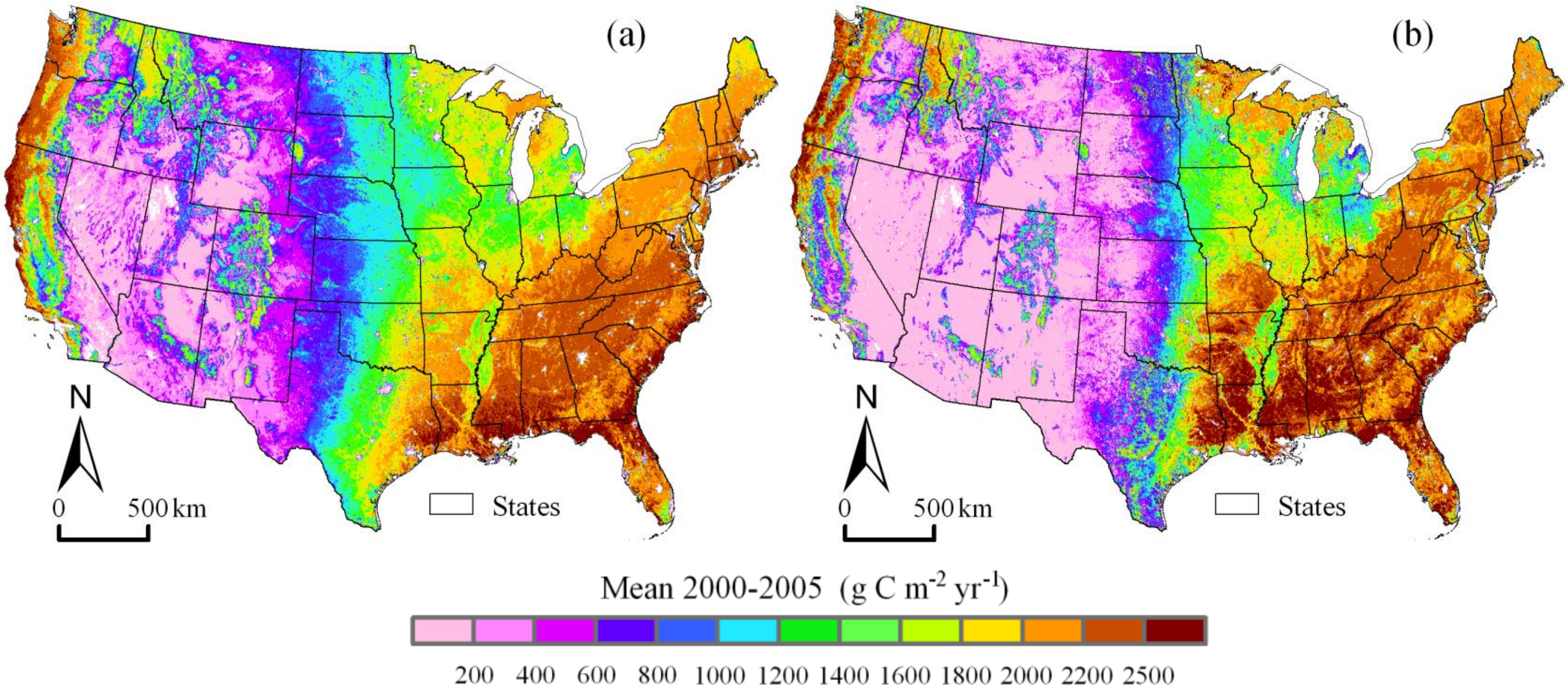
Annual GPP Assessment

SP1,SP2,SP3 sites



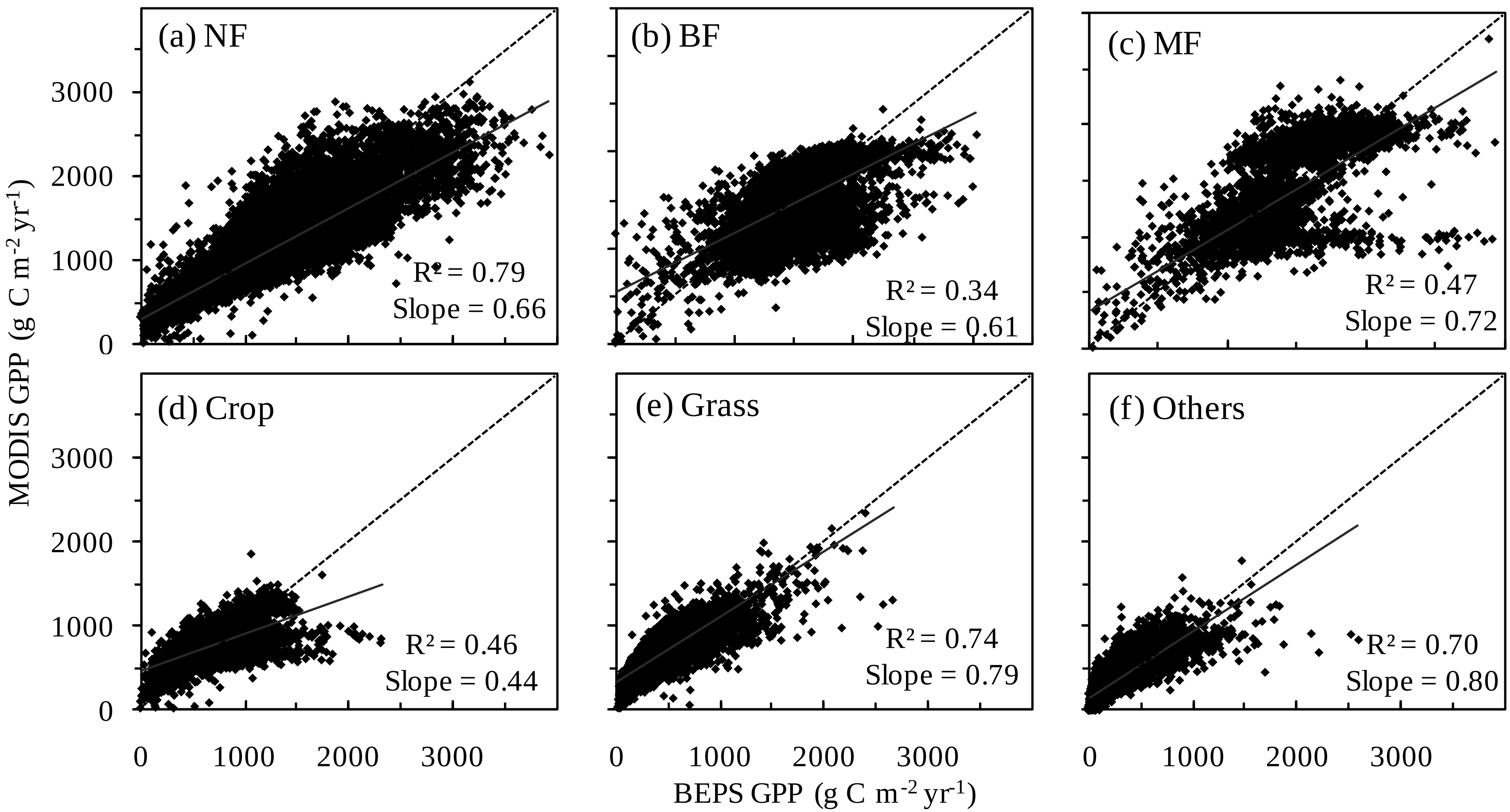
Continental GPP comparison

MODIS BEPS



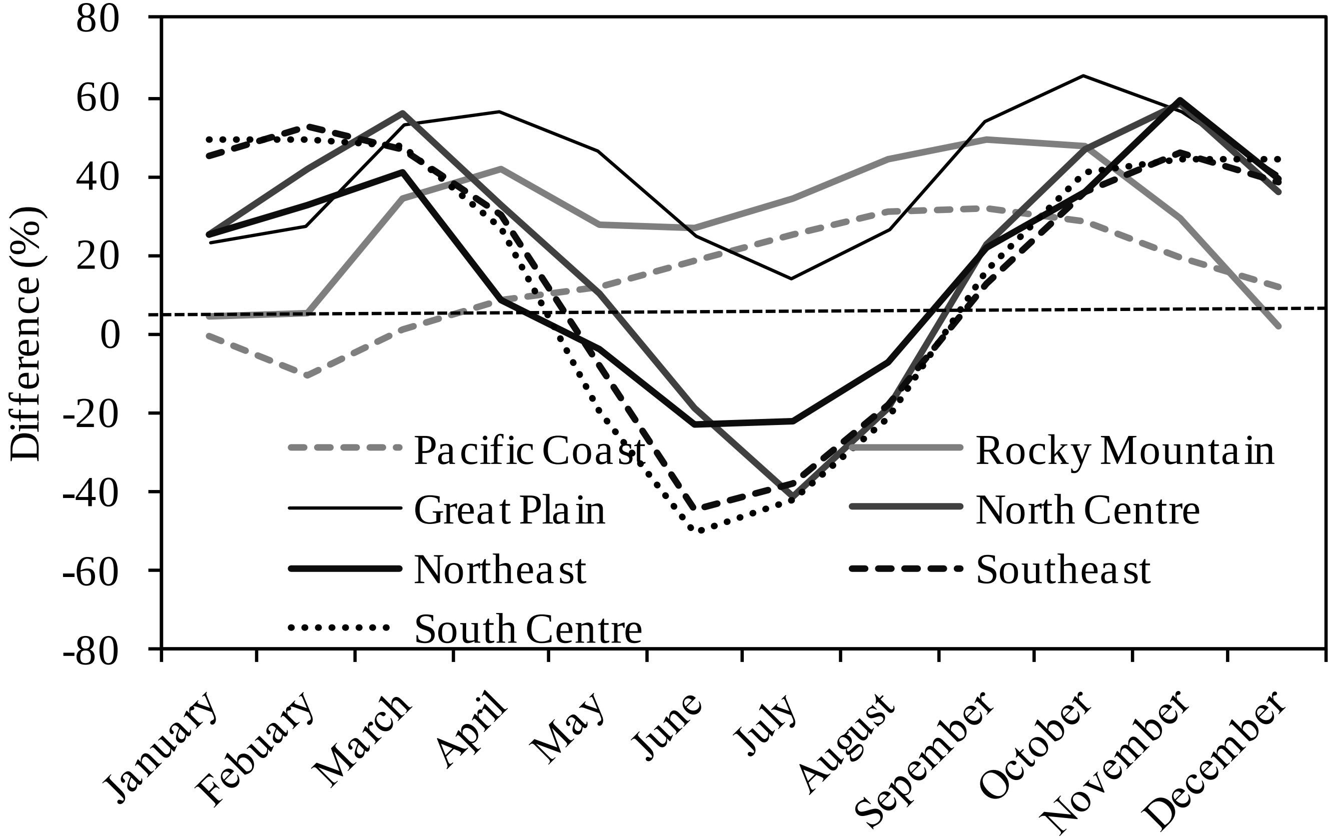
- MODIS and BEPS agree within 89% for the total annual GPP of the continental US.

Continental GPP comparison



- Underestimations of GPP mainly occur in clumped canopies and vice versa.

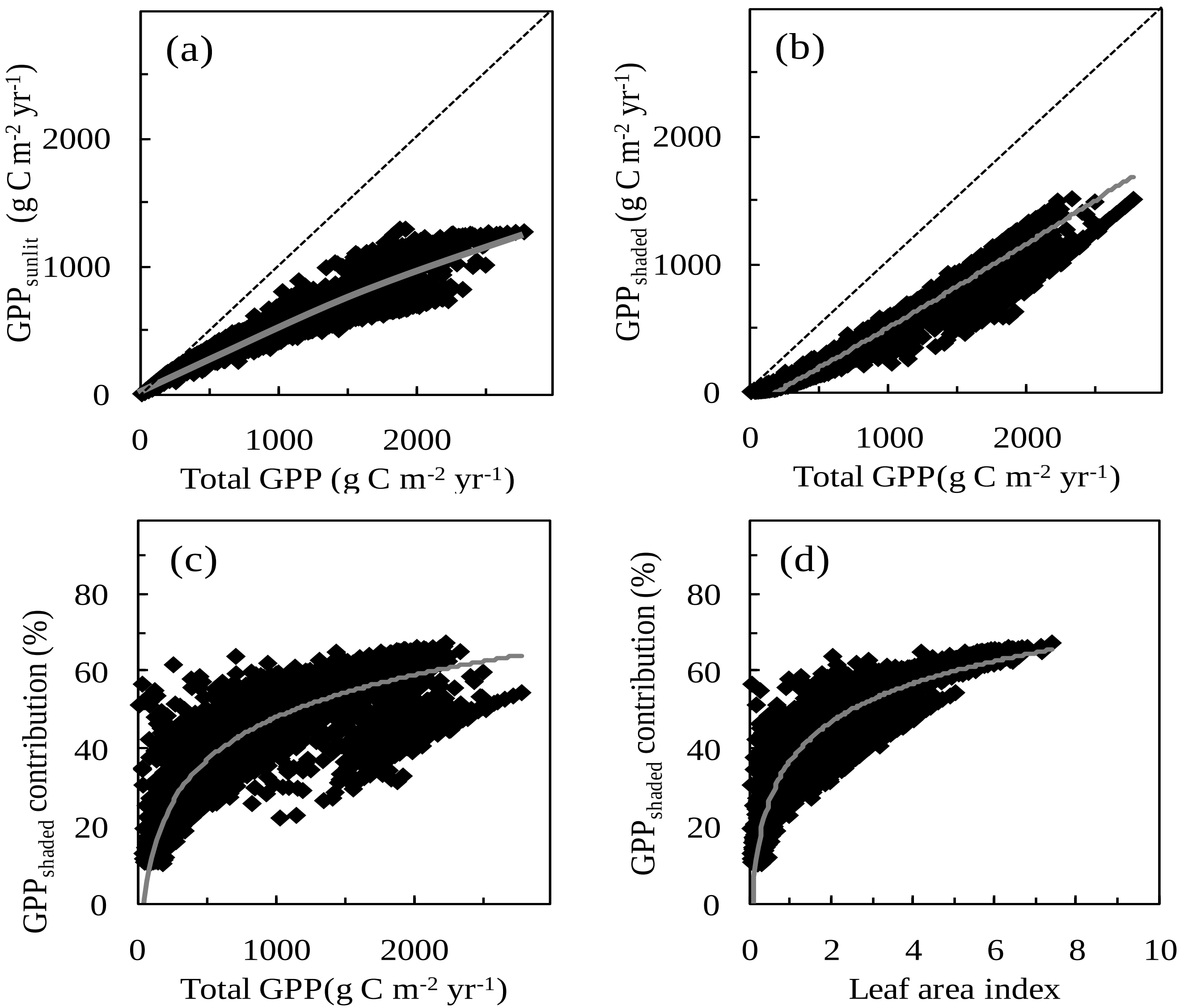
Continental GPP comparison



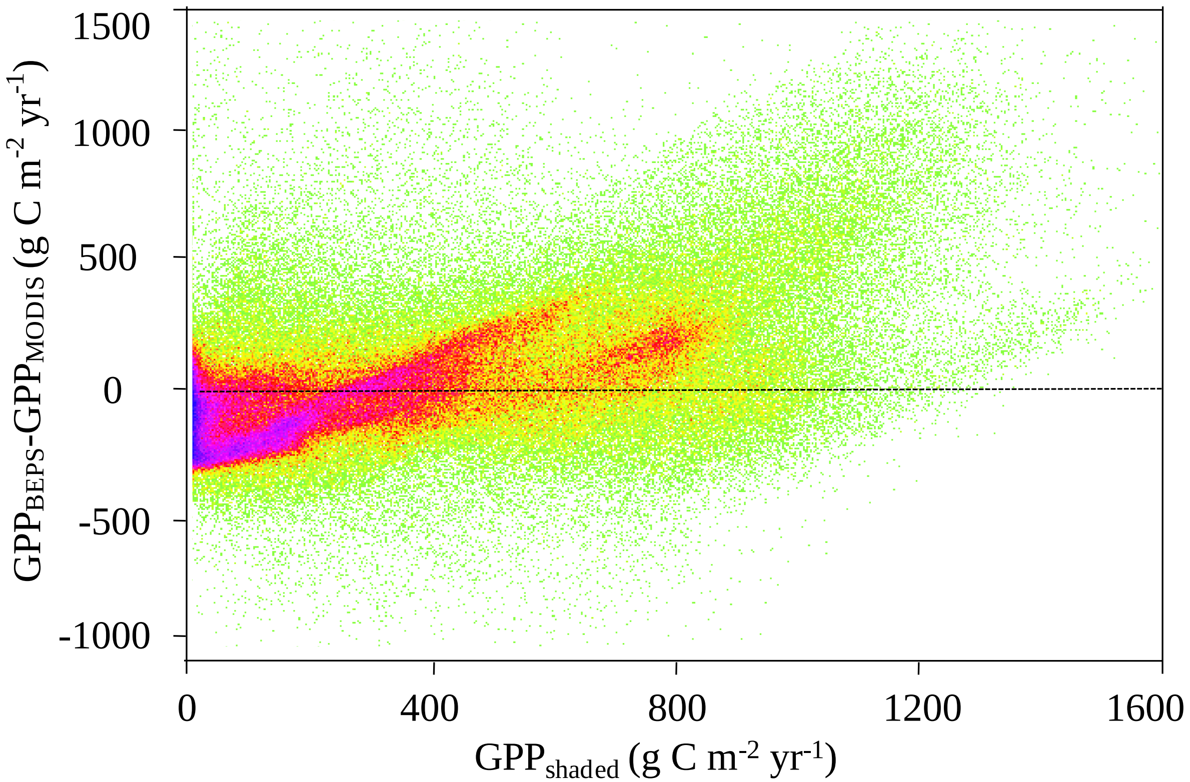
- MODIS overestimates GPP at low value end and underestimates GPP at high value end.

