Dynamic Regional Carbon Budget Based on Multi-Scale Data-Model Fusion

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Toward dynamic regional carbon budgets

High uncertainties exist in the magnitude, regional distribution, and temporal variations of the terrestrial carbon sink

Dynamic regional carbon budgets will

- **Provide spatially and temporally explicit, quantitative information on the terrestrial carbon sink**

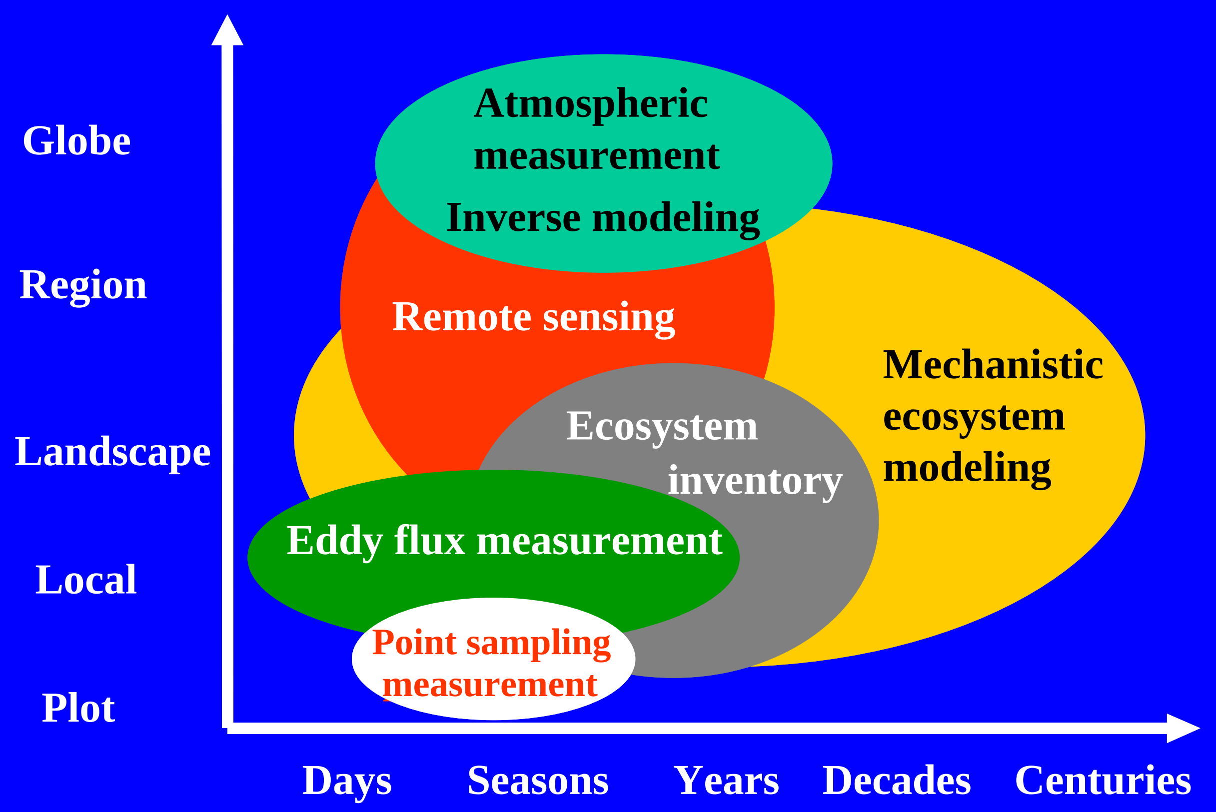
- **Link the spatio-temporal variations to specific driving forces and mechanisms**

The quantitative and mechanistic information is fundamentally important to

- **Effective implementation of the Kyoto Protocol, which request each signatory country to report annual GHG inventory**

- **Planning and practicing regional ecosystem carbon management**

Various approaches based on different techniques have been used in regional carbon budgets



The estimates using different approaches vary widely, for example,

- **For the US, from 0.1 to 0.8 Gt C yr^{-1}, and atmosphere-based estimate is about twice of land-based estimate (e.g. Pacala et al. 2001; Houghton, 2003)**

- **For Europe, from 0.1 to 0.5 Gt C yr^{-1}, and atmosphere-based estimate is about 3 times of land-based estimate (e.g. Jassens et al. 2003)**

The estimates using differ approaches vary widely, for example,

- **For the tropics**, from a substantial source to a moderate sink (Malhi and Grace 2001). Land use-induced C release is 2.2 Gt C yr^{-1} based on statistical data (Houghton et al. 2003), but just 0.9 Gt C yr^{-1} based on remote sensing data (DeFries et al 2002)

- **For China**, from 0.02-0.09 Gt C yr^{-1} based on forest inventories (e.g. Fang et al. 2002, Li et al. 2003) and ecosystem modeling (Cao et al. 2003)

And the studies did not clearly identify the causal factors or mechanisms, for example,

- Some studies estimated the “natural” mechanism play a significant role (e.g. Friedlingstein et al. 1998), but others attributed primarily to land use mechanism (e.g. Caspersen et al. 2000)

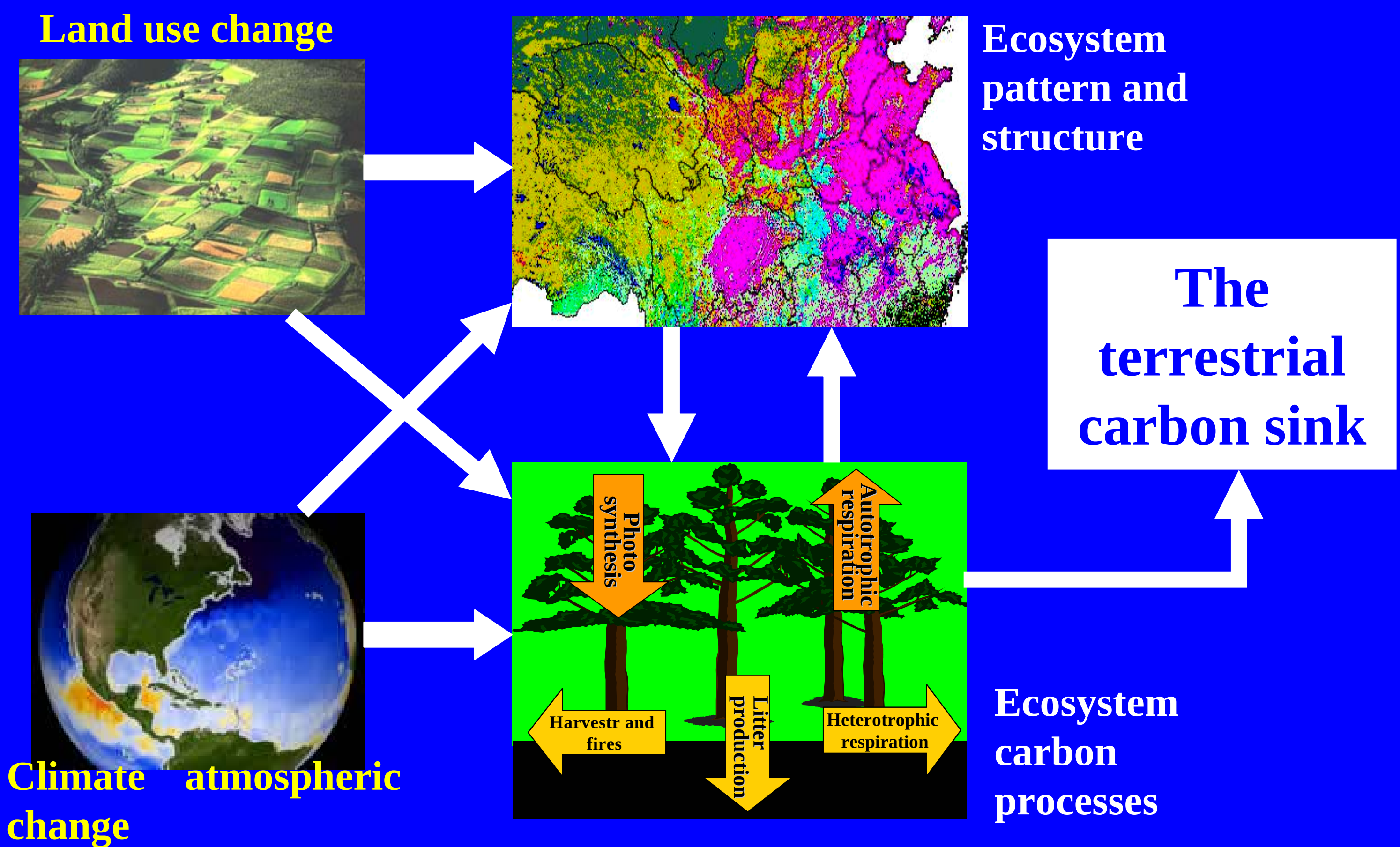
- Remote sensing-based studies attributed the increasing carbon sink in the north to warming (e.g. Myneni et al. 2001), but ecosystem observations and modeling indicate to increases in precipitation (e.g. Nemani et al. 2002, Cao et al. 2002)

The high uncertainties arise mainly from incomplete carbon accounting or using inappropriate methodologies

1. Incomplete carbon accounting

Existing regional carbon budgets are mostly based on measured changes in the carbon stocks or fluxes of single ecosystems (forest, grass, crop etc) or single ecosystem components (standing biomass, soil carbon etc)

2. Lack of quantification of the combined effect of different driving forces on both ecosystem pattern and process



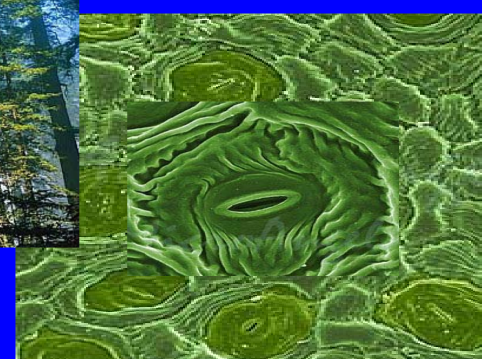
3. Most studies on mechanisms of ecosystem carbon cycle or on the response of environmental changes neglect their different effects at different scales

Regional pattern

Community composition

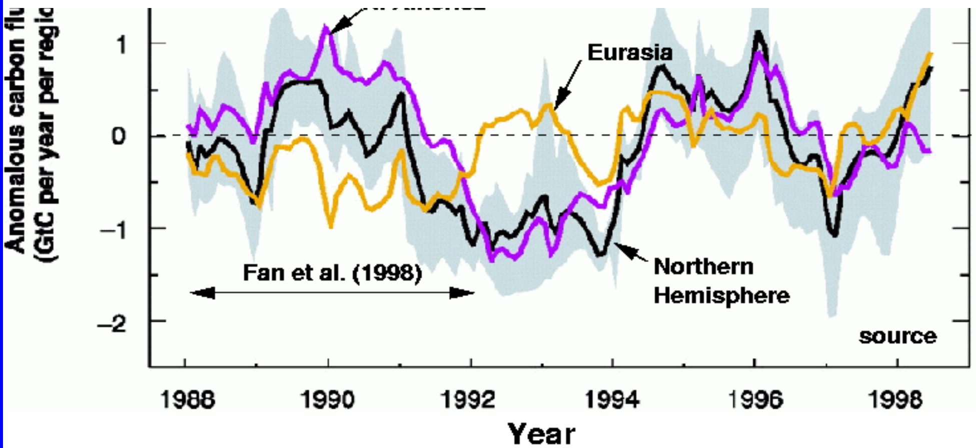
Canopy structure

micro- eco-physiology



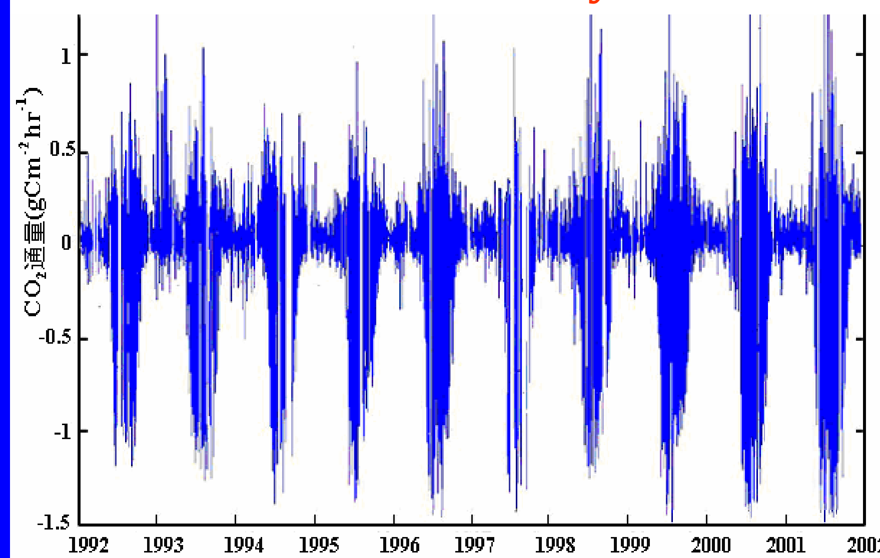
4. Regional carbon budgets are often based on measurements of changes in ecosystem carbon stocks or fluxes for a short time (few years)

Net C flux at global and continental scales



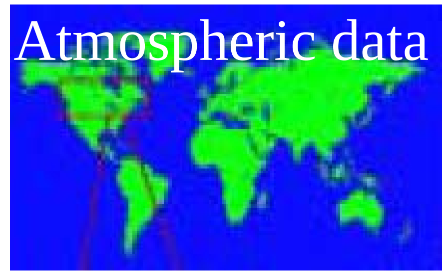
Bousquet et al. 2000. Science 290, 1342–1346. Figure 4A.