Physiological reasons

Needleleaf forest



Physiological reasons



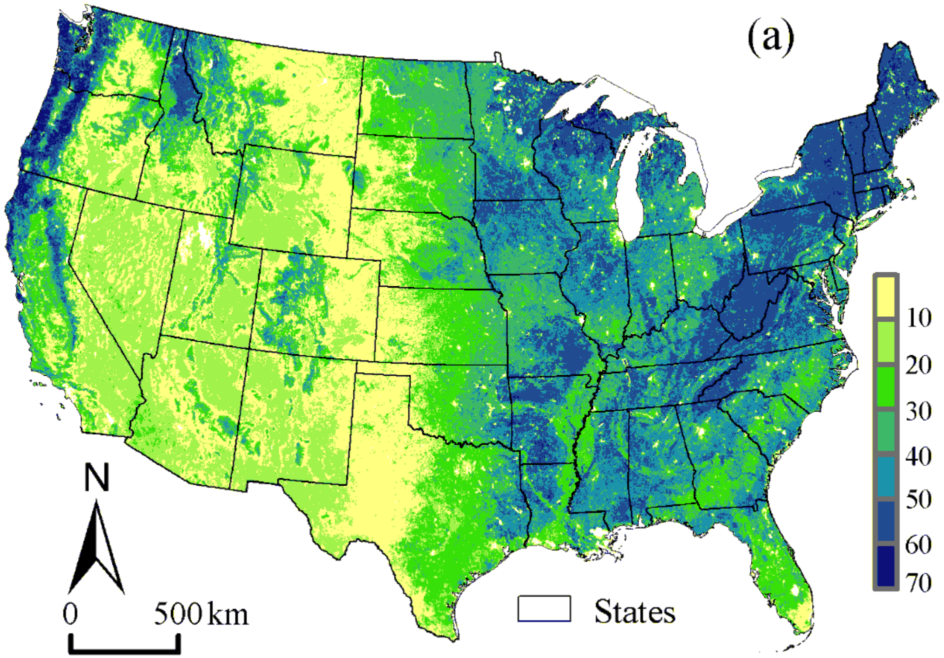
Other reasons: eg.,

Soil nutrient availability (fertilized vs. non-fertilized treatments)

Changes associated with stand development and aging

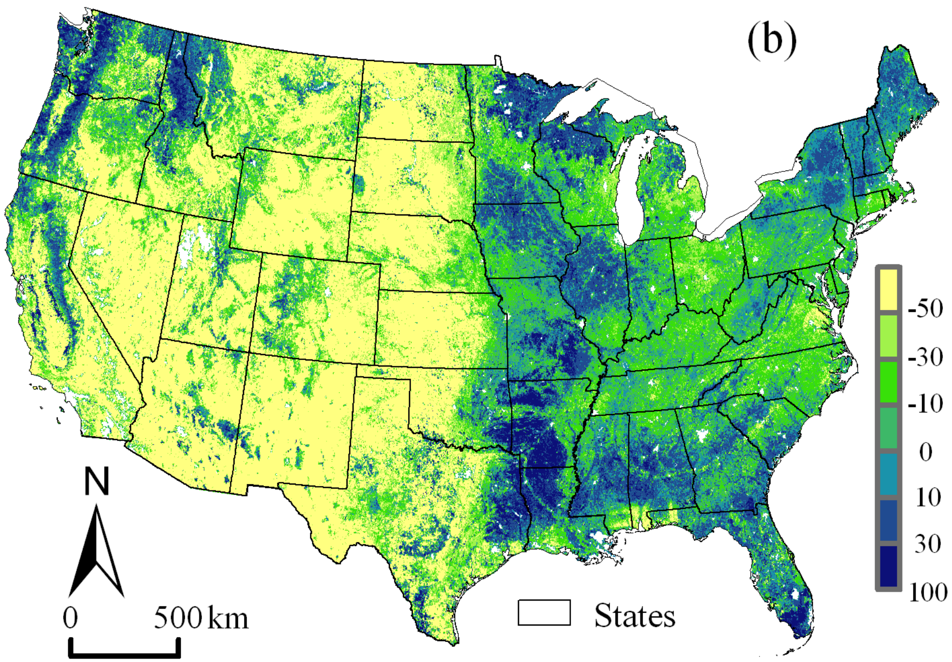
Physiological reasons

Contribution (%) of shaded leaves



$$\frac{GPP_{shaded}}{GPP} \times 100$$

Differences (%) of GPP_{BEPS} and GPP_{MODIS}



$$\frac{GPP_{BEPS} - GPP_{MODIS}}{GPP_{BEPS}} \times 100$$

- Biases of MODIS GPP are positively correlated with contributions of shaded leaves.
- The biases would produce considerable distortions in spatio-temporal patterns of GPP.

Upgrade big-leaf LUE model by two-leaf principles

(1) Build two-leaf MOD17 LUE-GPP model:

$$GPP = LUE_{\max\_sun} f(u_{1,2,i....}) APAR_{sun} + LUE_{\max\_shaded} f(u_{1,2,i....}) APAR_{shaded}$$

(2) Separate different irradiance processing of sunlit and shaded leaves:

$$L_{sun} = 2\cos\theta(1\text{-}\exp(\text{-}0.5L\Omega/\cos\theta))$$

$$L_{shade} = L - L_{sun}$$

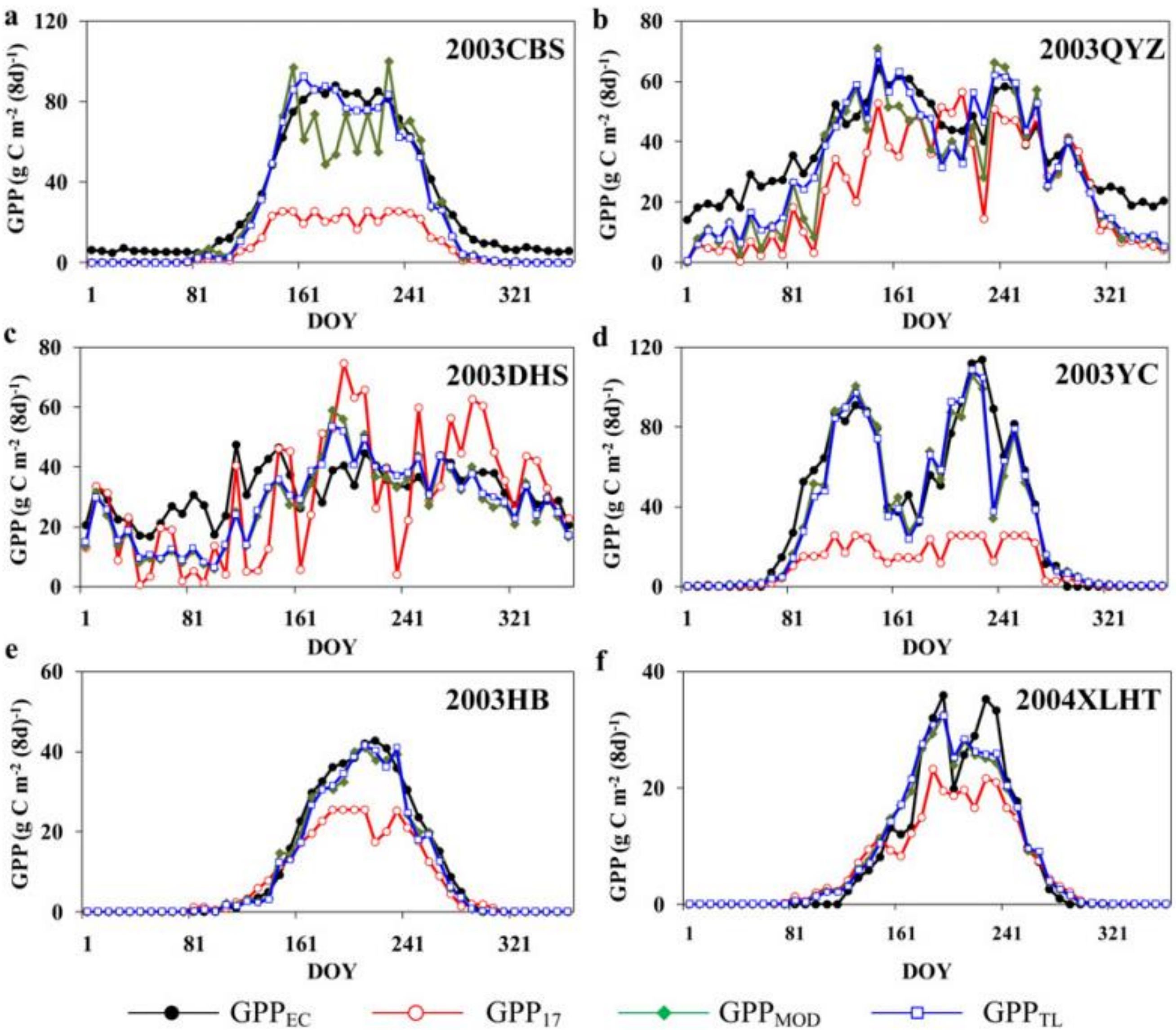
$$S_{sunlit} = S_{dir}\cos\alpha/\cos\theta + S_{shaded}$$

$$S_{shaded} = (S_{dif} - S_{dif,under})/LAI + C$$

$$C = 0.07\Omega S_{dir}(1.1 - 0.1LAI)\exp(-\cos\theta)$$

$$S_{dif,under} = S_{dif}\exp(-0.5\Omega LAI/\cos\bar{\theta})$$

$$\cos\bar{\theta} = 0.537 + 0.025LAI$$



长白山

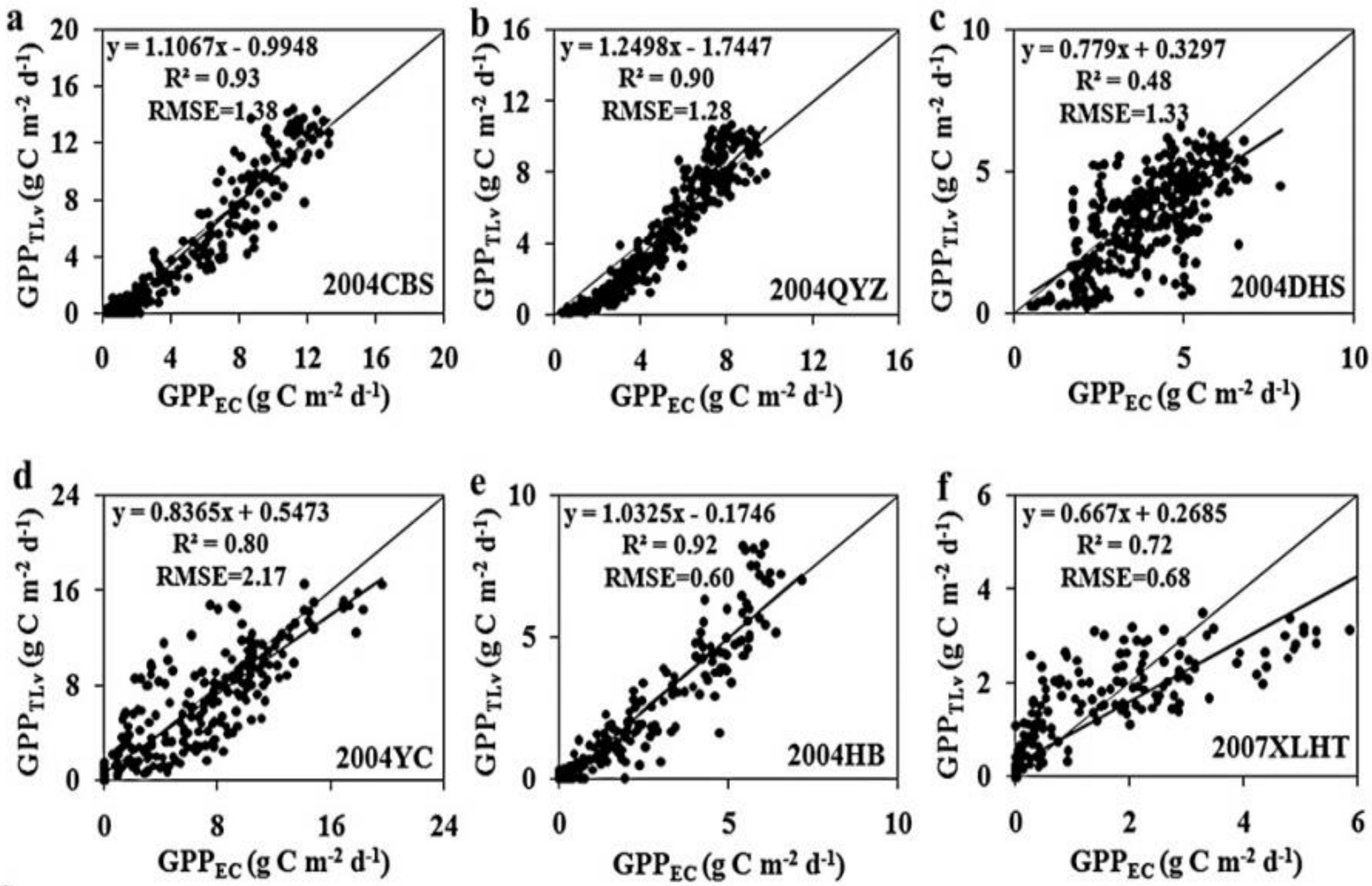
千烟洲

鼎湖山

禹城

海北

内蒙



a
y = 1.1067x - 0.9948
R² = 0.93
RMSE=1.38
2004CBS
b
y = 1.2498x - 1.7447
R² = 0.90
RMSE=1.28
2004QYZ
c
y = 0.779x + 0.3297
R² = 0.48
RMSE=1.33
2004DHS
d
y = 0.8365x + 0.5473
R² = 0.80
RMSE=2.17
2004YC
e
y = 1.0325x - 0.1746
R² = 0.92
RMSE=0.60
2004HB
f
y = 0.667x + 0.2685
R² = 0.72
RMSE=0.68
2007XLHT
GPP_TLv (g C m-2 d-1)
GPP_EC (g C m-2 d-1)

Part II
Non-disturbance and disturbance effects on Carbon sinks and sources in forests

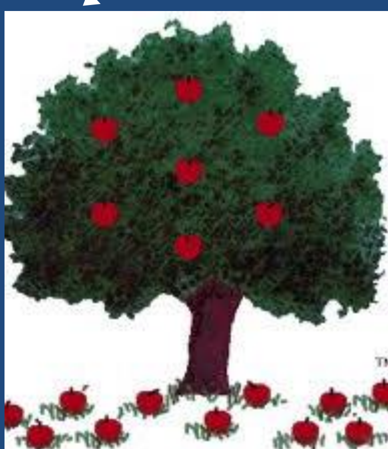
Carbon Cycle

Disturbances

A = Photosynthesis
(CO_2, N, Temp., etc.)

NPP = A - B
NEP = NPP - C

B =Autotrophic Respiration
(Temp., biomass, etc.)



C = Heterotrophic Respiration
(Temp., C pools, etc.)

NBP=NEP–Fires –Harvest –Insect-induced Mortality

Mechanisms for C sinks

- **Disturbance Effects**
  - Regrowth after disturbance
  - C emission caused by fire, harvest and insect
- **Non-disturbance Effects**

  (growth/respiration enhancement)
  - Climate (T, P)
  - CO_2
  - Nitrogen deposition

Schimel et al., 2000; Thornton et al., 2002; Chapin et al., 2002; Houghton et al., 2003; Birdsey et al., 2003, 2006; Zaehle et al., 2006; Luyssaert etl., 2010

Questions?

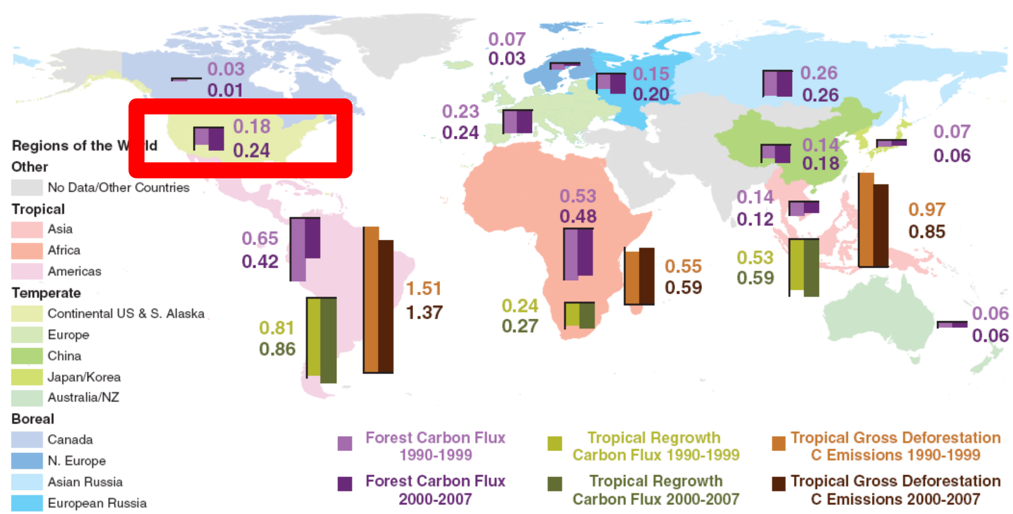
- What are the causes of C sinks and sources, disturbance effects and non-disturbance effects?
- What are the contributions to the C sinks from different regions?

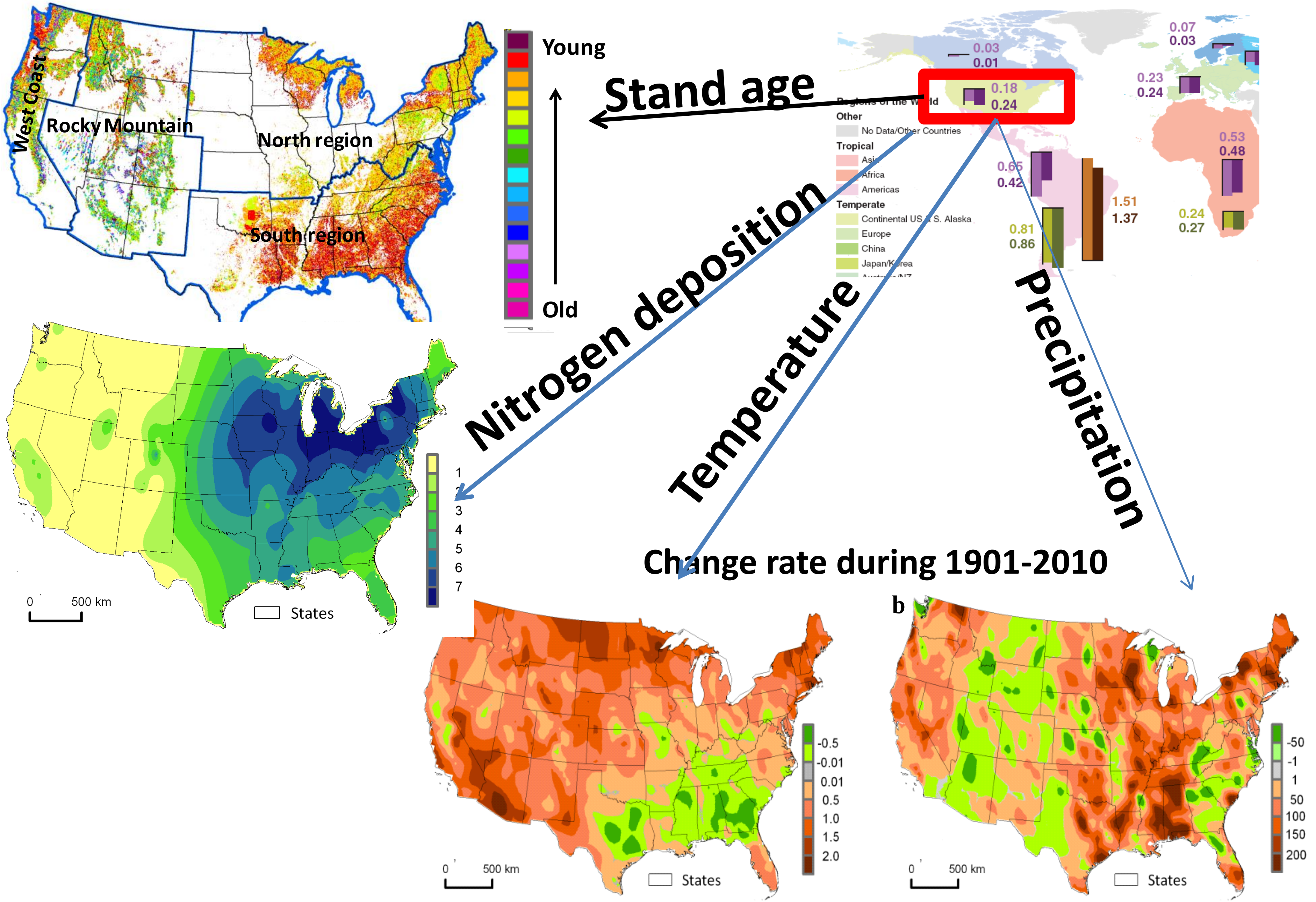
To attribute the total sink to disturbance and non-disturbance factors

US forests and C sink

- area accounts for 5.9% of the global forests
- thought to be a large sink (10%)
- large uncertainties in the magnitude, spatial distribution and causes of the sink

The world forest sink
2.4 ±0.4 Pg C





Units for deposition (g N/m2/yr), T (C/100yr) and P (mm/100yr).

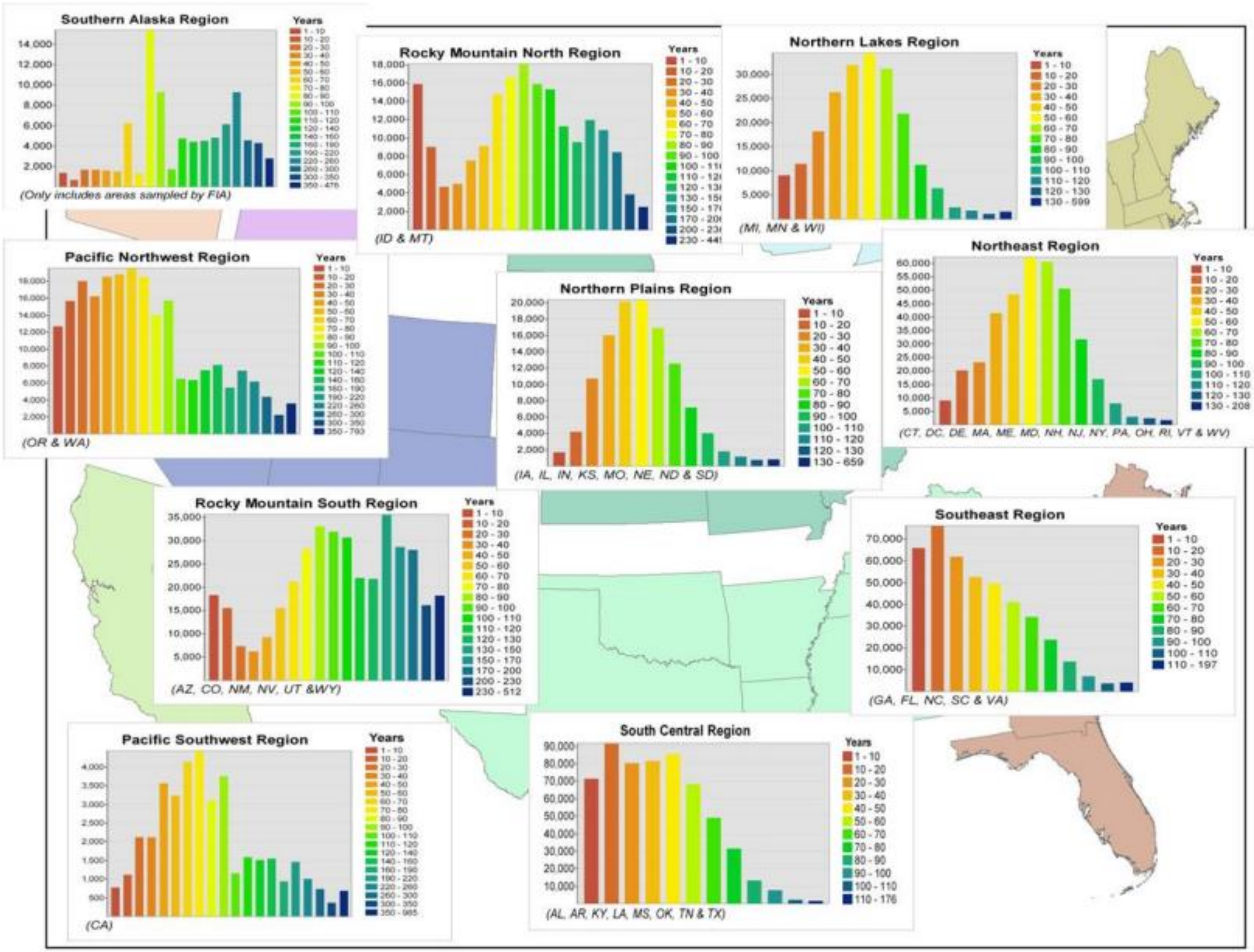


Fig. 4. The US forest age structures in different regions.

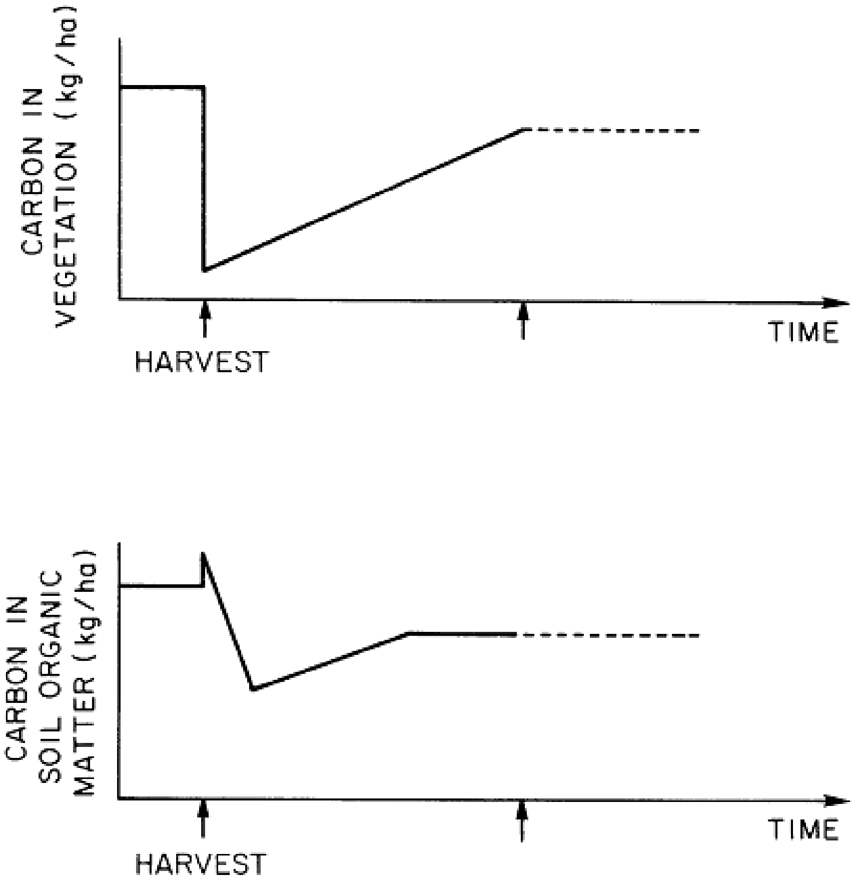


FIG. 1. Idealized curves describing the changes per unit land area in the carbon content of vegetation and soil, following harvest of a forest. The second arrows indicate where the forest has regrown sufficiently to be harvested again. The dashed line shows one of several responses.

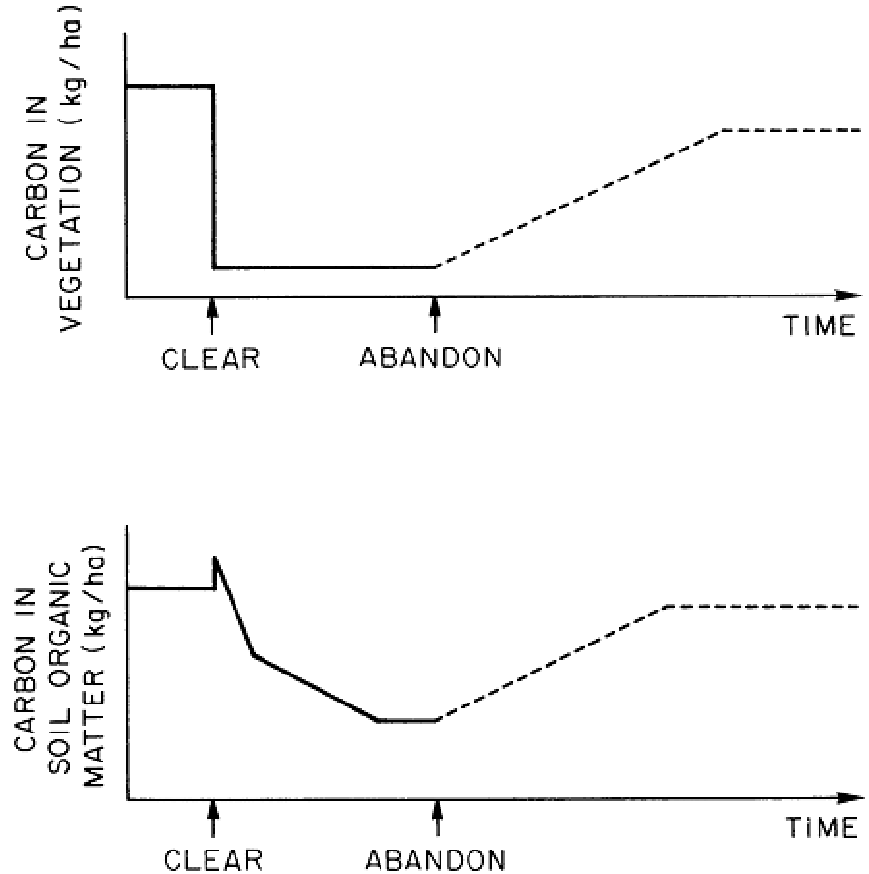


FIG. 2. Idealized curves describing the changes per unit land area in the carbon content of vegetation and soil following clearing of forest for agriculture. The dashed line shows the changes that occur if agricultural land is abandoned.

Ref. Moore et al., 1981; Houghton et al., 1983, 1987

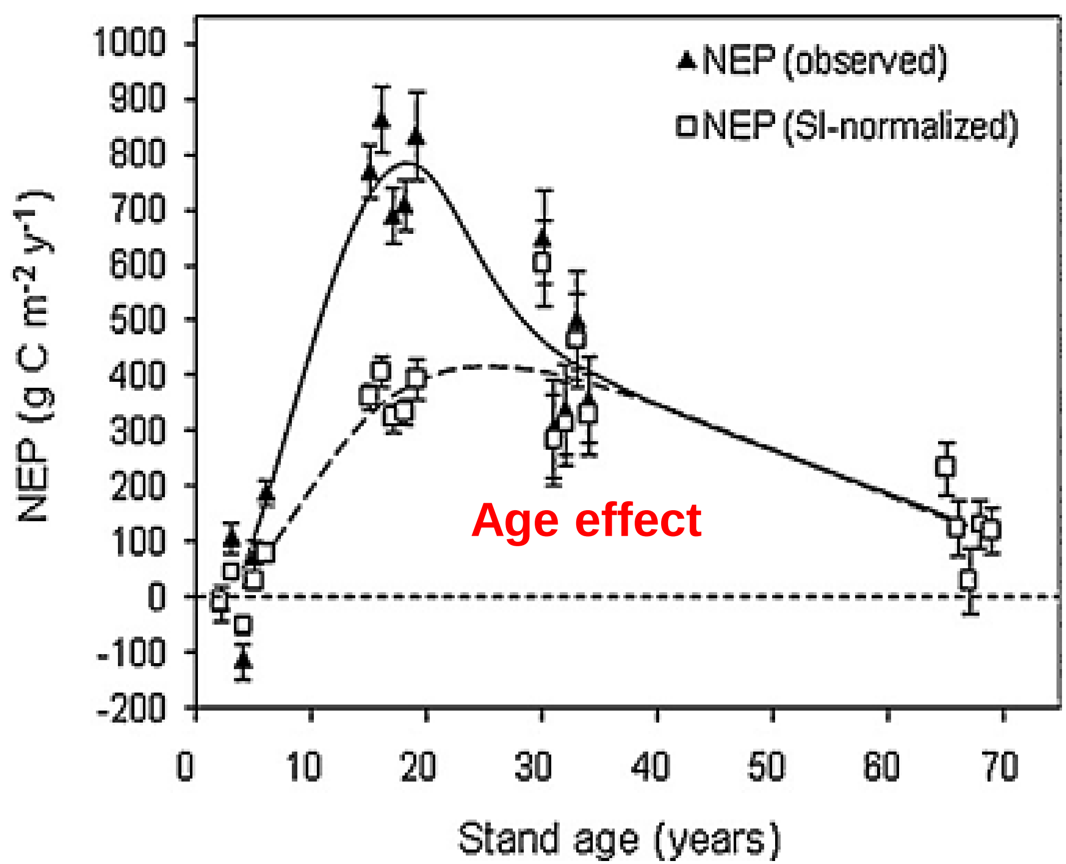


Fig. 10. Observed and site index (SI) normalized annual net ecosystem productivity (NEP), gross ecosystem productivity (GEP), and ecosystem respiration (RE) across the Turkey Point forest chronosequence over 5 years (2003–2007). Lines through data points are fitted for visual purposes only.