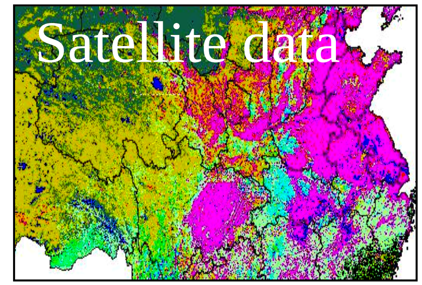
Net C flux from at ecosystem level

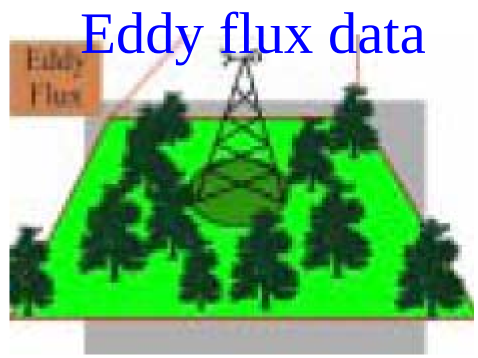


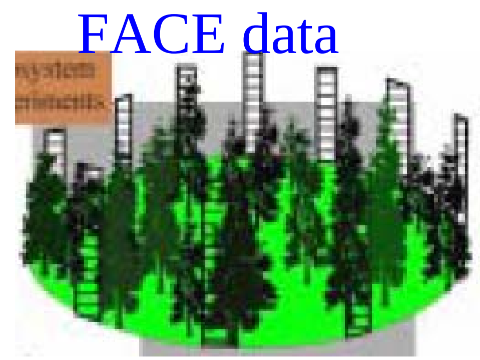
In the past decade, there have been extensive and intensive observations at different scales using various technologies

However, the rich data have not been exploited in regional carbon budgets because of lack of an approach to assimilate the data obtained at multiple scales









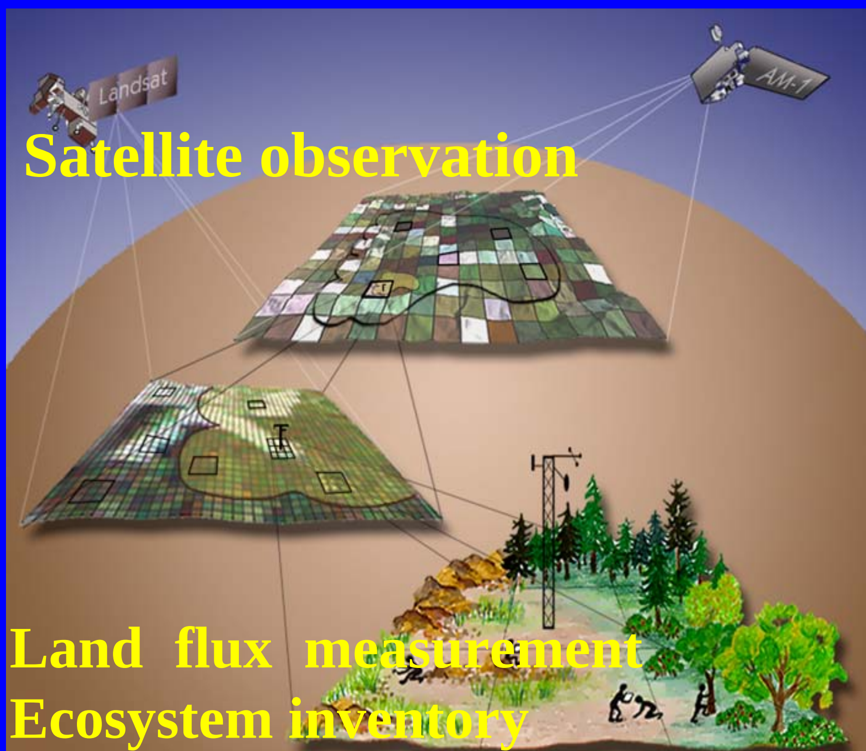
Traditional cross-scaling approaches used in regional carbon budgets:

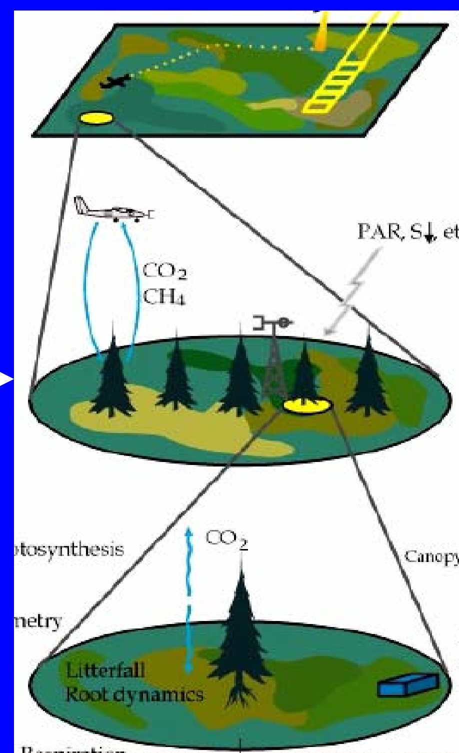
The "top-down" approach (based on atmospheric measurement and inverse inverse modeling, satellite remote sensing) is difficulty to identify the driving force and mechanisms of ecosystem changes

The "Bottom-Up" approach directly extrapolates small-scale results (from controlled experiments and point observation) or uses mechanistic models based small-scale studies, neglecting mechanisms that operate at large scales

A new cross-scaling approach is emerging: data-model fusion based on multi-scale observation and cross-scale mechanistic modeling

Multi-scale observation





Cross-scale modeling

A multi-scale data-model fusion system

Multi-Scale Observations

From site to landscape to regional scales using techniques, e.g. satellite remote sensing, eddy covariance, ecosystem inventory

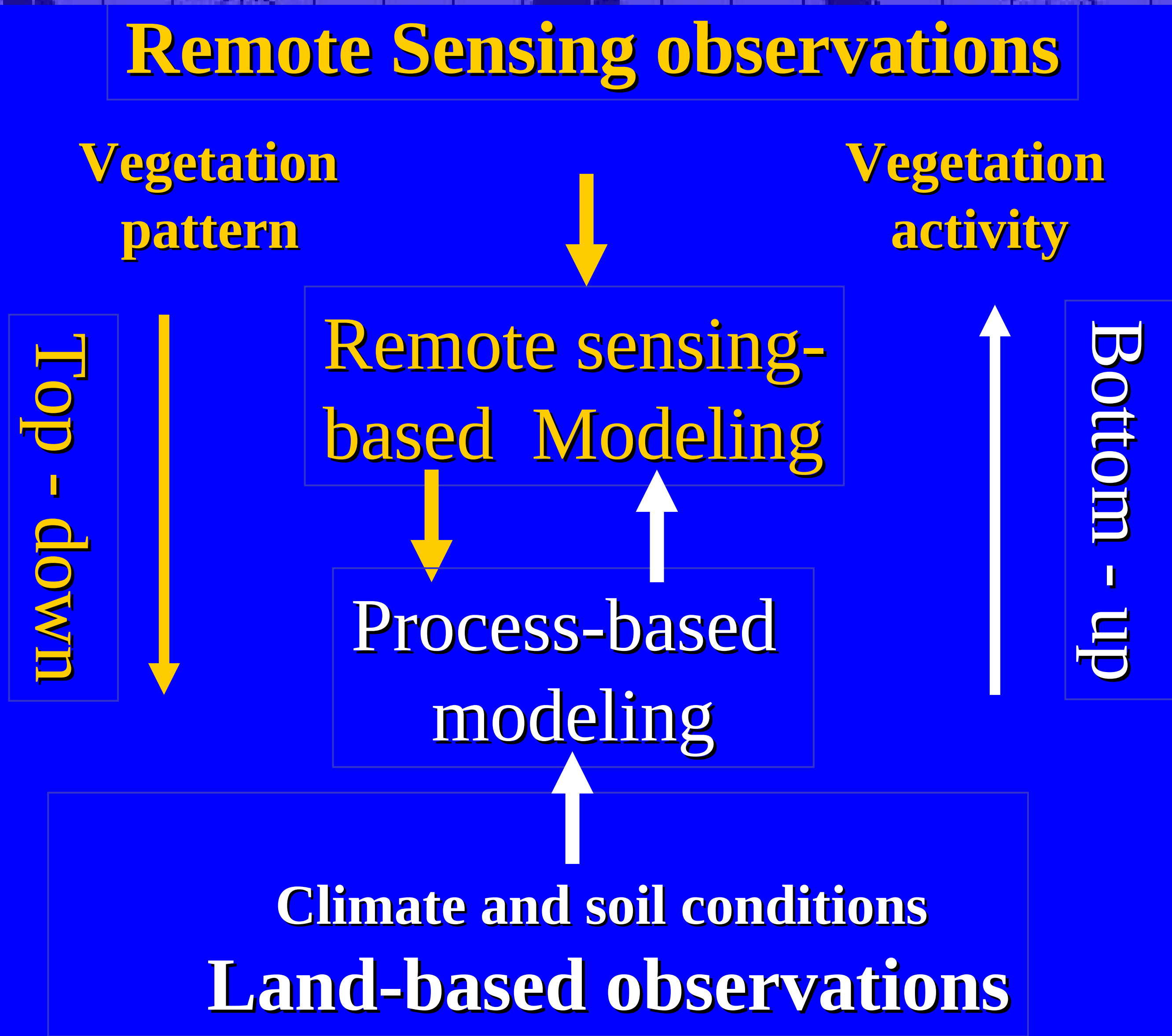
Cross-Scale Data-Model Fusion

Integrate multi-scale data into new-generation ecosystem models to simulate cross-scale mechanistic interconnections

Dynamic data assimilation

Continuously assimilating multi-scale observational data into dynamic simulation to achieve realistic ecological forecasting

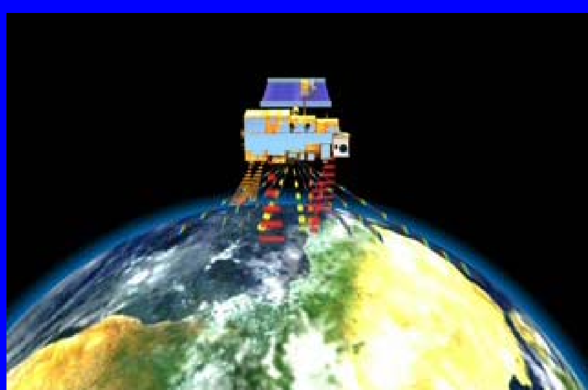
We have developed an approach to combine satellite observation and mechanistic modeling



Satellite remote sensing is currently the only means available to

- **observe actual changes in ecosystem pattern and activity at regional scales and high resolutions**
- **reflect the combined effect of various driving forces**

But cannot directly measure carbon fluxes or stocks, is weak in detecting mechanisms of ecosystem changes