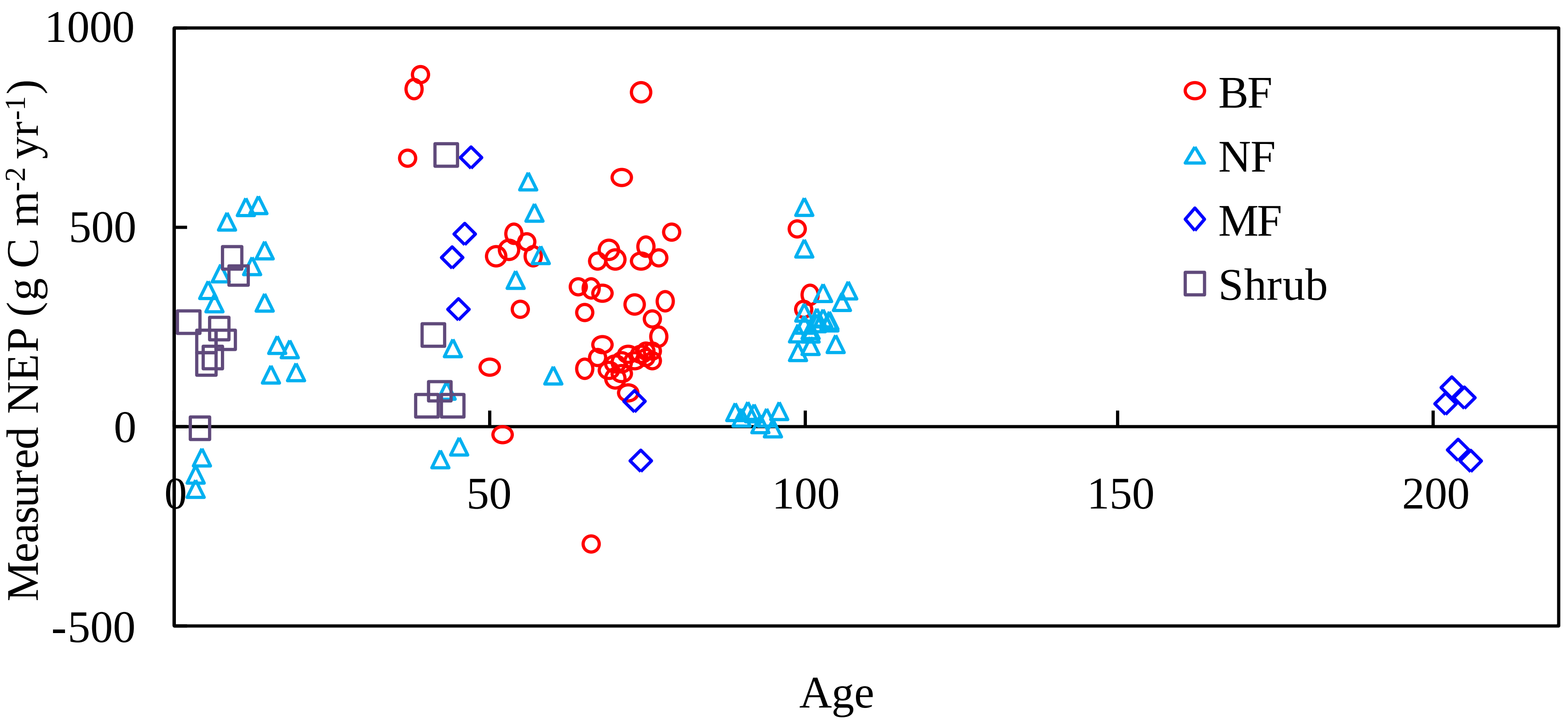
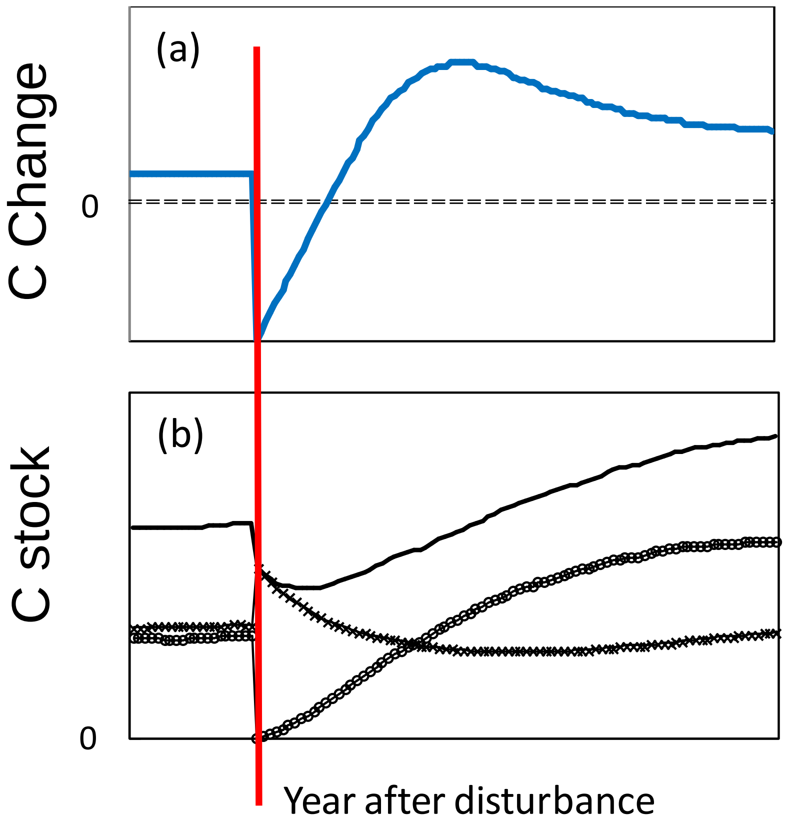


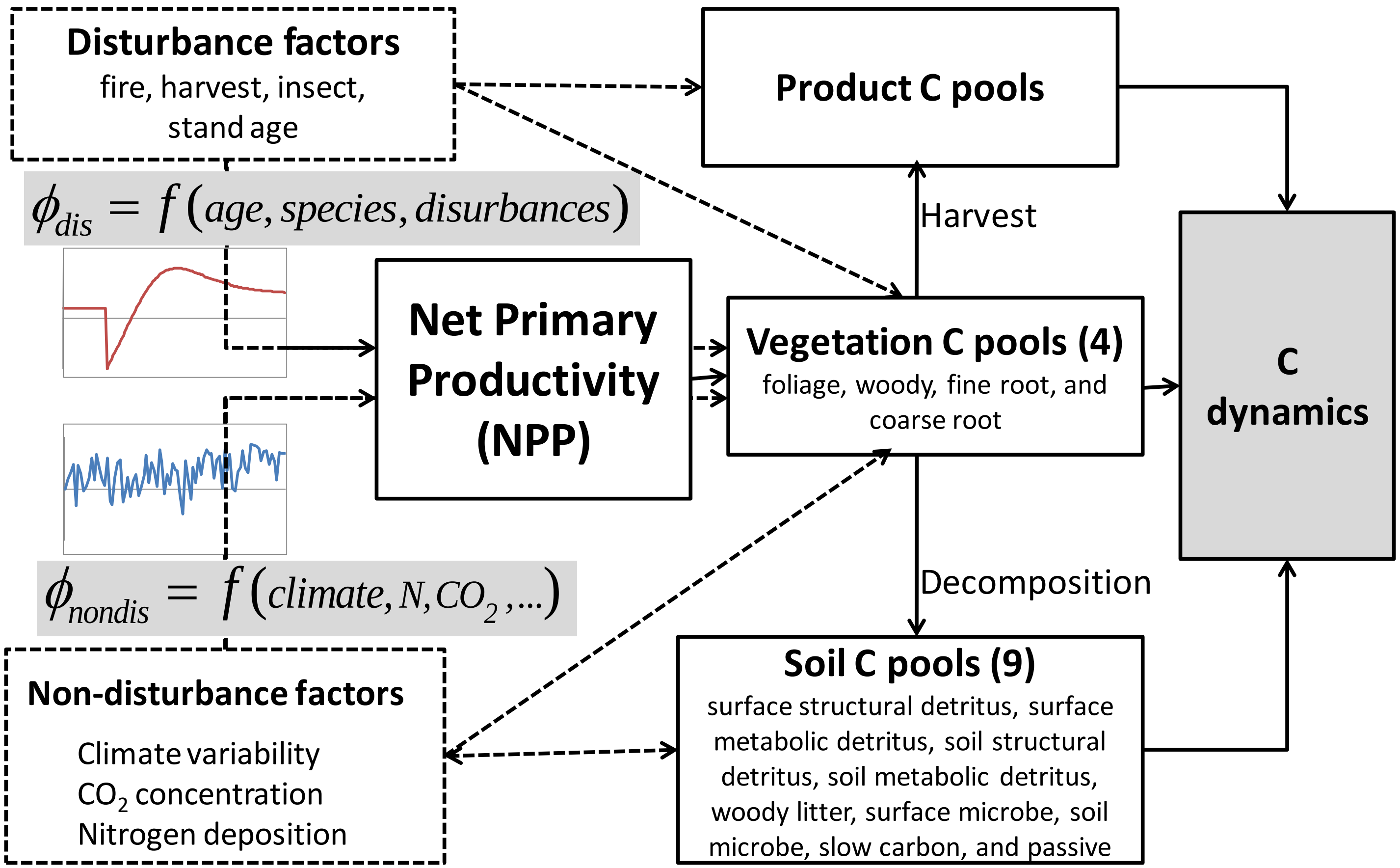
Fig. Measured and simulated NEP values at 35 Ameriflux sites (175 site-years).

Principles and Methods



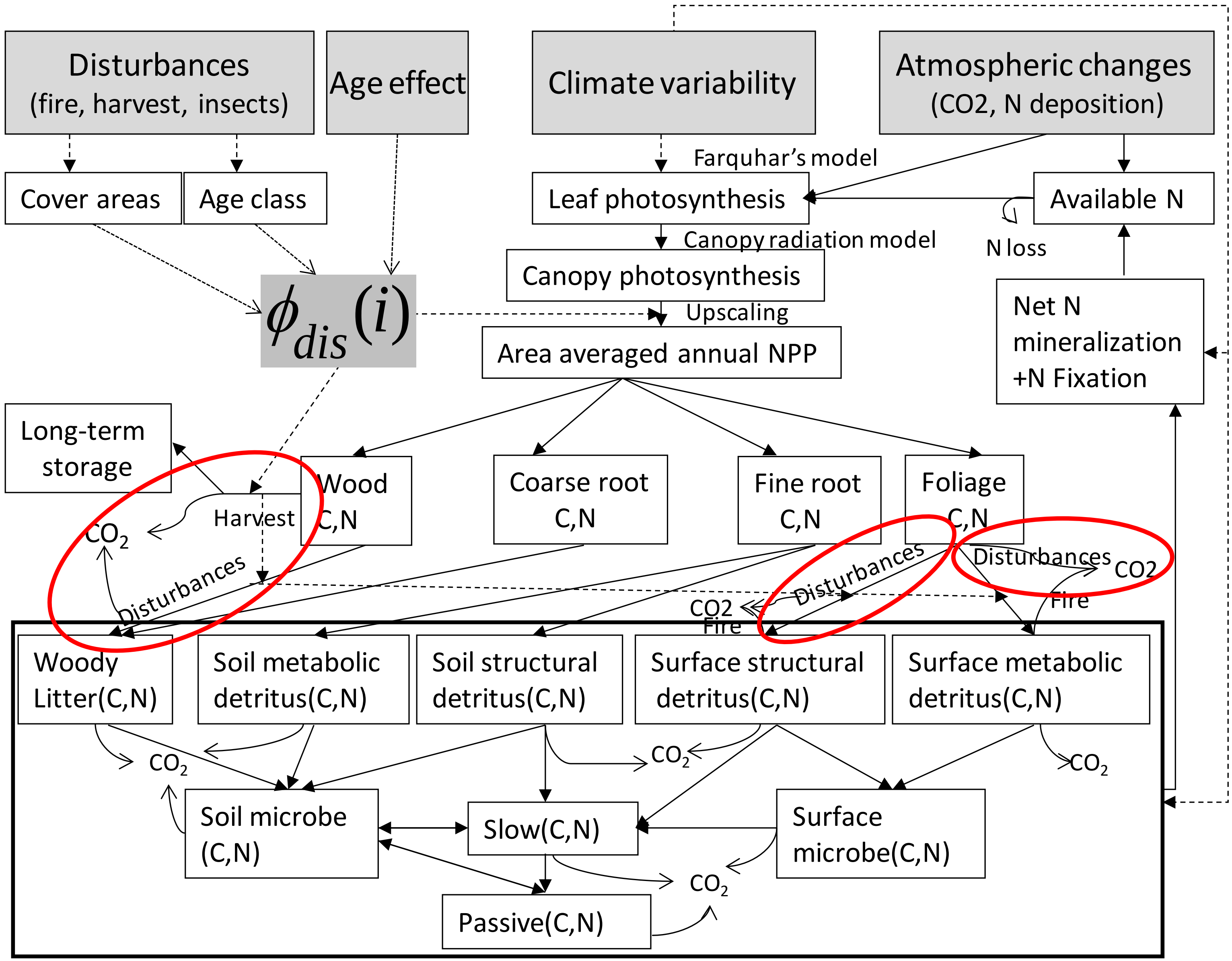
function(age)

Integrated Terrestrial Ecosystem Carbon Model (InTEC)

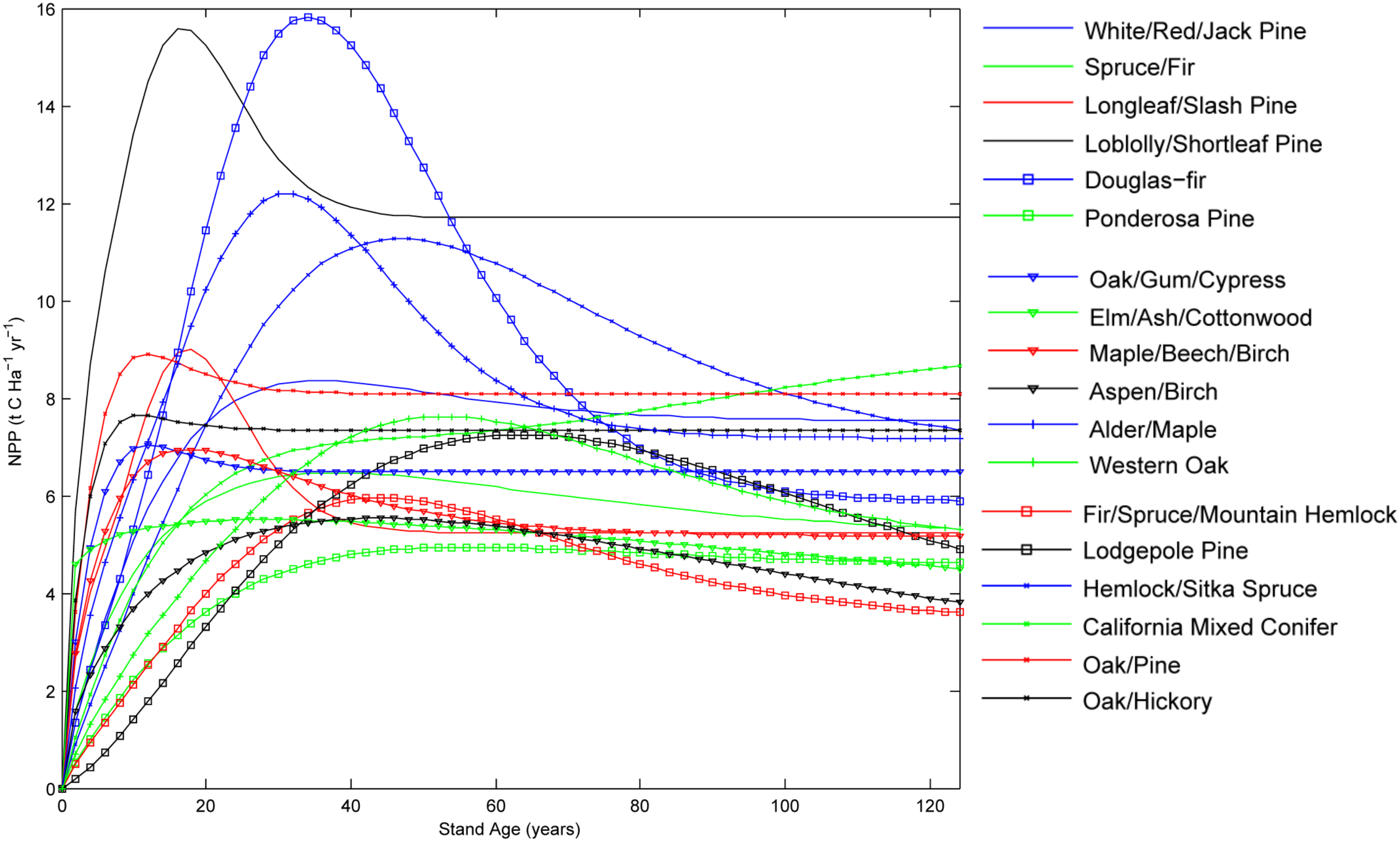


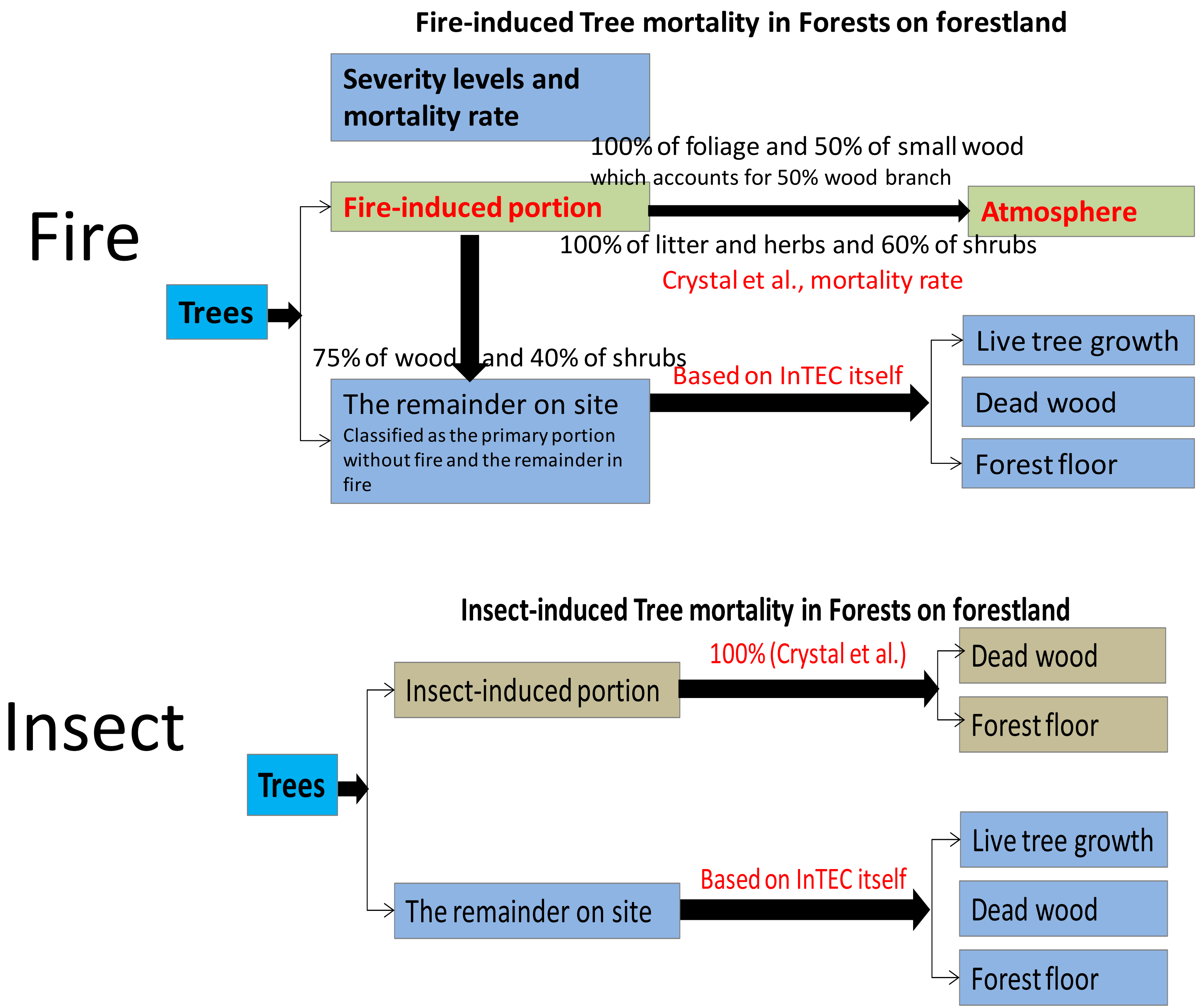
Stand age: from inventory and disturbance data

Regrowth curves: from inventory for species groups


Disturbances
(fire, harvest, insects)
Age effect
Climate variability
Atmospheric changes
(CO2, N deposition)
Cover areas
Age class
Farquhar's model
Leaf photosynthesis
Available N
N loss
Canopy radiation model
Canopy photosynthesis
Upscaling
$\phi_{dis}(i)$
Area averaged annual NPP
Net N
mineralization
+N Fixation
Long-term
storage
Harvest
CO_2
Wood
C,N
Coarse root
C,N
Fine root
C,N
Foliage
C,N
Disturbances
Disturbances
Disturbances
CO2
CO2
Fire
Fire
Woody
Litter(C,N)
Soil metabolic
detritus(C,N)
Soil structural
detritus(C,N)
Surface structural
detritus(C,N)
Surface metabolic
detritus(C,N)
CO_2
CO_2
CO_2
Soil microbe
(C,N)
Slow(C,N)
Surface
microbe(C,N)
CO_2
Passive(C,N)

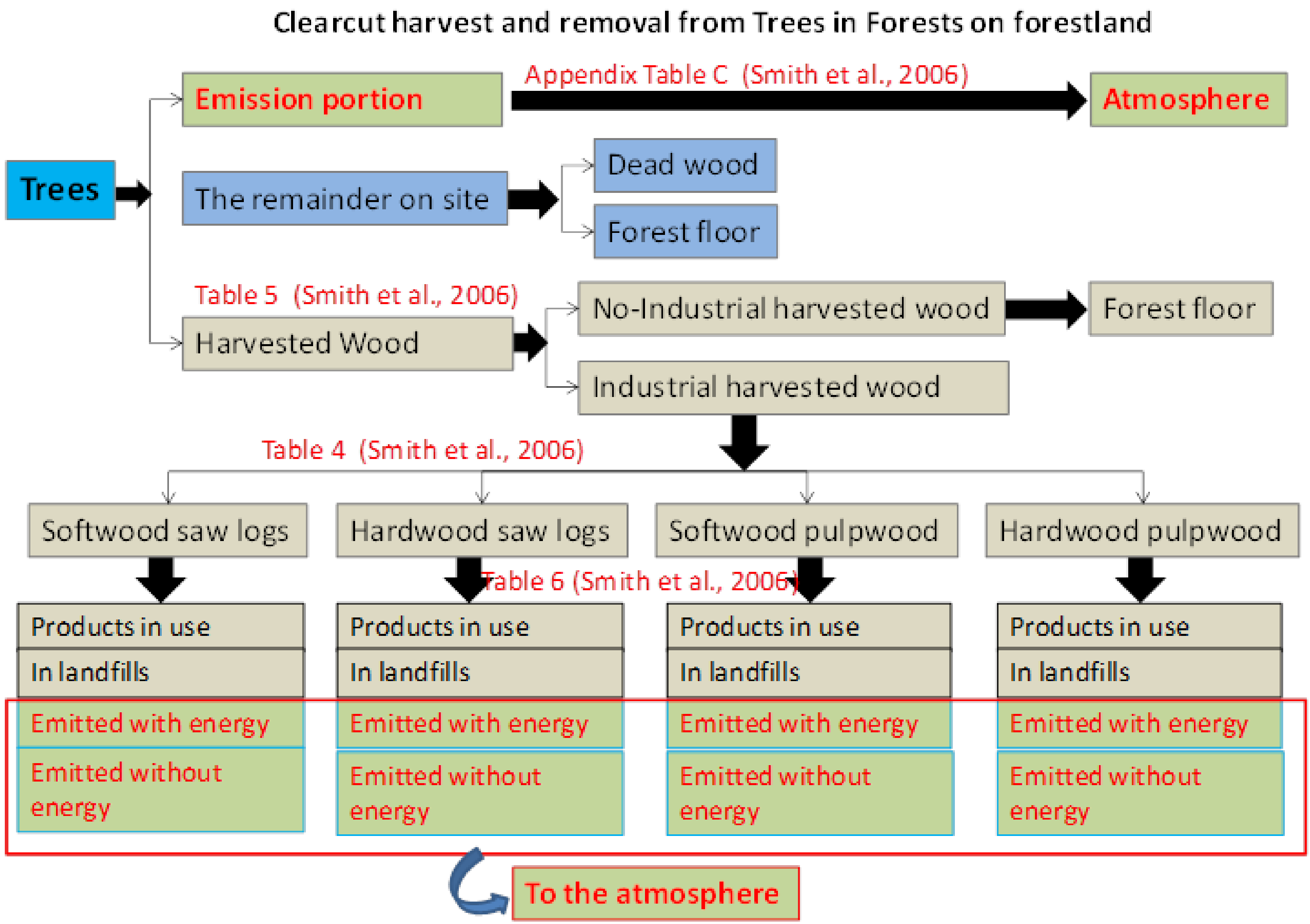
NPP-age relationships for US forests



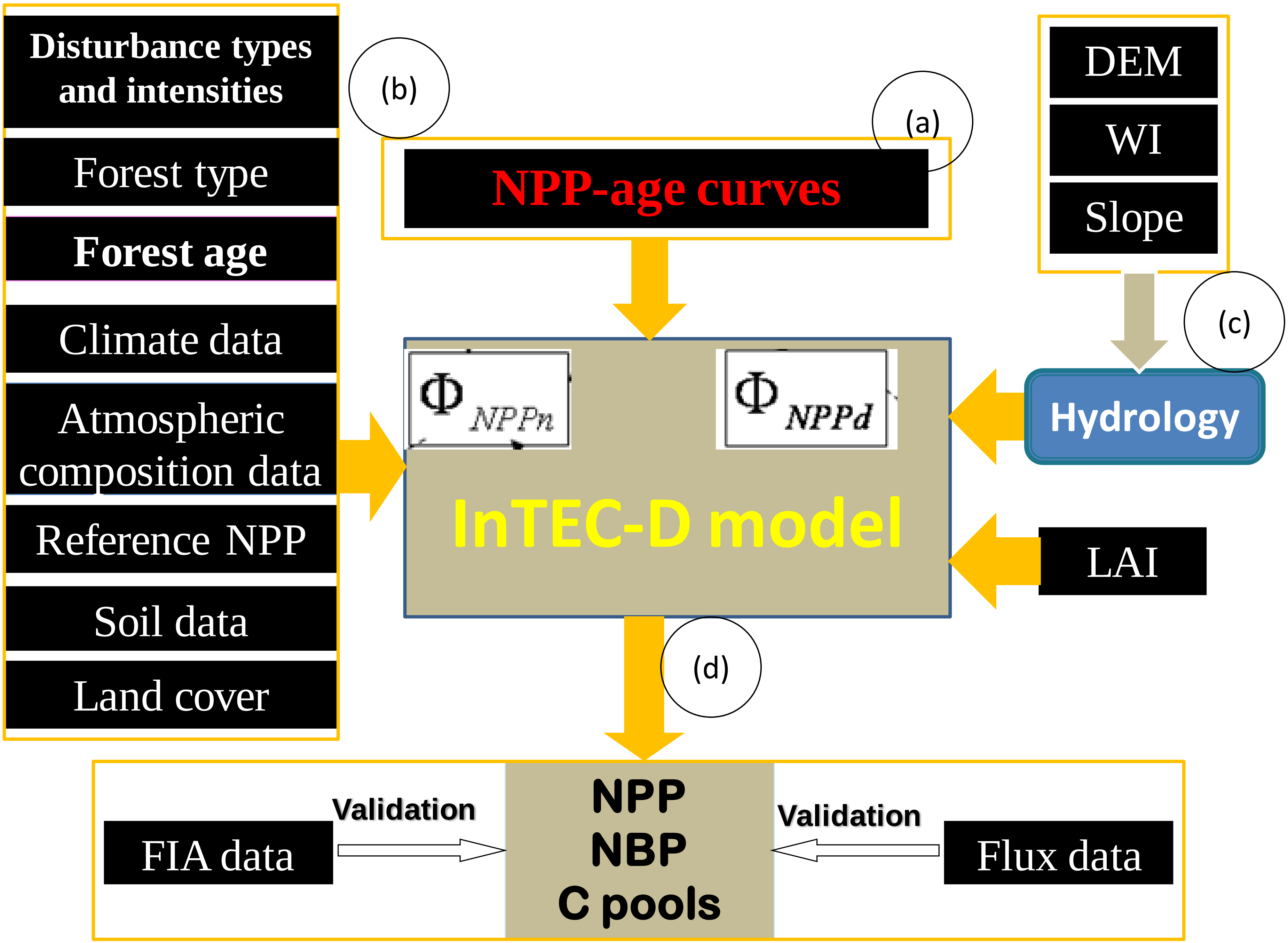


Fire-induced Tree mortality in Forests on forestland
Severity levels and mortality rate
Fire
Trees
Fire-induced portion
100% of foliage and 50% of small wood
which accounts for 50% wood branch
Atmosphere
100% of litter and herbs and 60% of shrubs
Crystal et al., mortality rate
75% of wood and 40% of shrubs
The remainder on site
Classified as the primary portion without fire and the remainder in fire
Based on InTEC itself
Live tree growth
Dead wood
Forest floor
Insect-induced Tree mortality in Forests on forestland
Insect
Trees
Insect-induced portion
100% (Crystal et al.)
Dead wood
Forest floor
The remainder on site
Based on InTEC itself
Live tree growth
Dead wood
Forest floor