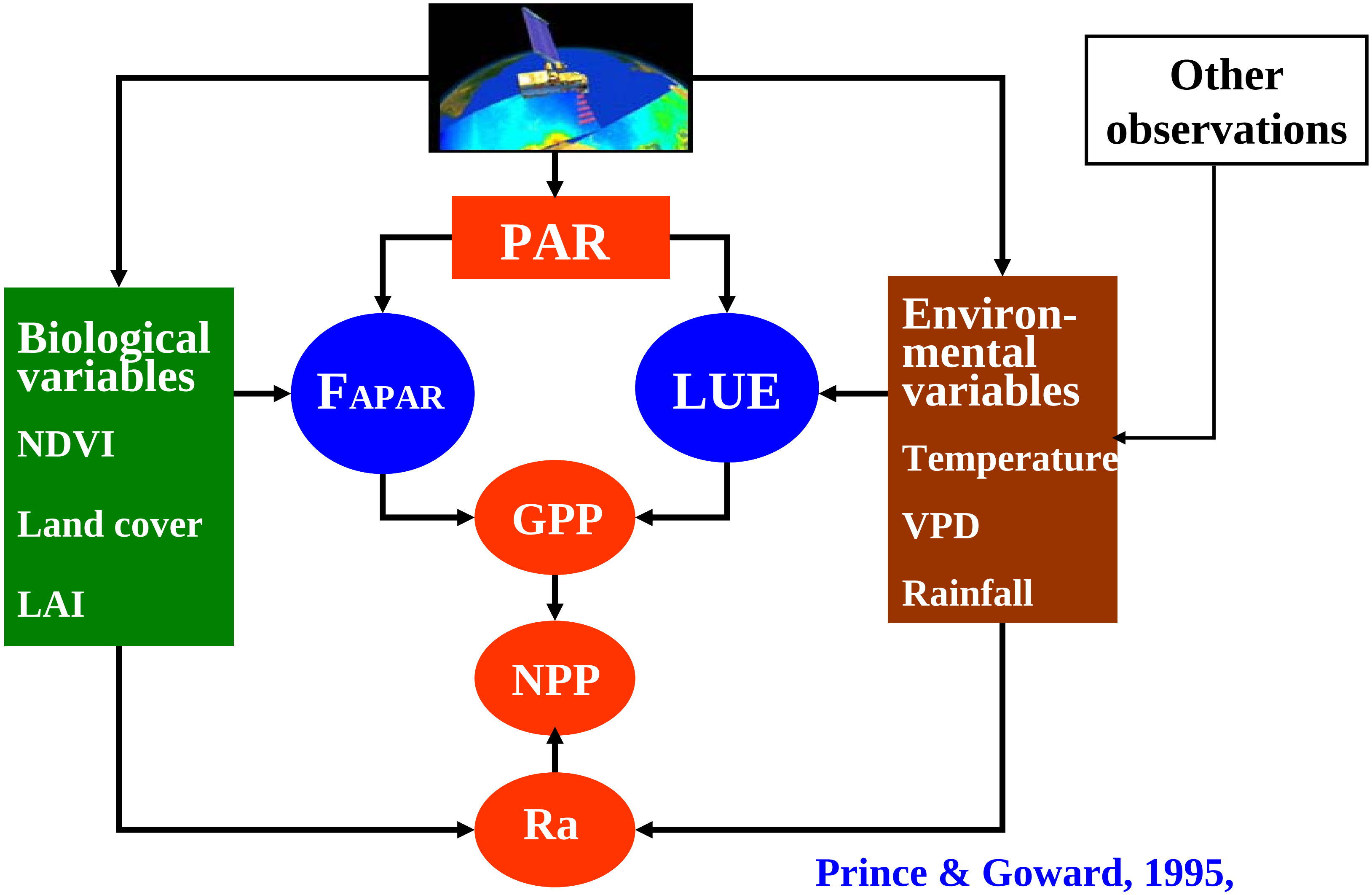


Mechanistic modeling is the best approach to

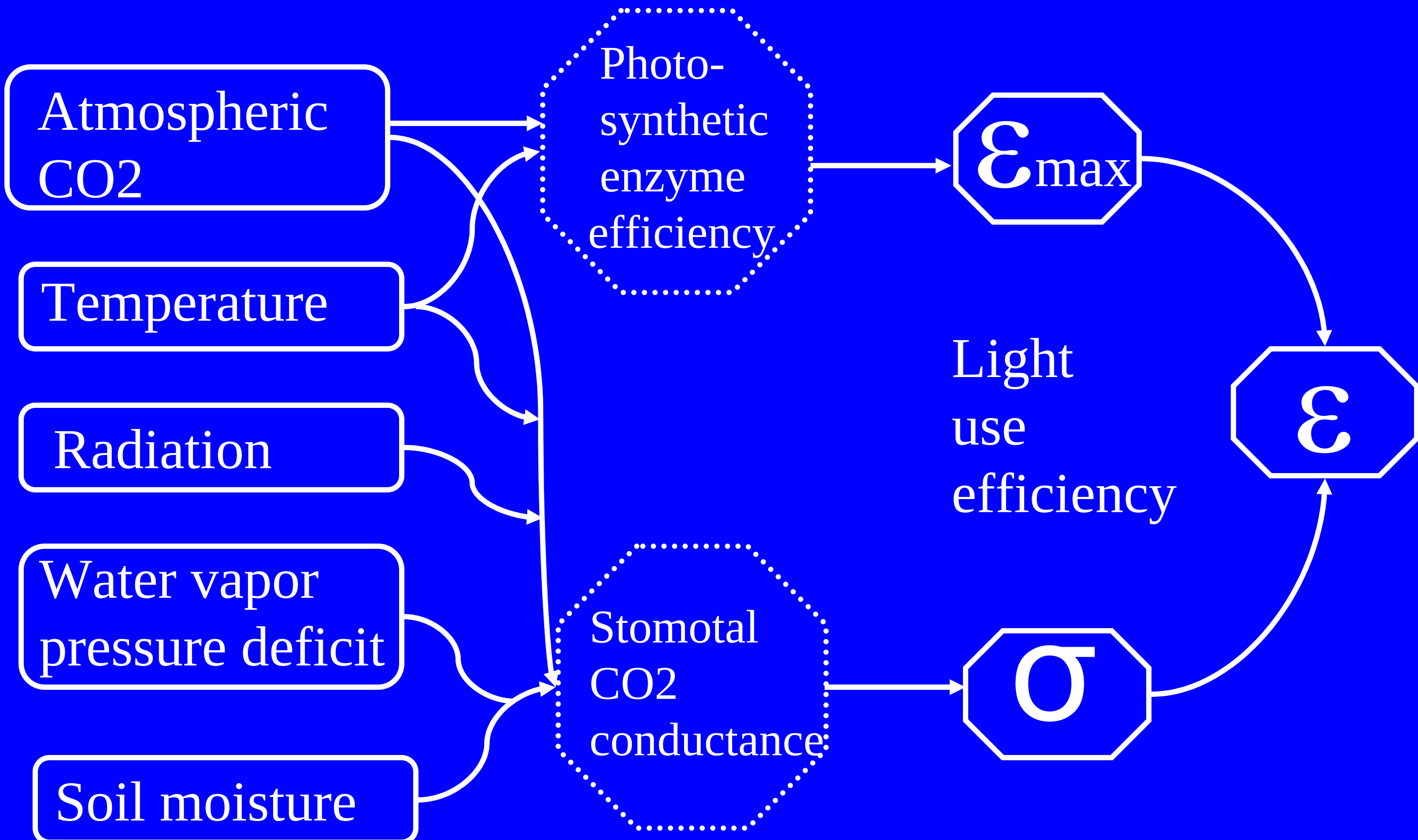
- Integrate observational data at different scales, using different technologies,
- Build mechanistic, quantitative connections of ecosystem processes at different scales
- Conduct diagnostic analysis to understand ecosystem mechanisms
- Rebuild and predict ecosystem changes

But it is difficult to validate mechanistic models at large scale, particularly for modeling regional ecosystem pattern

A remote sensing-based ecosystem model: GLO-PEM



Prince & Goward, 1995,
Cao et al. 2004



GLO-PEM estimates LUE on a mechanistic basis

(Cao et al. 2004)

GLO-PEM's calculation of NPP can be represented

$$NPP = \Sigma_t\ (PAR\ FPAR)\ (\varepsilon_{max}\ \sigma) - (R_g + R_m)$$

where (PAR FPAR) represents plant light harvesting, ε_{max} is the maximum light use efficiency in terms of gross primary production (GPP), σ is the reduction of ε_{max} by environmental conditions, and R_m and R_g are the maintenance and growth respiration.

Prince & Goward, 1995, Cao et al. 2004)

GLO-PEM Calculation of Light Using Efficiency

$$\varepsilon_g^* = 4.42\,\frac{Pi - \Gamma^*}{Pi + 2\Gamma^*} \qquad for\ C3$$

$$2.76\ g/MJ \qquad for\ C4$$

Potential light use efficiency

$$\sigma = \delta\, f(gs)$$

$$\delta = 1 - \frac{1}{1 + \exp(8NDVI - \frac{4(PAR - p)}{p})}$$

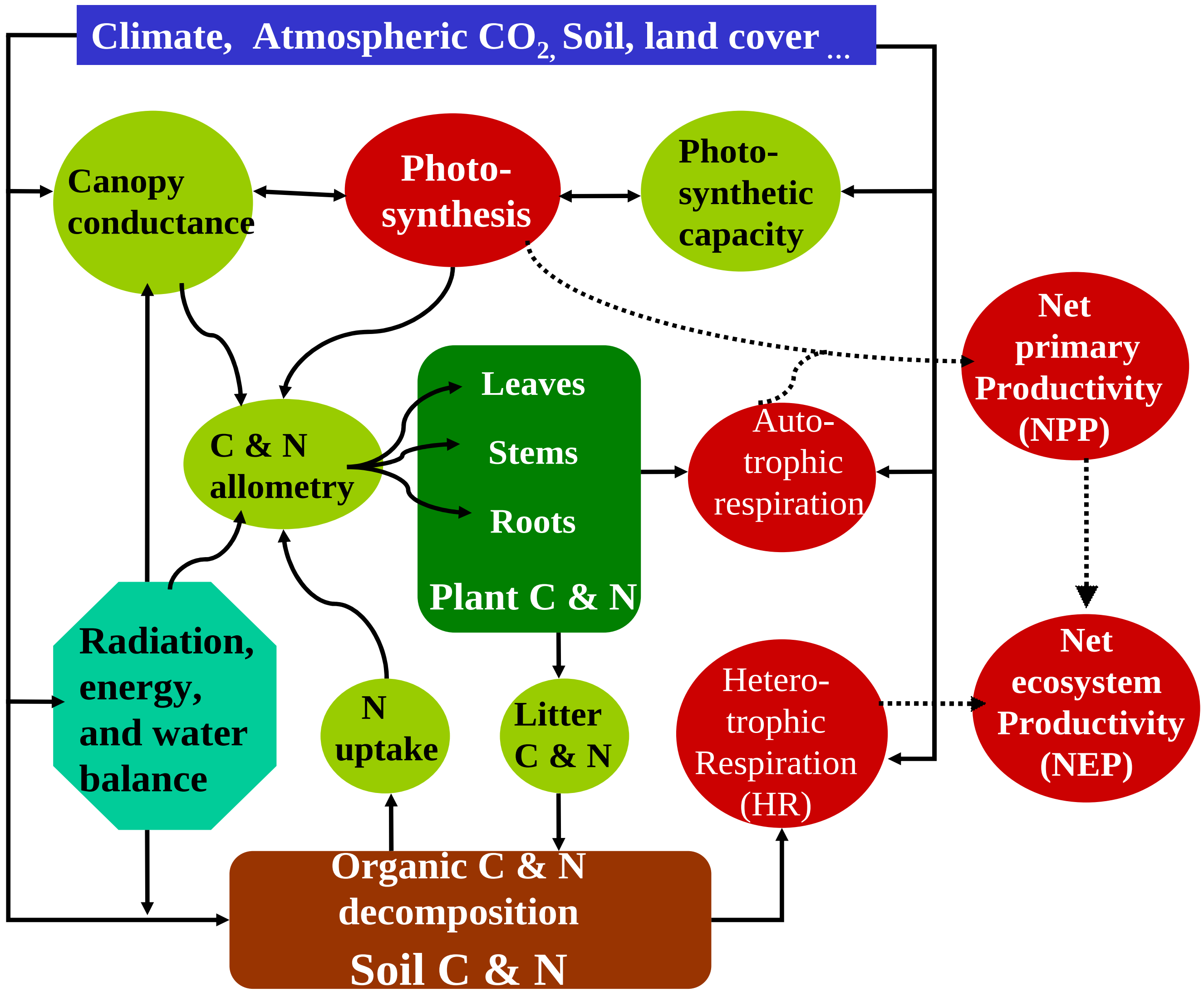
Radiation saturation

$$f(gs) = f(T)\, f(\delta q)\, f(\delta\theta)\, f(Pa)$$

Prince & Goward, 1995, Cao et al. 2004)

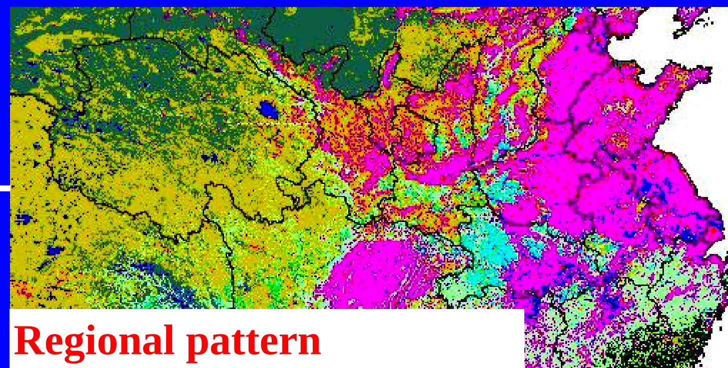
Effects of temperature, humidity, soil moisture, and Atmospheric CO2