Harvest

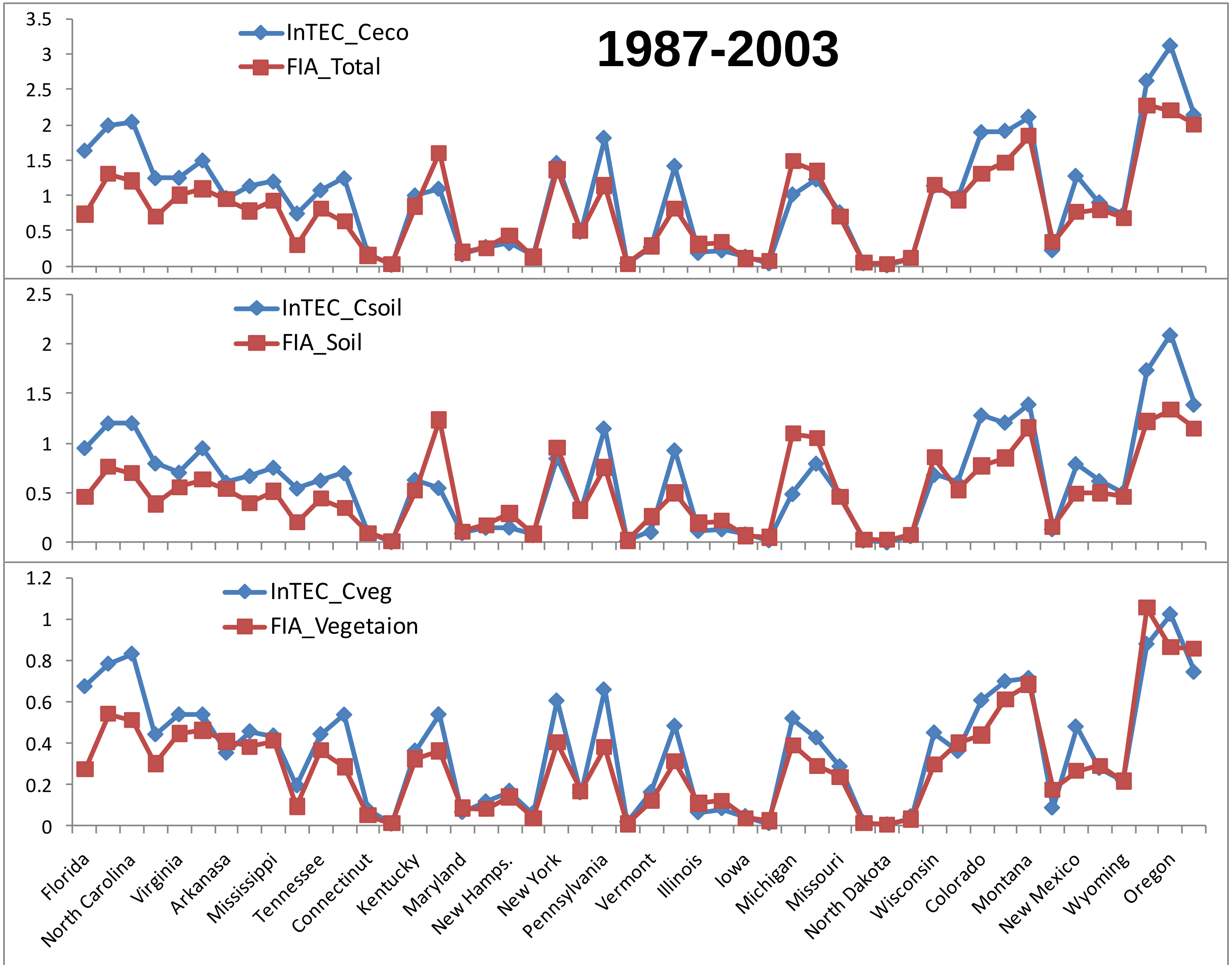


Clearcut harvest and removal from Trees in Forests on forestland
Trees
Emission portion
Appendix Table C (Smith et al., 2006)
Atmosphere
The remainder on site
Dead wood
Forest floor
Table 5 (Smith et al., 2006)
Harvested Wood
No-Industrial harvested wood
Forest floor
Industrial harvested wood
Table 4 (Smith et al., 2006)
Softwood saw logs
Hardwood saw logs
Softwood pulpwood
Hardwood pulpwood
Table 6 (Smith et al., 2006)
Products in use
In landfills
Emitted with energy
Emitted without energy
Products in use
In landfills
Emitted with energy
Emitted without energy
Products in use
In landfills
Emitted with energy
Emitted without energy
Products in use
In landfills
Emitted with energy
Emitted without energy
To the atmosphere

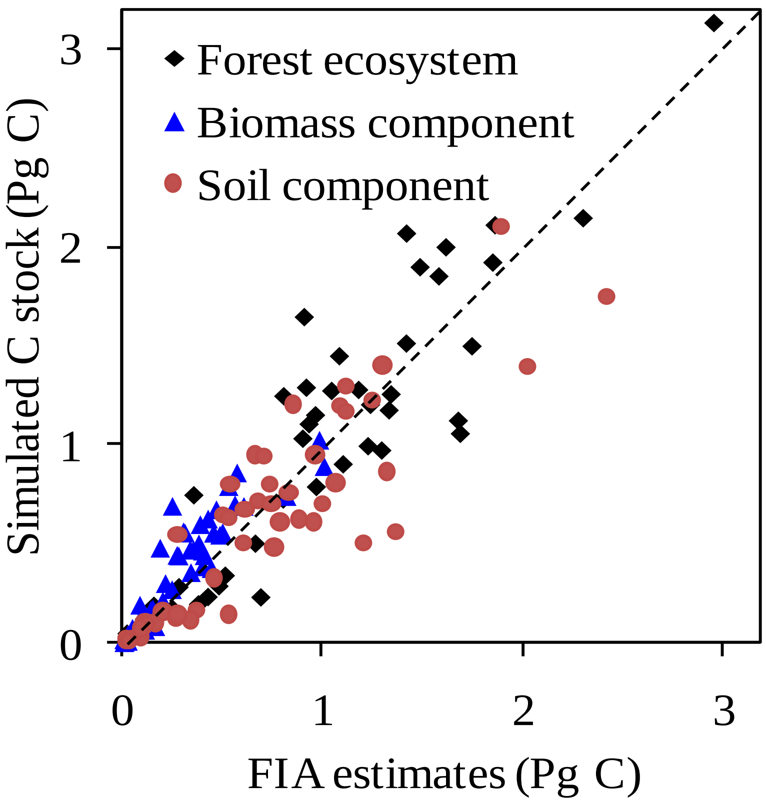


Disturbance types and intensities
Forest type
Forest age
Climate data
Atmospheric composition data
Reference NPP
Soil data
Land cover
(b)
(a)
NPP-age curves
DEM
WI
Slope
(c)
Hydrology
Φ_{NPPn}
Φ_{NPPd}
InTEC-D model
LAI
(d)
FIA data
Validation
NPP
NBP
C pools
Validation
Flux data

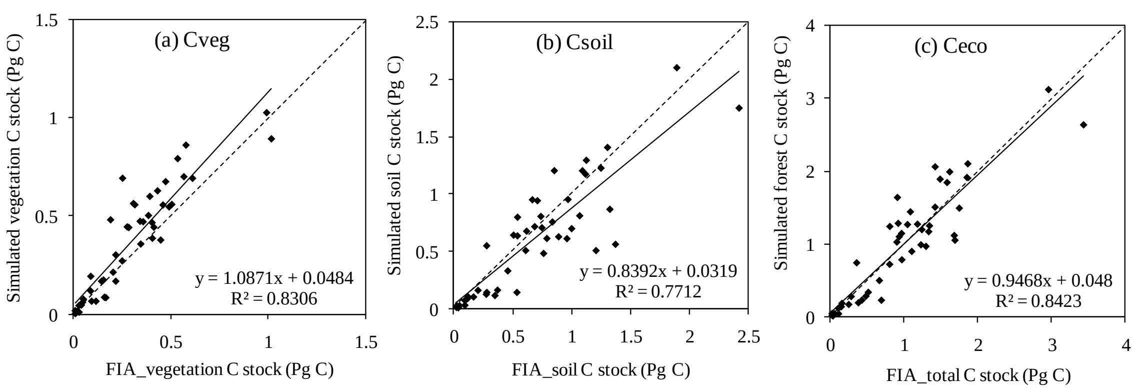
Comparison and validation

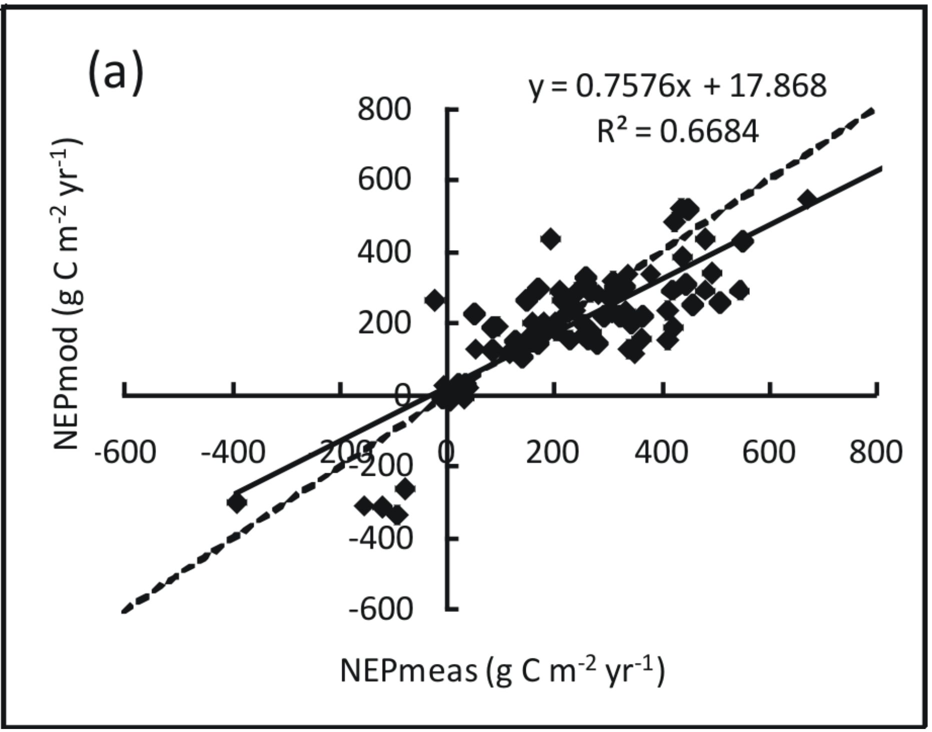


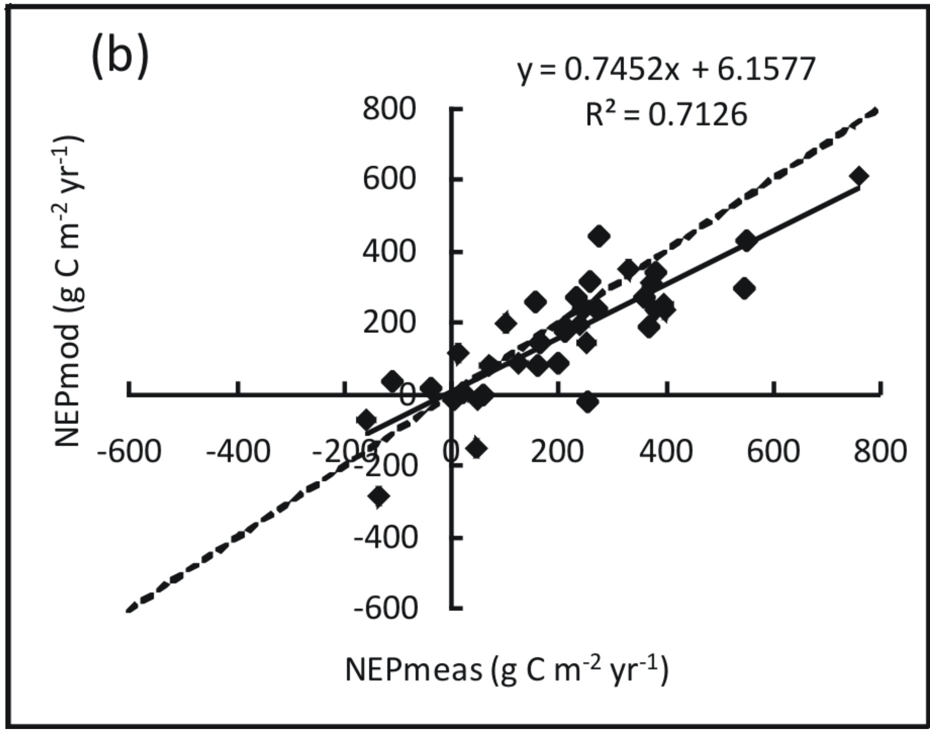
Comparison and validation



State-by-state in 48 lower states

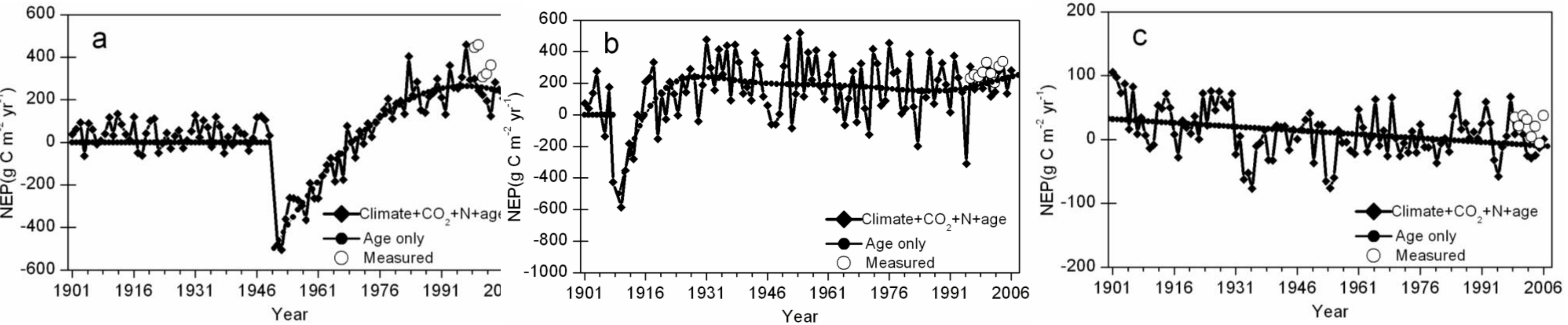




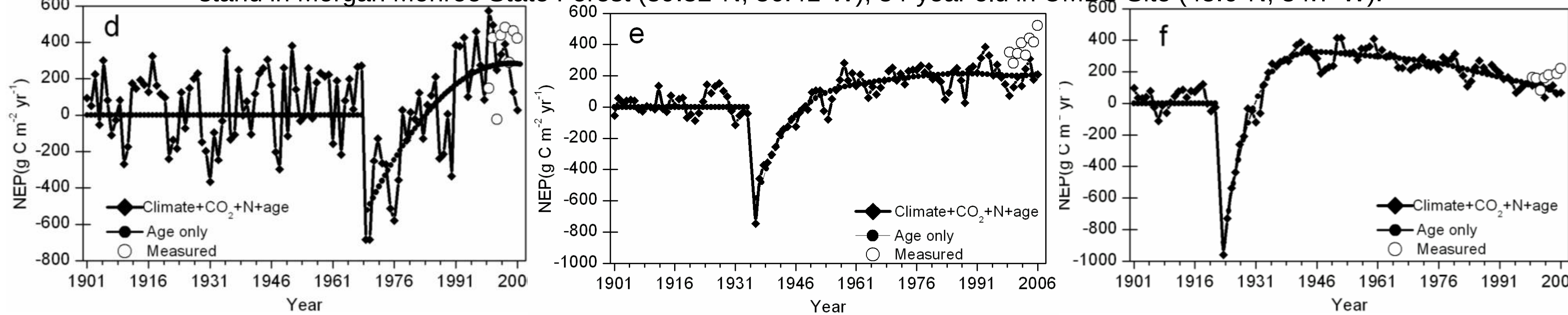


35 US Fluxsites

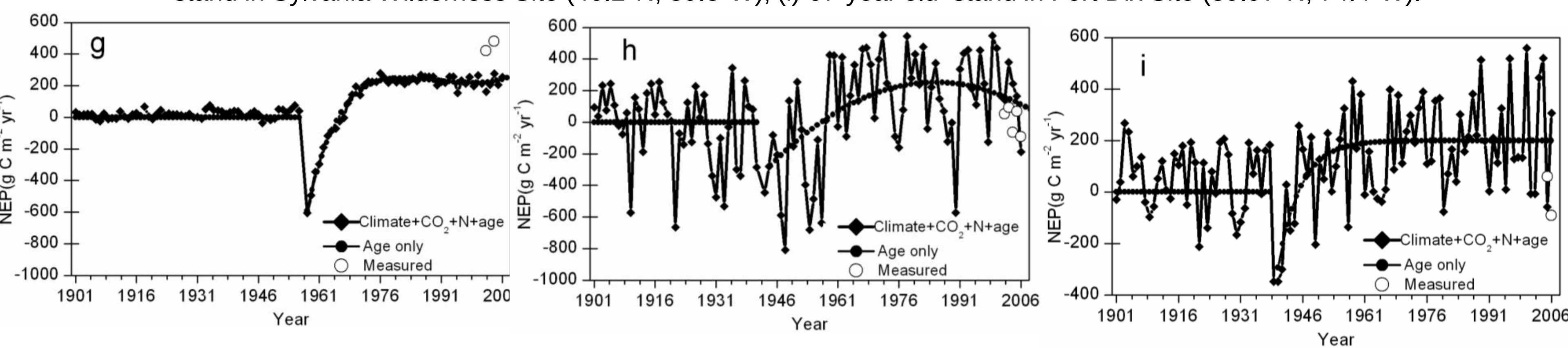
(1) Temporal series of NEP in needle forests (NF). (a) 56-year old stand in Wind River Crane Site (45.82ºN, 121.95ºW) ; (b) 97-year old stand in Howland Forest West Tower Site (45.2ºN, 68.7ºW); (c)173-year old stand in Niwot Ridge Site (40.03ºN, 105.5ºW).