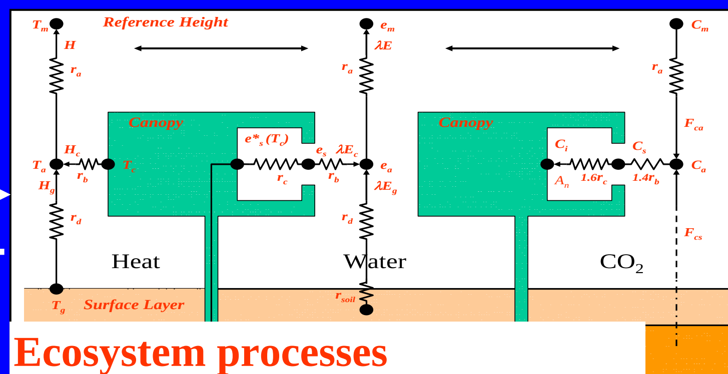
A process-based ecosystem model CEVSA



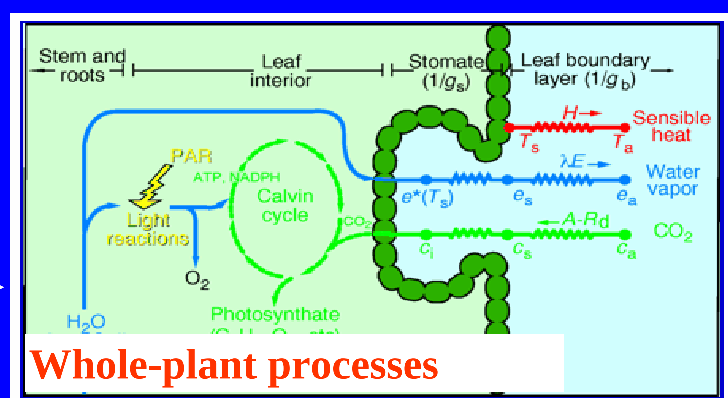
(Cao & Woodward 1998a, Cao et al. 2002)

CEVSA integrates the whole-plant and ecosystem processes


Regional pattern



Ecosystem processes

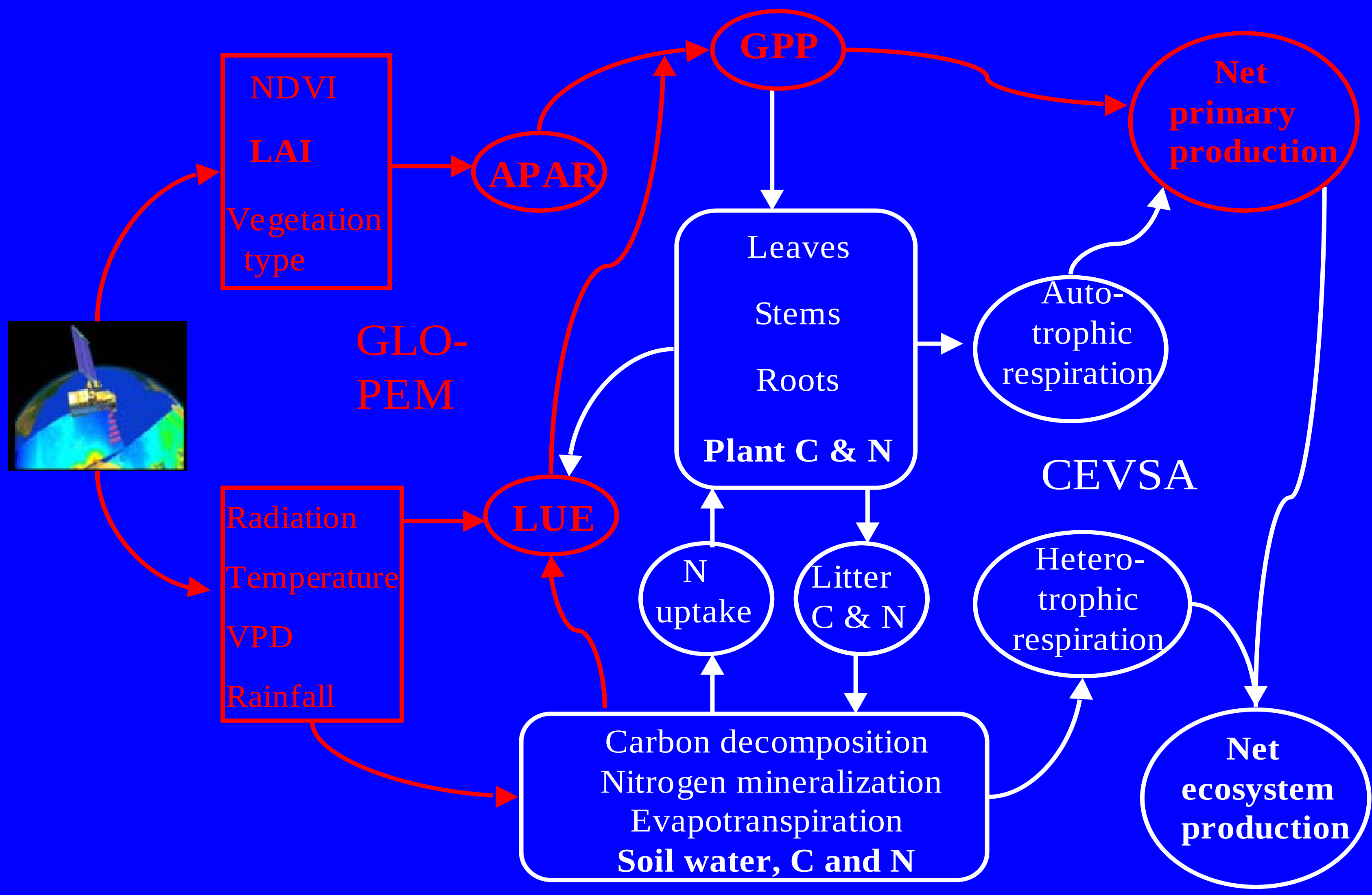


Whole-plant processes

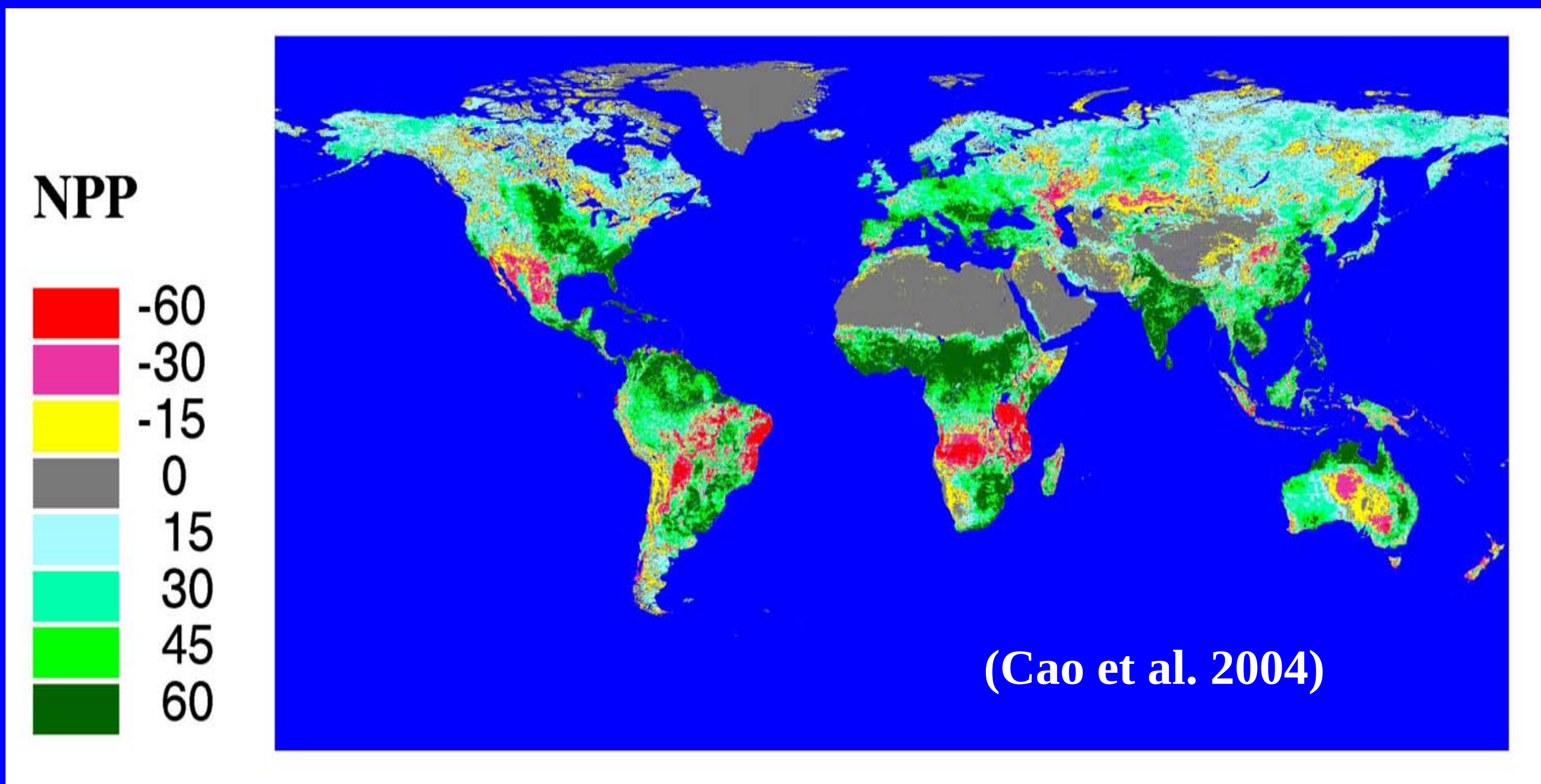
It uses satellite-based land cover map as an input to account vegetation pattern

(Cao & Woodward 1998a, Cao et al. 2002)

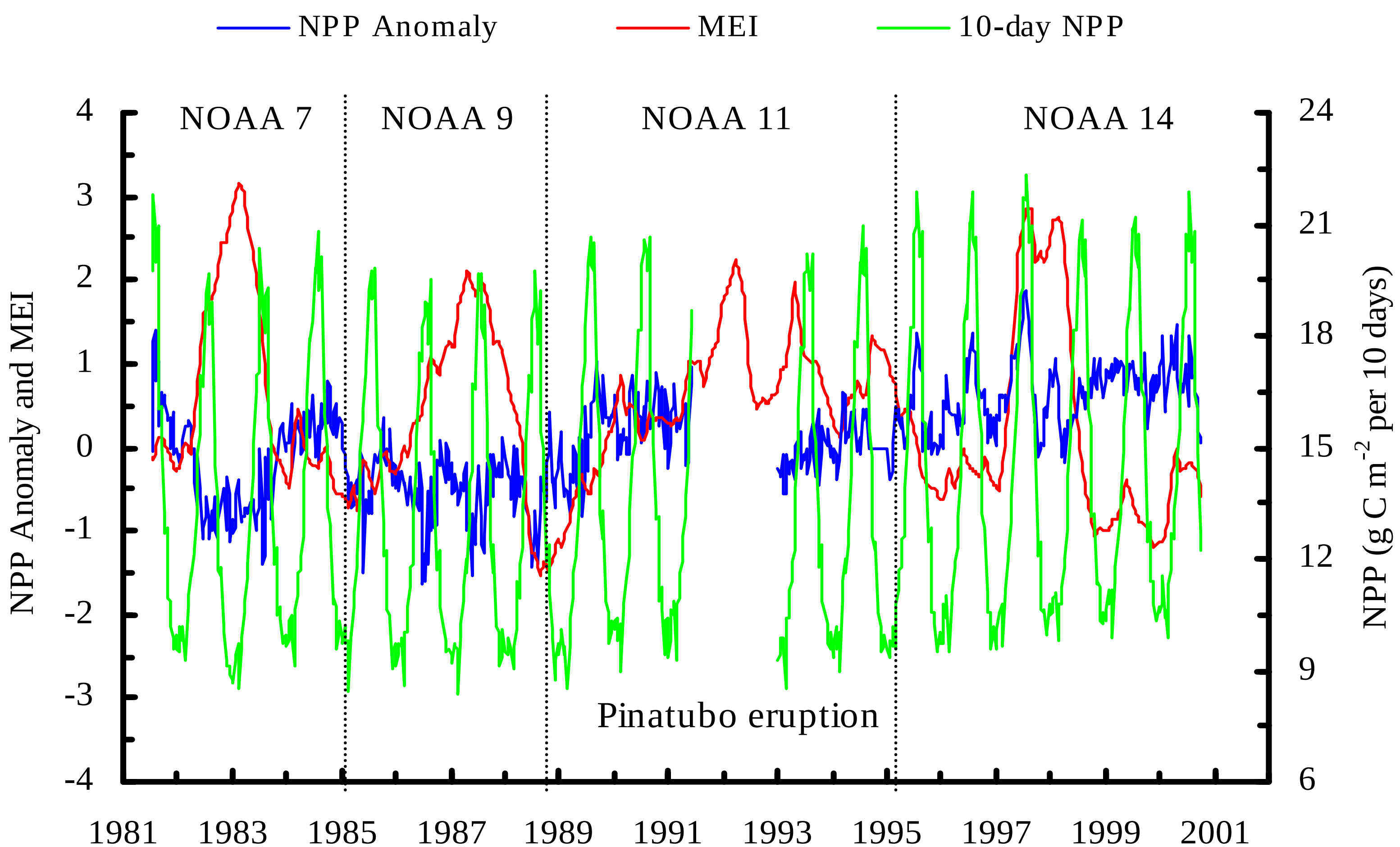
Couple the Remote Sensing- and Process-Based Model



Satellite-based estimate of changes in annual NPP from the 1980s to the 1990s

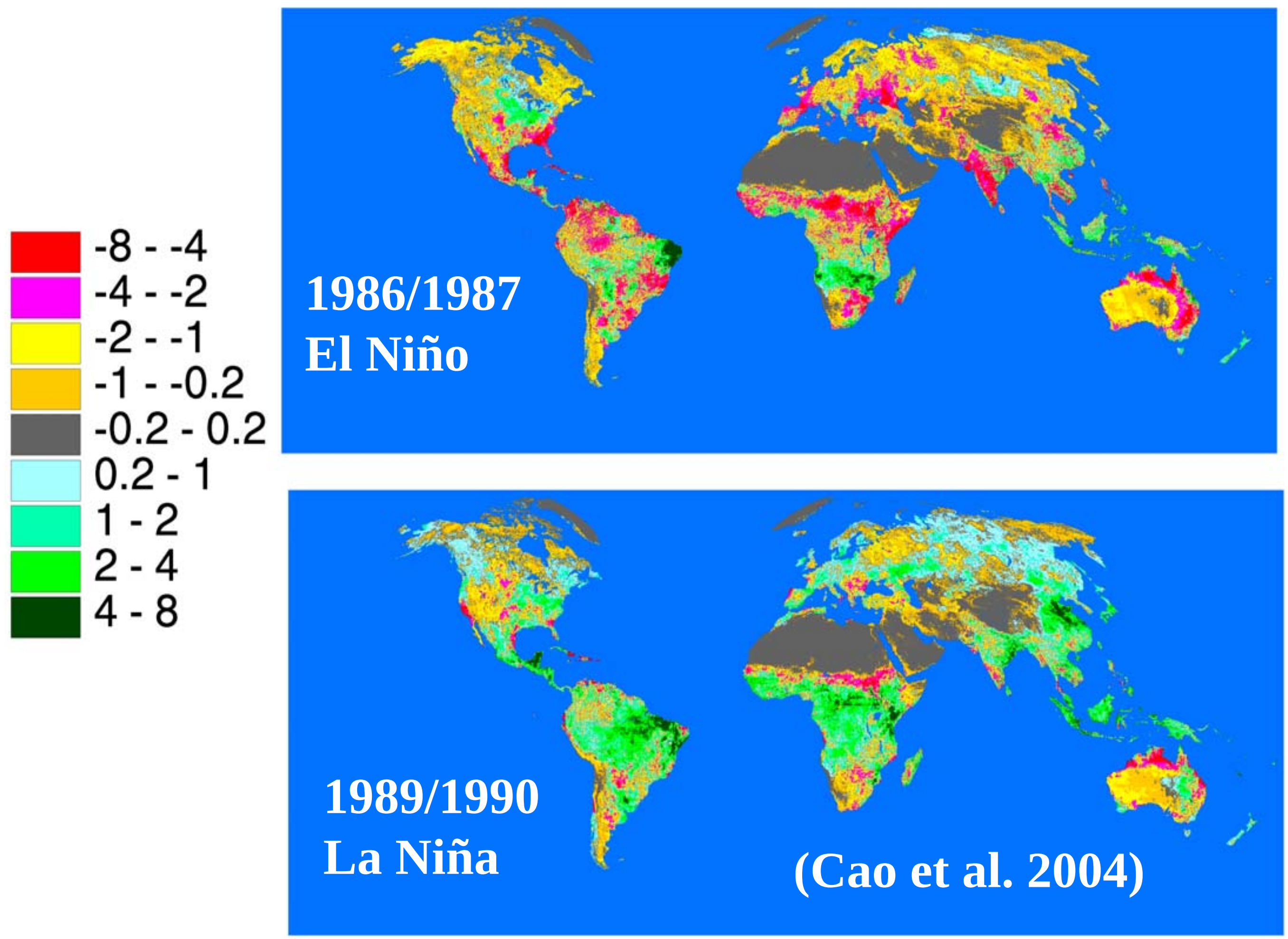


Satellite-detected global NPP variability and the dynamic response to the El Niño/La Niña cycle

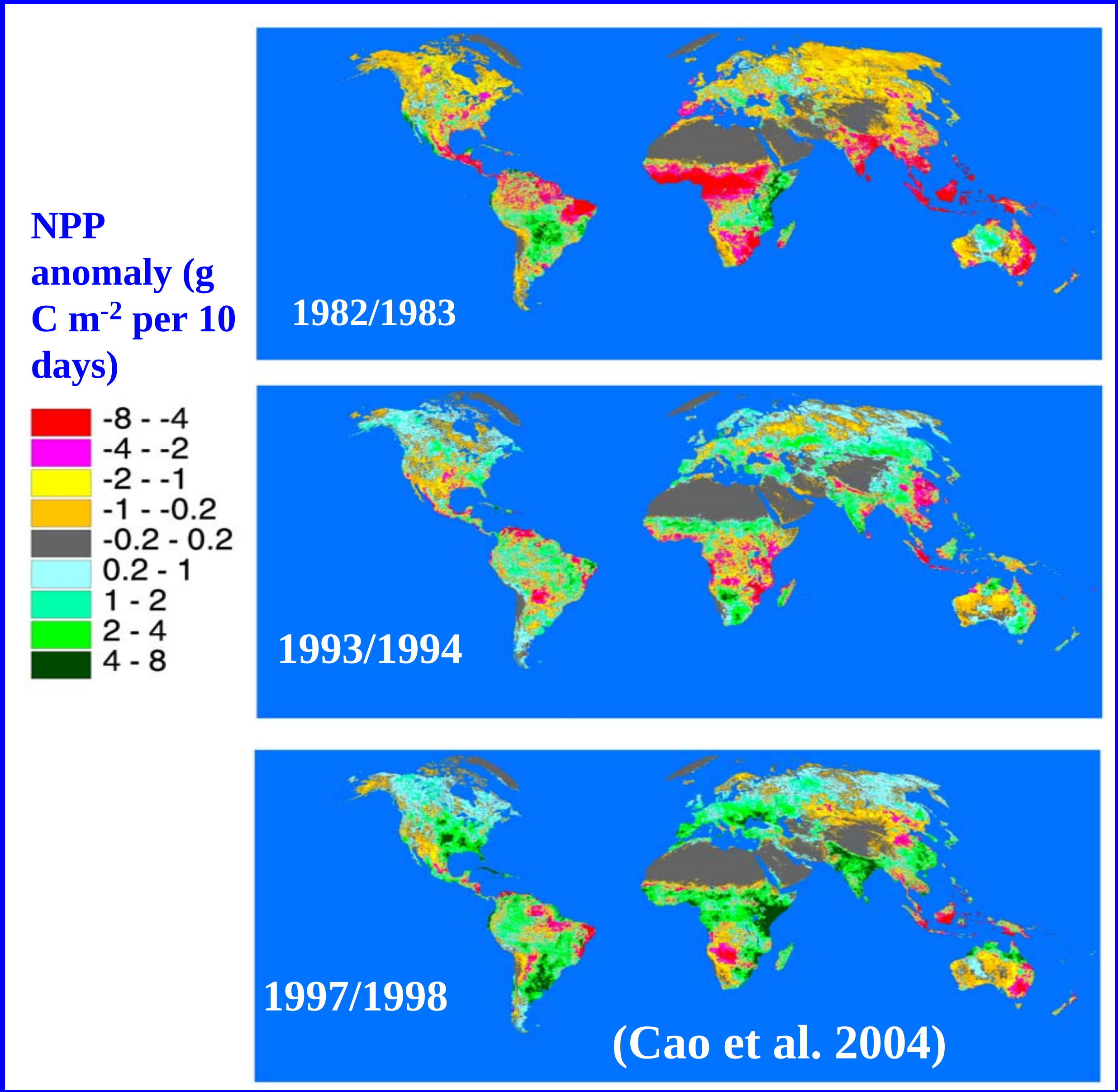


(Cao et al. 2004)

The regional pattern of NPP changes in a transition from an El Niño and to an a La Niña year