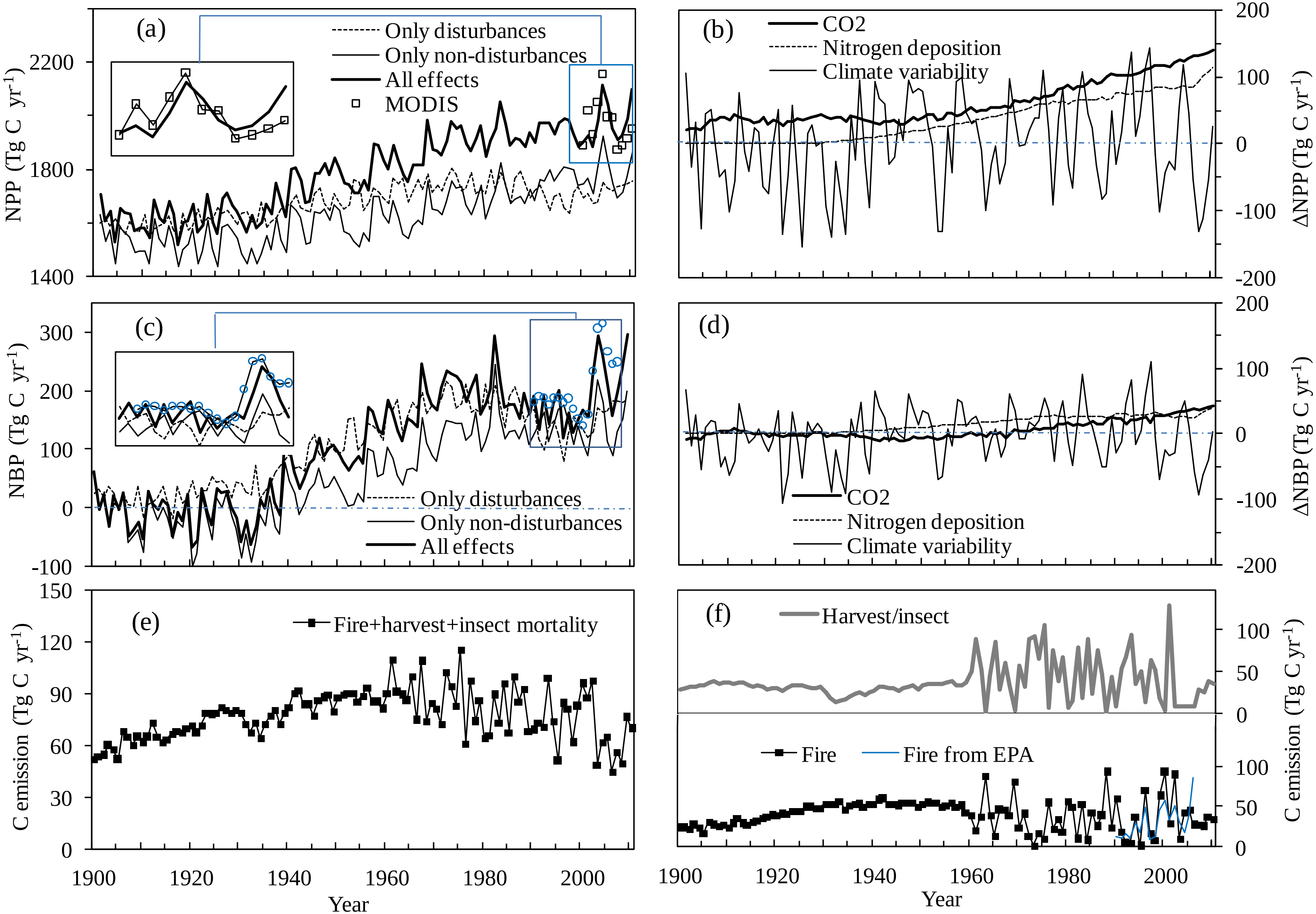


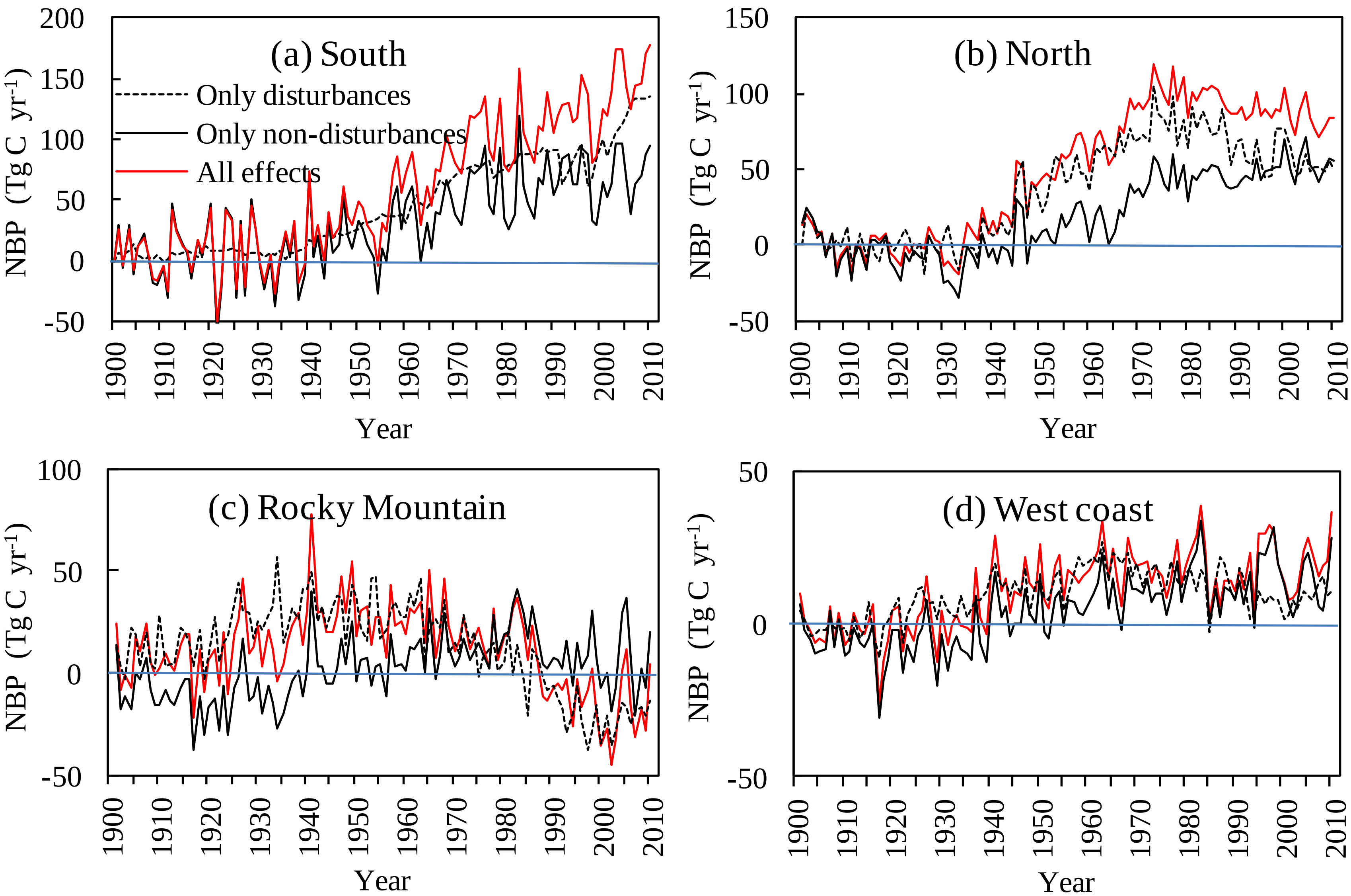
(2) Temporal series of NEP in broadleaf forests (BF). (d)37-year old stand in Willow Creek Site (45.8ºN, 90.1ºW); (e)71-year old stand in Morgan Monroe State Forest (39.32ºN, 86.41ºW); 84-year old in UMBS Site (45.6ºN, 84.7ºW).

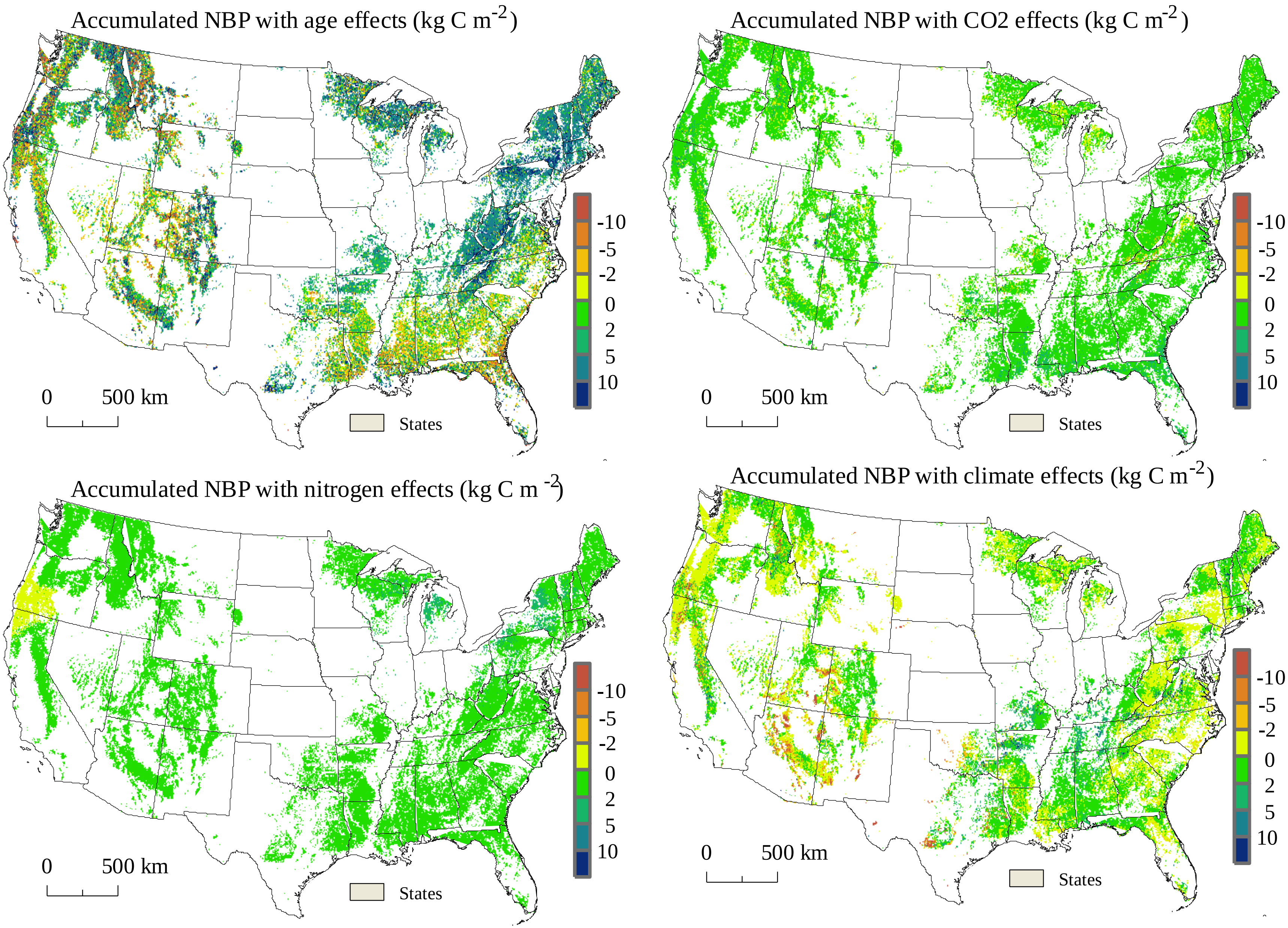


(3) Temporal series of NEP in mixed forests (MF). (g)49-year old stand in Little Prospect Hill(42.54ºN, 72.18ºW); (h) 64-year old stand in Sylvania Wilderness Site (46.2ºN, 89.3ºW); (i) 67-year old stand in Fort Dix Site (39.97ºN, 74.4ºW).



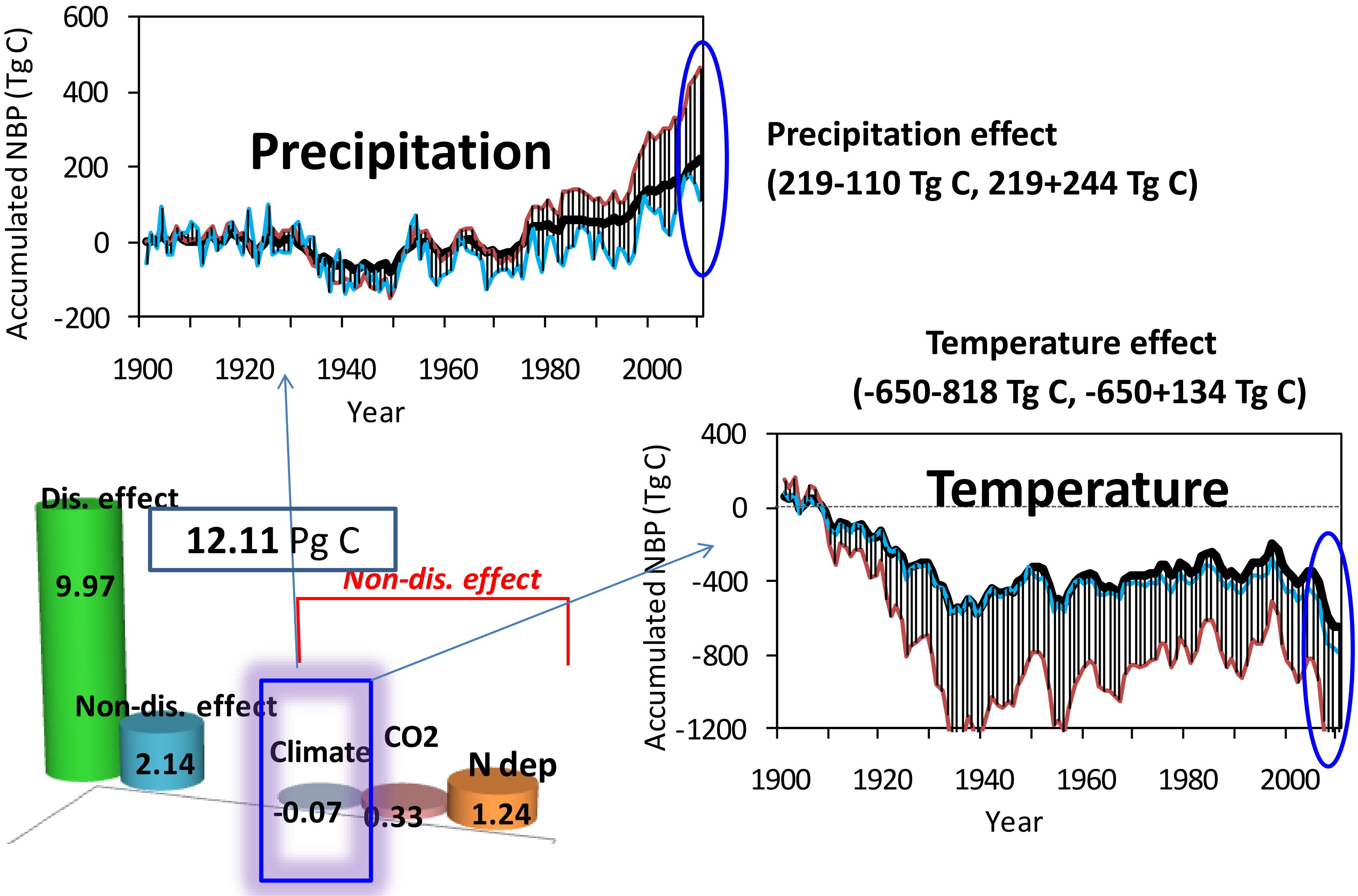

(a)
Only disturbances
Only non-disturbances
All effects
MODIS
NPP (Tg C yr-1)
2200
1800
1400
(b)
CO2
Nitrogen deposition
Climate variability
ΔNPP (Tg C yr-1)
200
100
0
-100
-200
(c)
NBP (Tg C yr-1)
300
200
100
0
-100
Only disturbances
Only non-disturbances
All effects
(d)
ΔNBP (Tg C yr-1)
CO2
Nitrogen deposition
Climate variability
(e)
Fire+harvest+insect mortality
C emission (Tg C yr-1)
150
120
90
60
30
0
(f)
Harvest/insect
Fire
Fire from EPA
C emission (Tg C yr-1)
100
50
0
1900
1920
1940
1960
1980
2000
Year