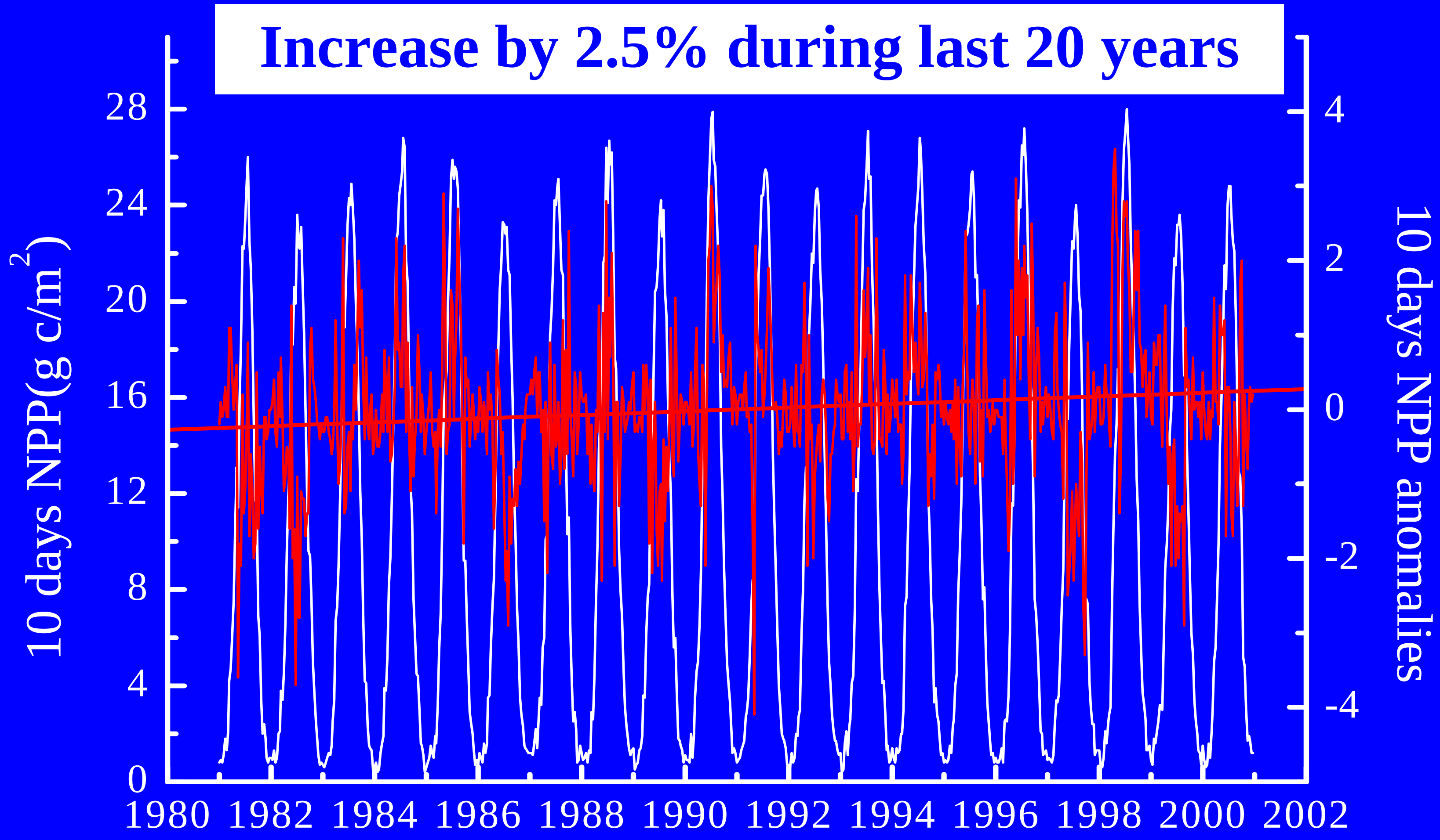


The different regional pattern of NPP changes in different El Niño year

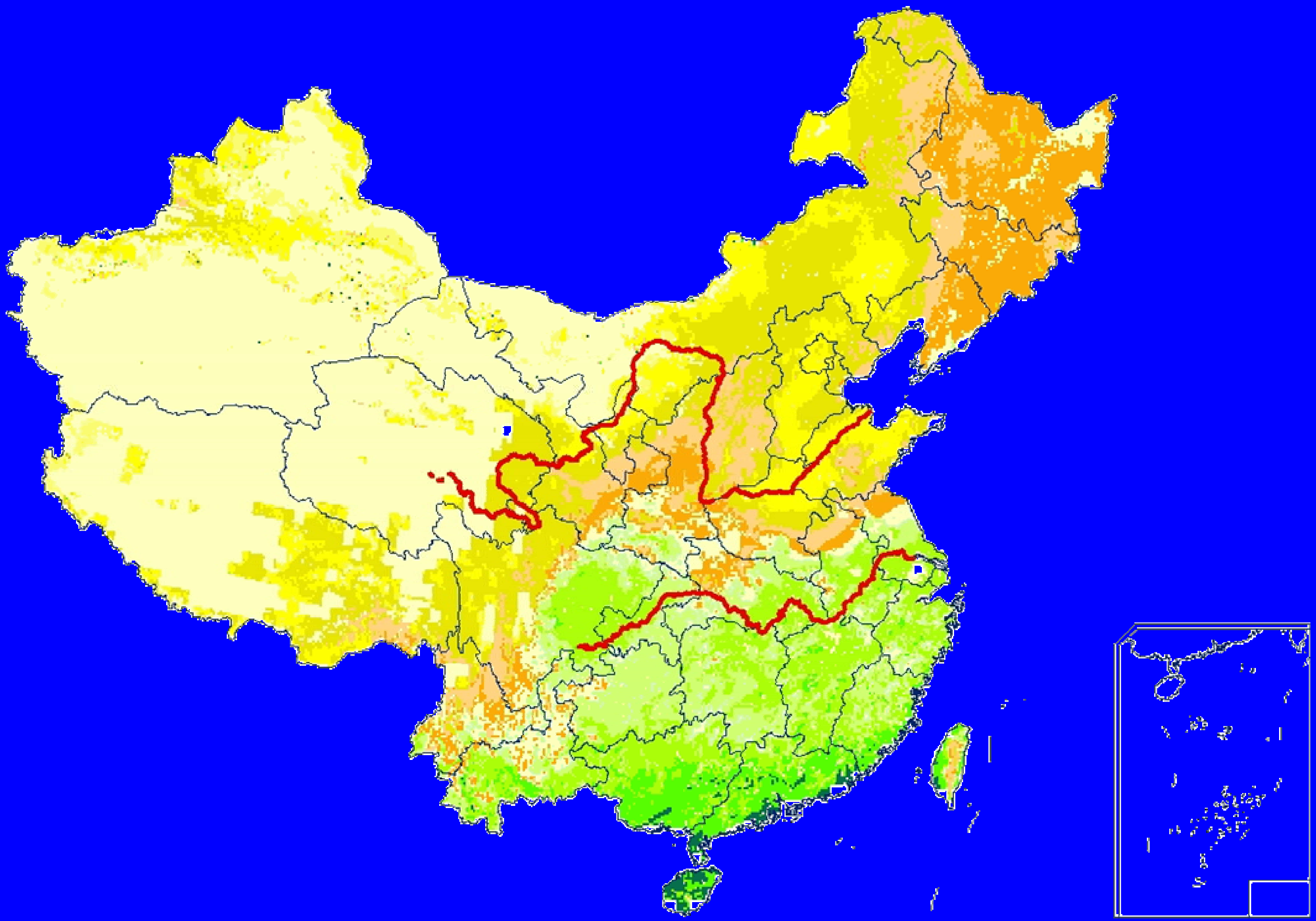


Seasonal and interannual changes in NPP in China

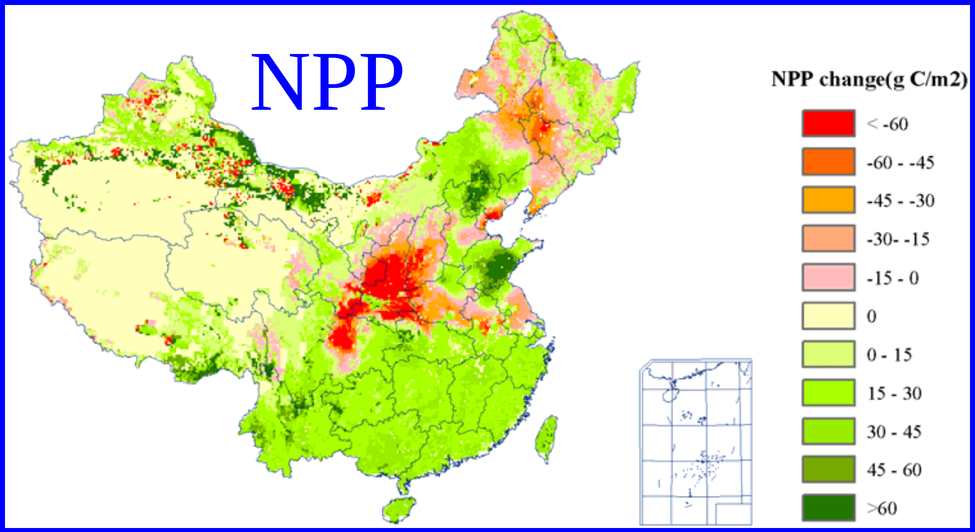
(Net Primary Productivity, CO_2 fixation by plants)



Interannual Variation in NPP (1981-2000)

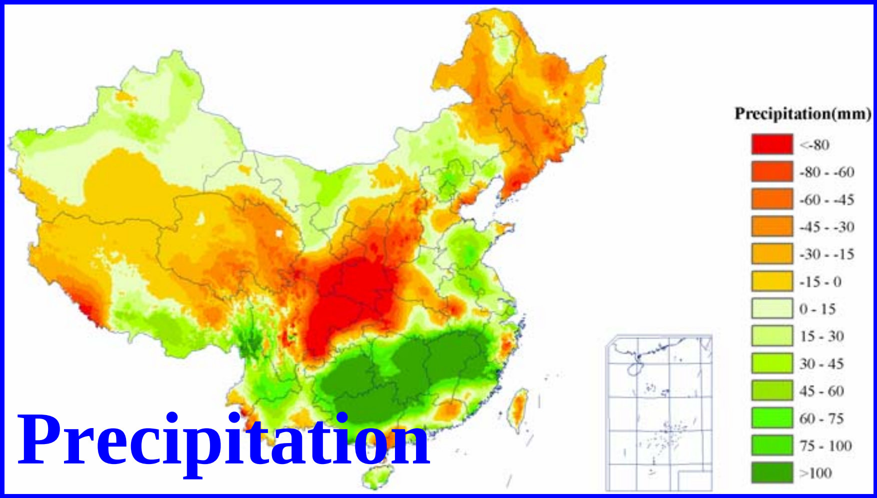


NPP changes from the 1980s to the 1990s



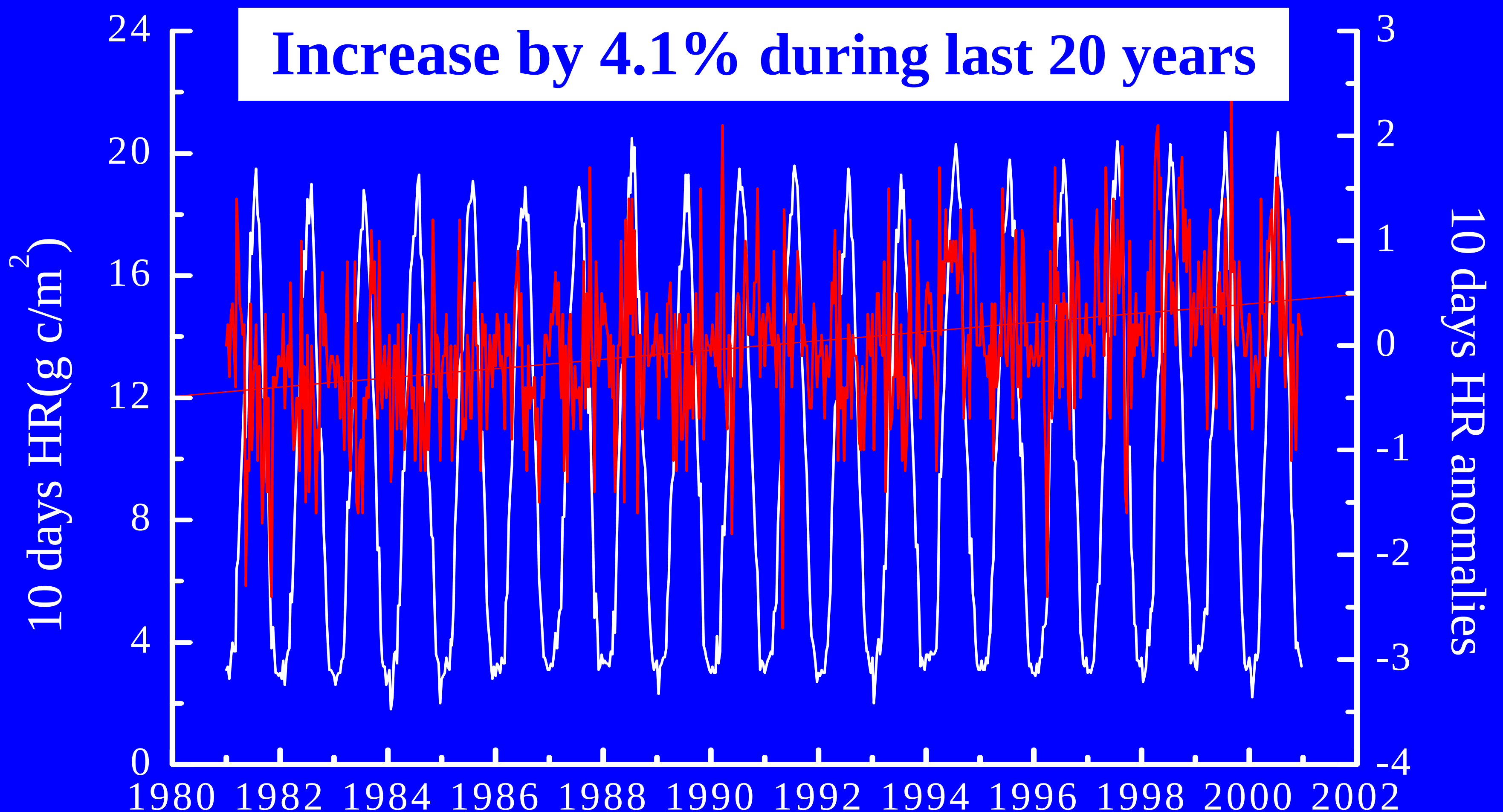
Total NPP (Gt C/yr)