(a) South
Only disturbances
Only non-disturbances
All effects
NBP (Tg C yr-1)
200
150
100
50
0
-50
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year
(b) North
150
100
50
0
-50
Year
(c) Rocky Mountain
100
50
0
-50
Year
(d) West coast
50
0
-50
Year

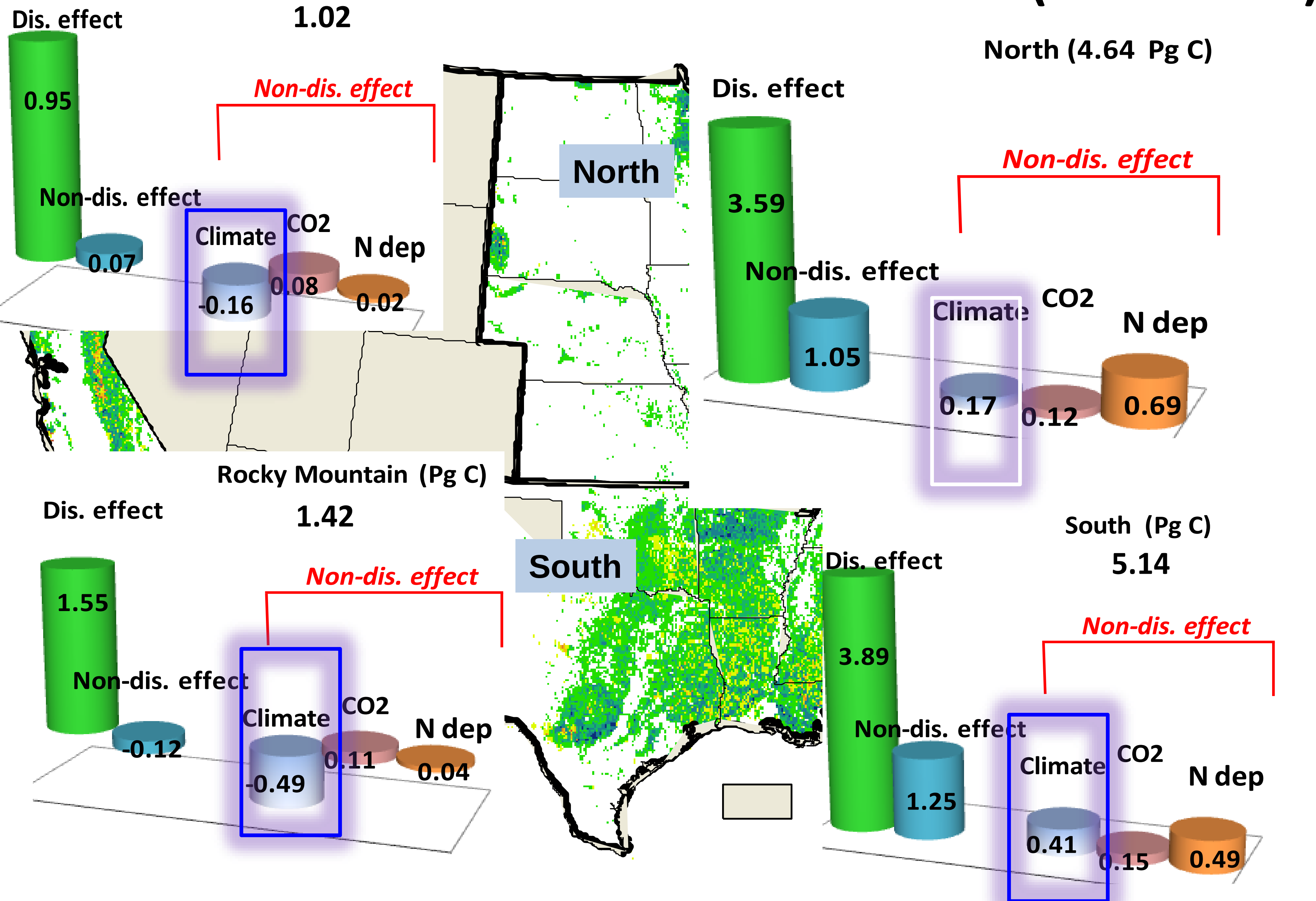


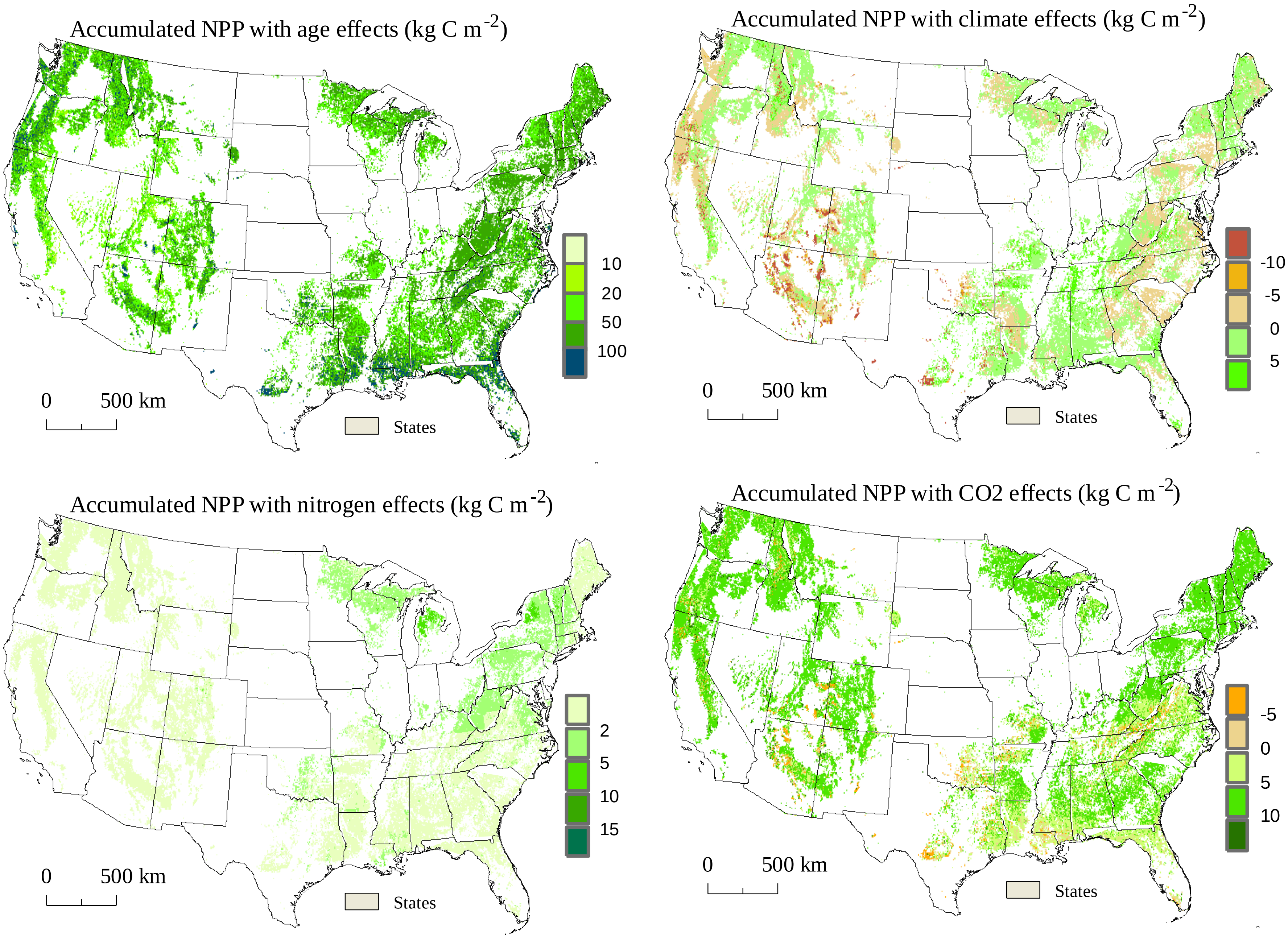
Accumulated NBP with age effects (kg C m-2)
-10
-5
-2
0
2
5
10
0
500 km
States
Accumulated NBP with CO2 effects (kg C m-2)
-10
-5
-2
0
2
5
10
0
500 km
States
Accumulated NBP with nitrogen effects (kg C m-2)
-10
-5
-2
0
2
5
10
0
500 km
States
Accumulated NBP with climate effects (kg C m-2)
-10
-5
-2
0
2
5
10
0
500 km
States

For whole US forests, 1901-2010

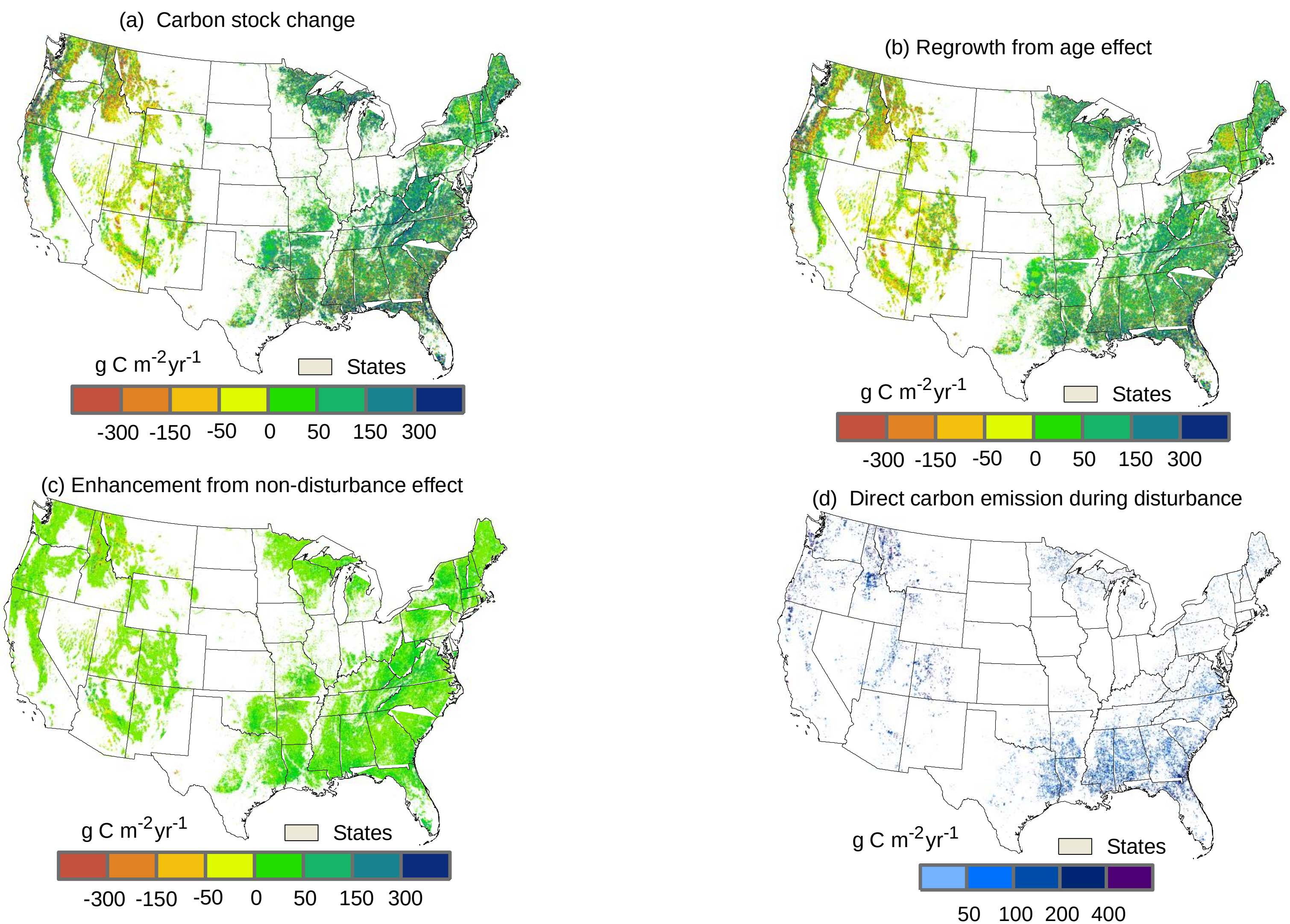


tion to acumulated NBP (1901-2010)




Accumulated NPP with age effects (kg C m-2)
10
20
50
100
0 500 km
States
Accumulated NPP with climate effects (kg C m-2)
-10
-5
0
5
0 500 km
States
Accumulated NPP with nitrogen effects (kg C m-2)
2
5
10
15
0 500 km
States
Accumulated NPP with CO2 effects (kg C m-2)
-5
0
5
10
0 500 km
States

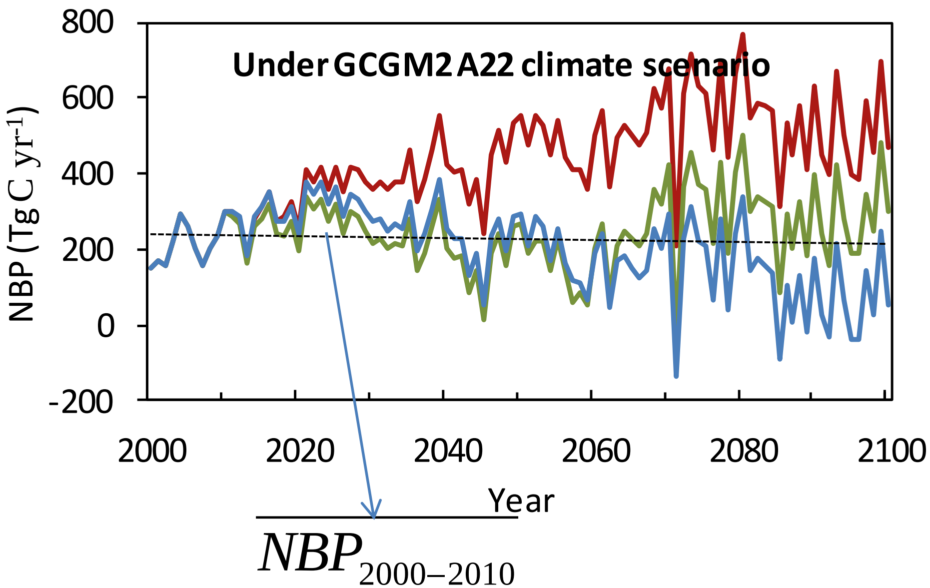
Maps of ecosystem carbon stock change from 1991 to 2010 due to (a) overall effect, (b) regrowth, (c) direct carbon emission during disturbance, and (d) non-disturbance factors, over conterminous USA

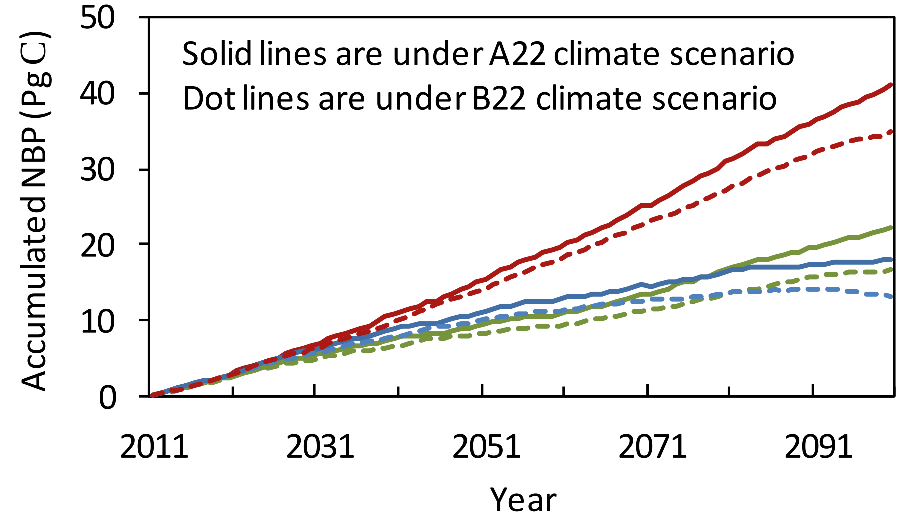


Future Projections

Three disturbance scenarios:

- With age change and no disturbances
- With fixed age and no disturbances
- With age change and disturbances





USDA United States Department of Agriculture

Past and Prospective Carbon Stocks in Forests of Northern Wisconsin

A Report from the Chequamegon-Nicolet National Forest Climate Change Response Framework

USDA United States Department of Agriculture

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Forest Service | Rocky Mountain Research Station | General Technical Report RMRS-GTR-xxxx | November 2019

Acknowledgements

Jingming Chen, Liming He, Univerisity of Toronto

Yude Pan, USFS

Rich Birdsey, USFS

Christopher M. Gough, Virginia Commonwealth University

Jiquan Chen, our Chair

Timothy A. Martin, University of Florida

Danilo Dragoni, Indiana University