1980s	**3.23**
1990s	**3.31**

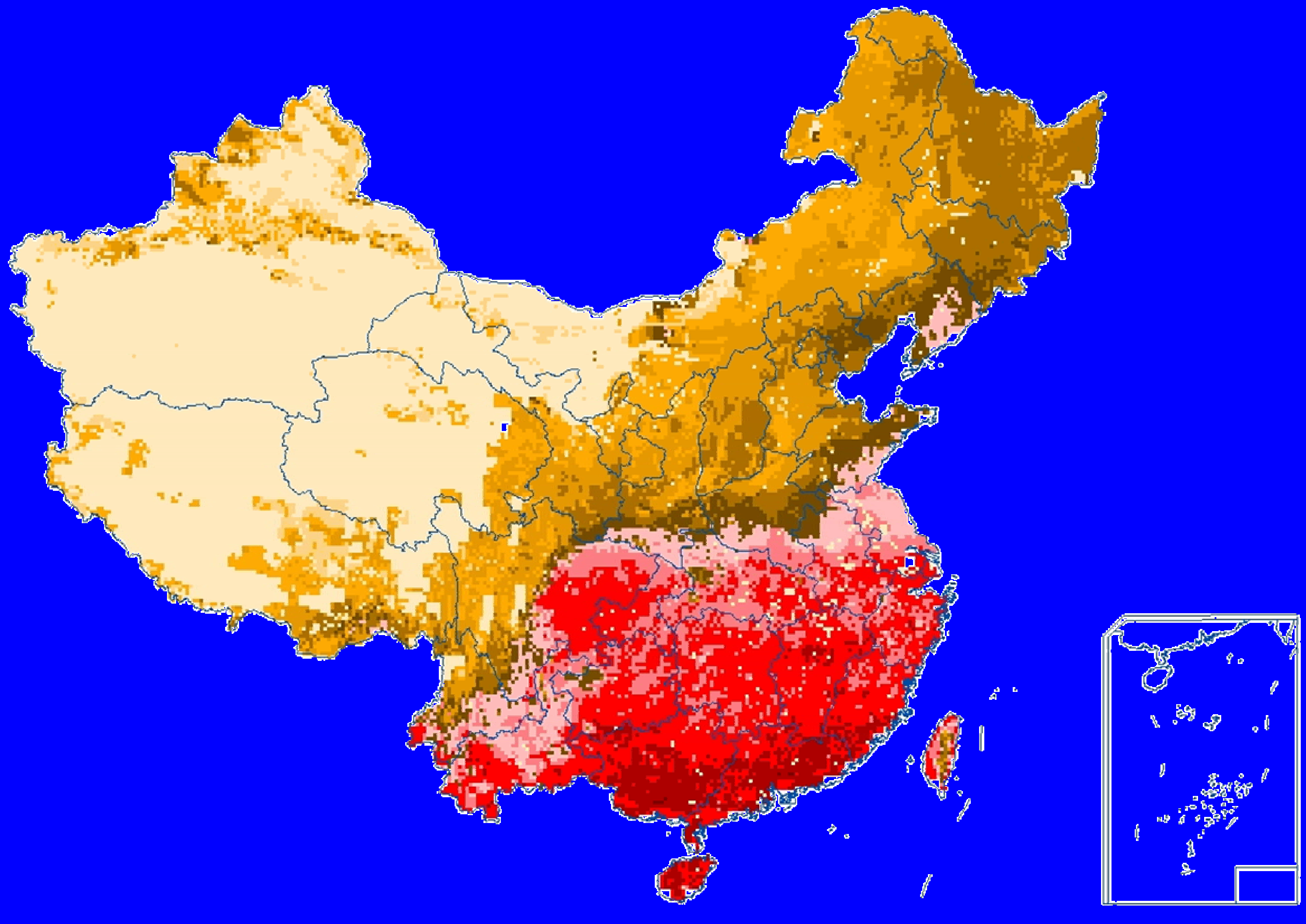


Seasonal and interannual change in HR

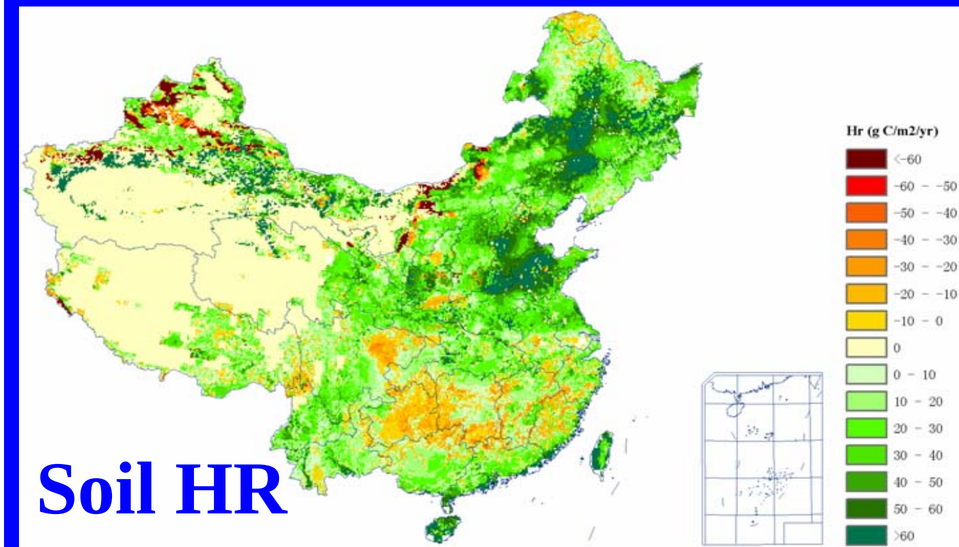
（Soil heterotrophic respiration, carbon release）



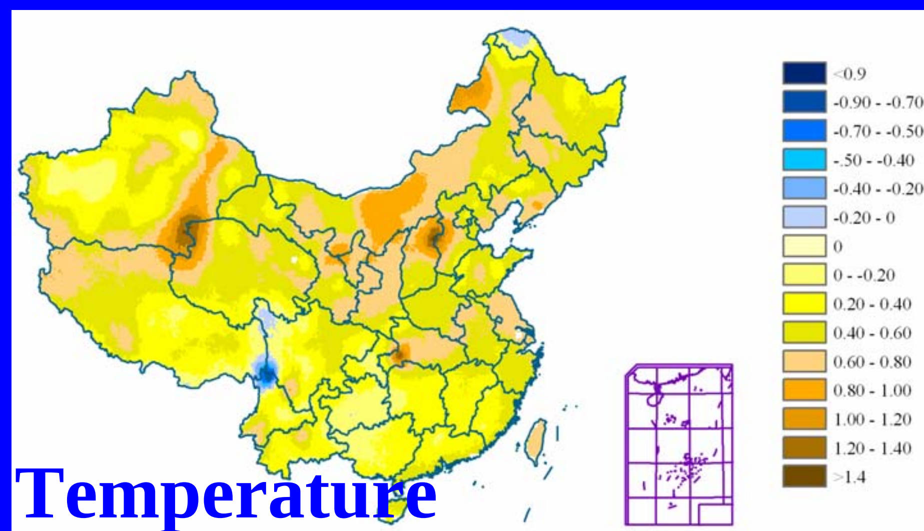
Interannual Variation in HR (1981-2000)



Soil HR changes from the 1980s to the 1990s

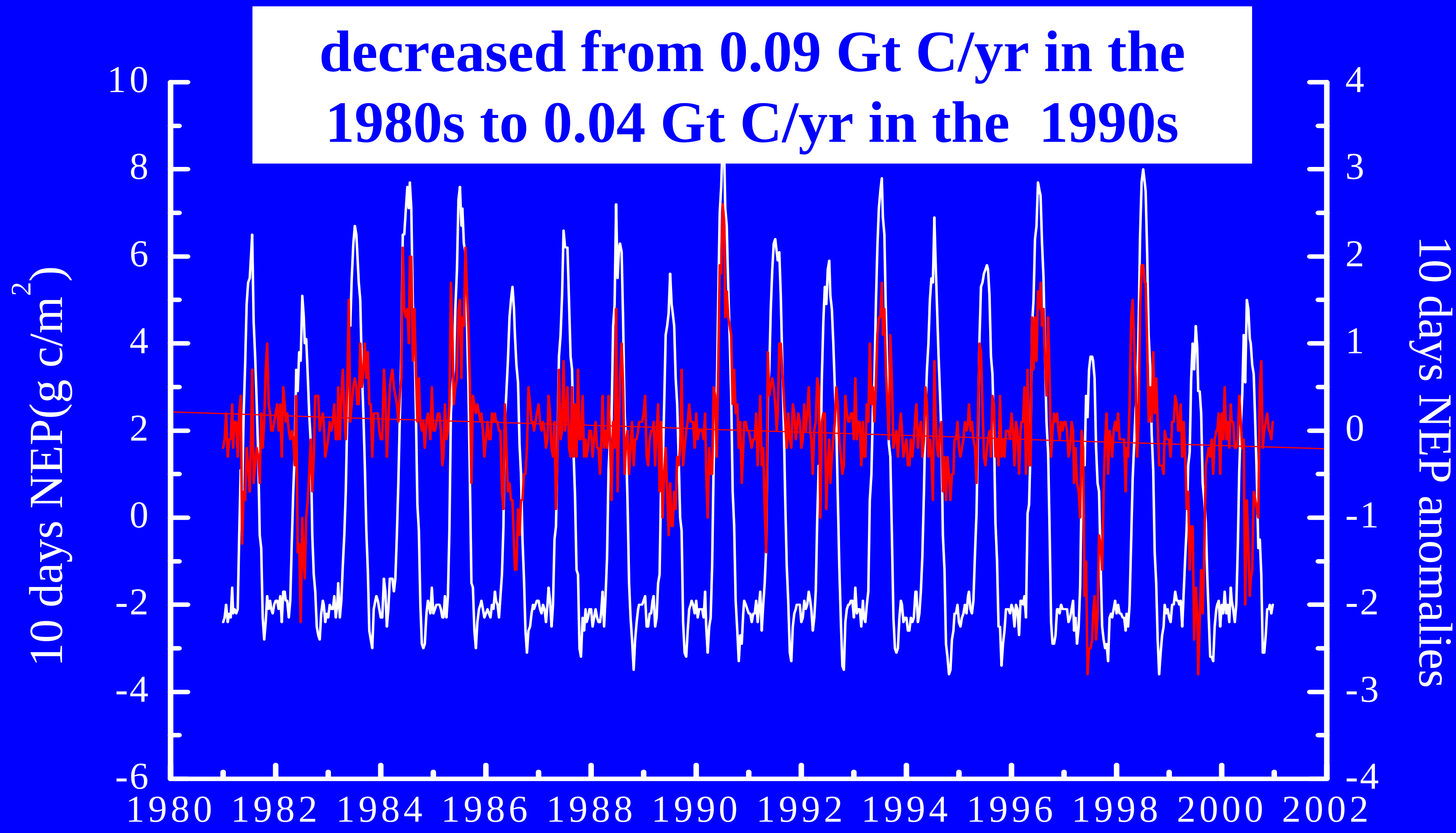


	Total HR (Gt C/yr)
1980s	3.14
1990s	3.27

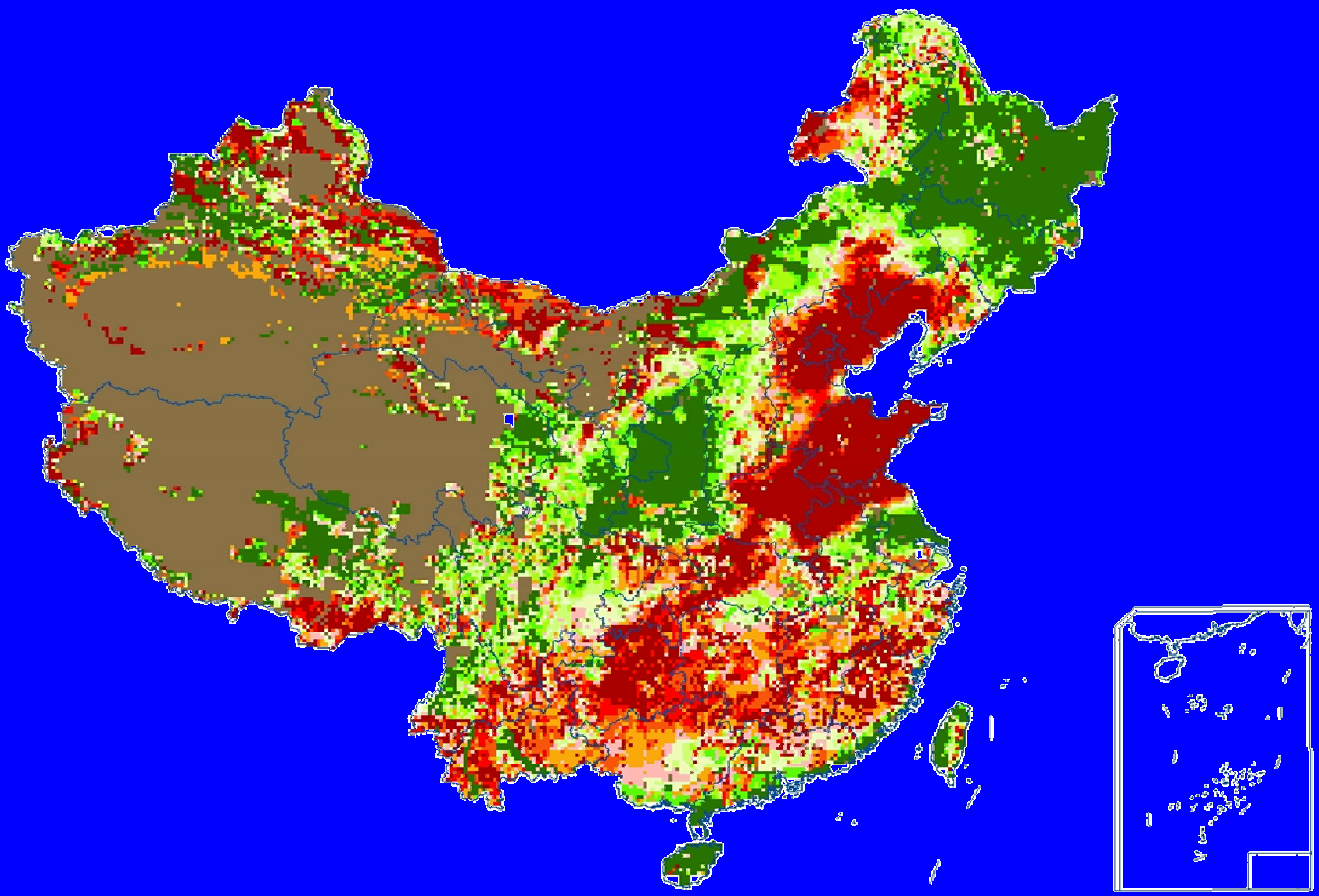


Seasonal and interannual changes in NEP

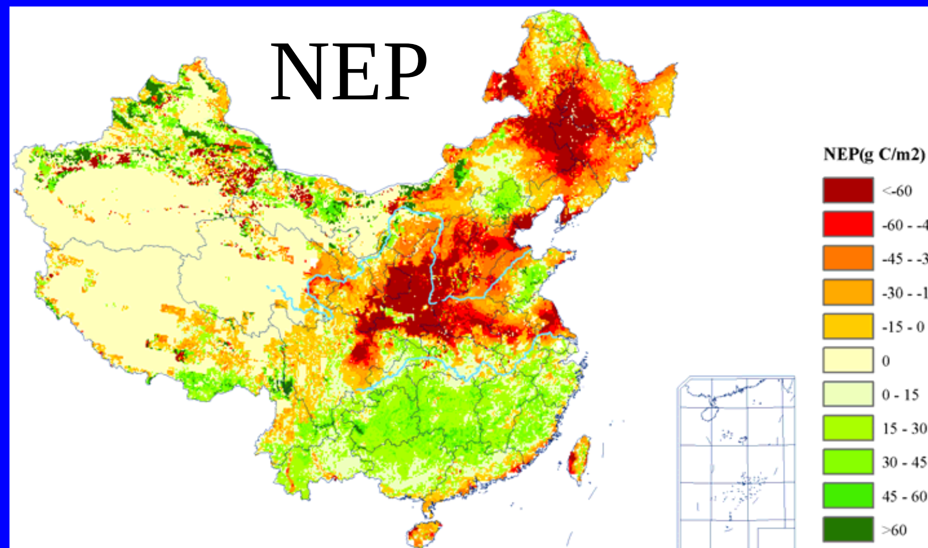
(Net Ecosystem Productivity, net carbon uptake or release)

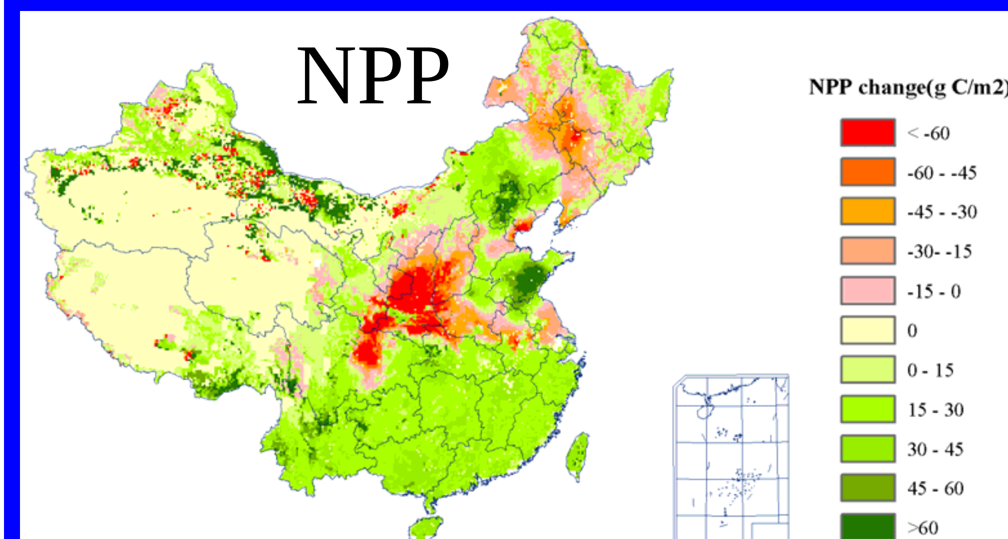


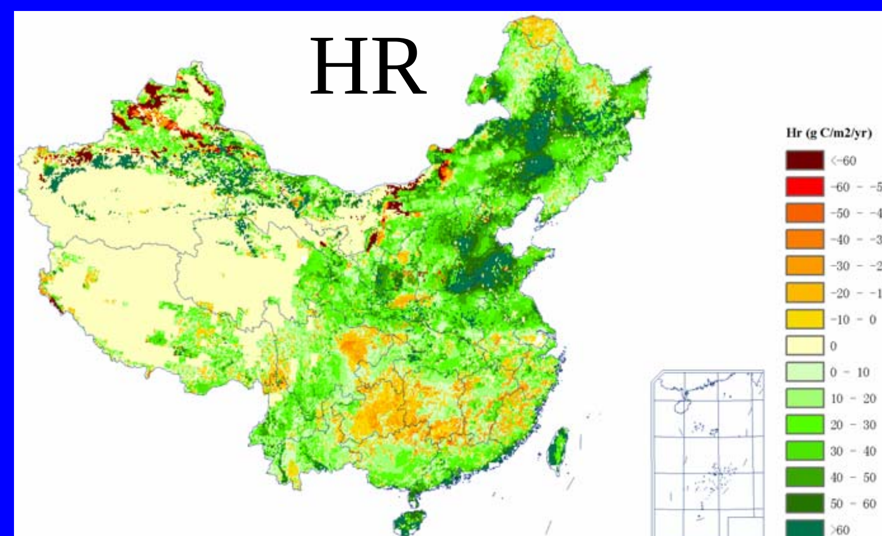
Interannual Variation in NEP (1981-2000)



Changes from the 1980s to the 1990s

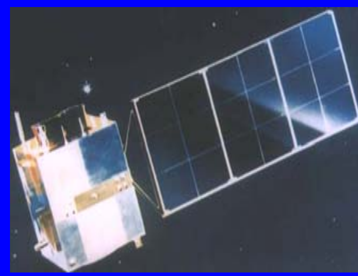






Research direction

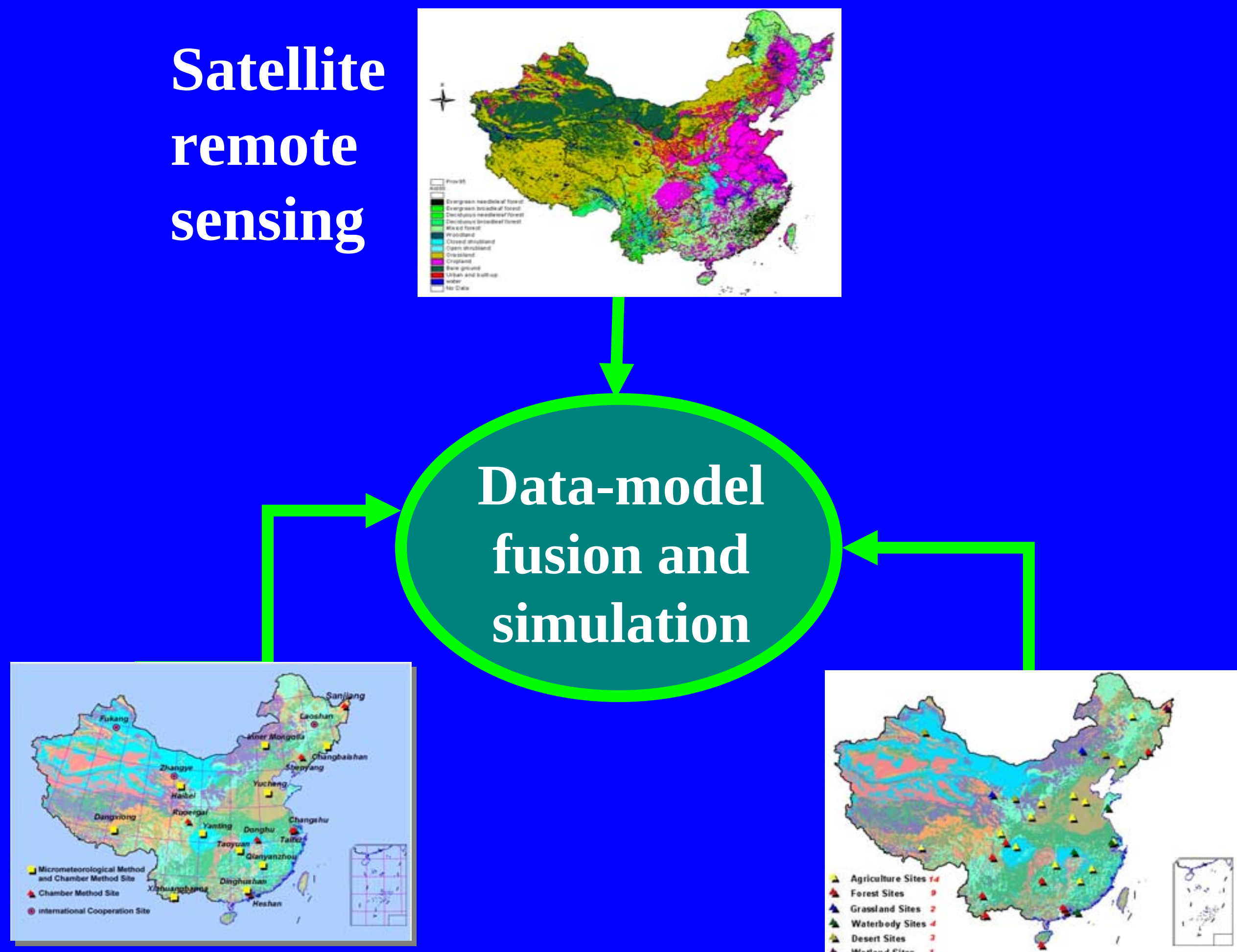
To conduct joint observations with remote sensing and eddy flux measurement at ChinaFlux sites



Research direction

Assimilate data from intensive site measurement into remote sensing-based and mechanistic ecosystem models

Satellite remote sensing

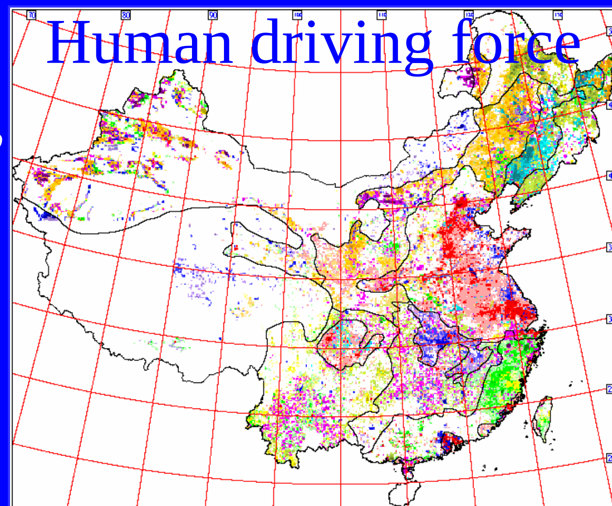


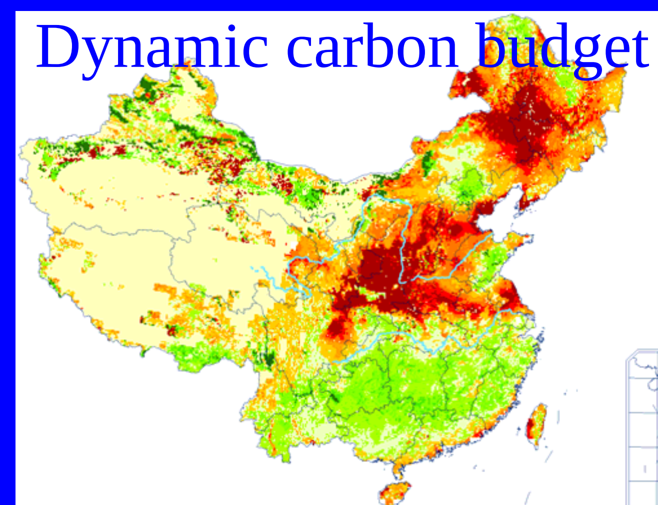
ChinaFlux (8 sites)

CERN (36 stations)

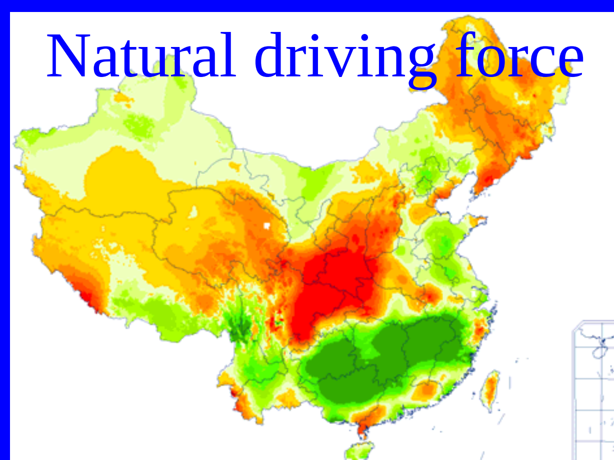
Research direction

A comprehensive, dynamic national carbon budget





Quantification of naturally and human induced changes



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Thank You !!