New Progress in the Global Carbon Assimilation System (GCAS)

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Content

（1） Introduction to the Global Carbon Assimilation System （GCAS)

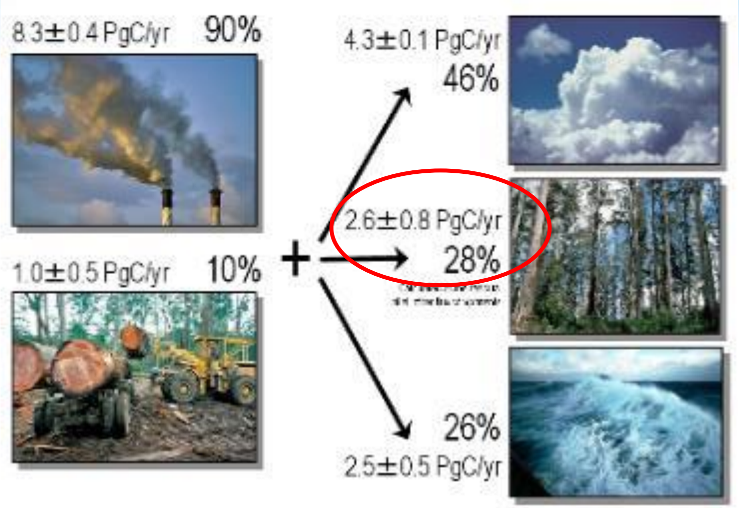
（2） Ecosystem model in GCAS

（3） Applications of GCAS

- Optimization of the global terrestrial carbon flux
- Optimization of China’s anthropogenic carbon emission.

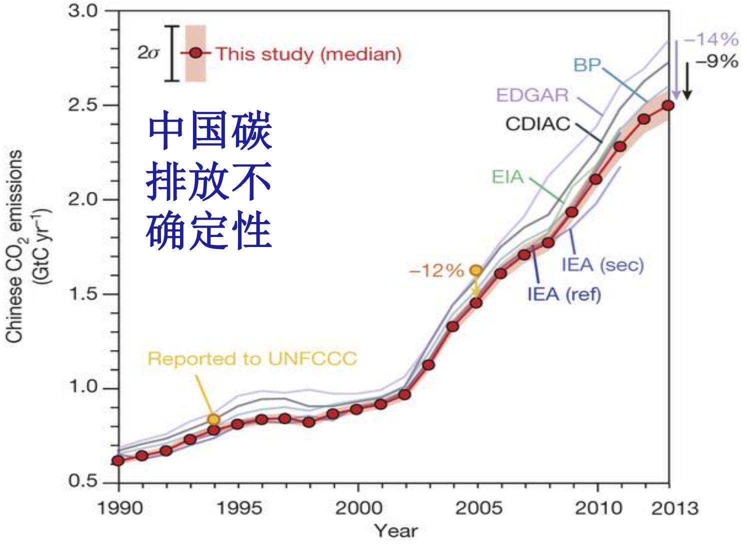
Motivations

1. The magnitude and distribution of terrestrial sinks are uncertain.



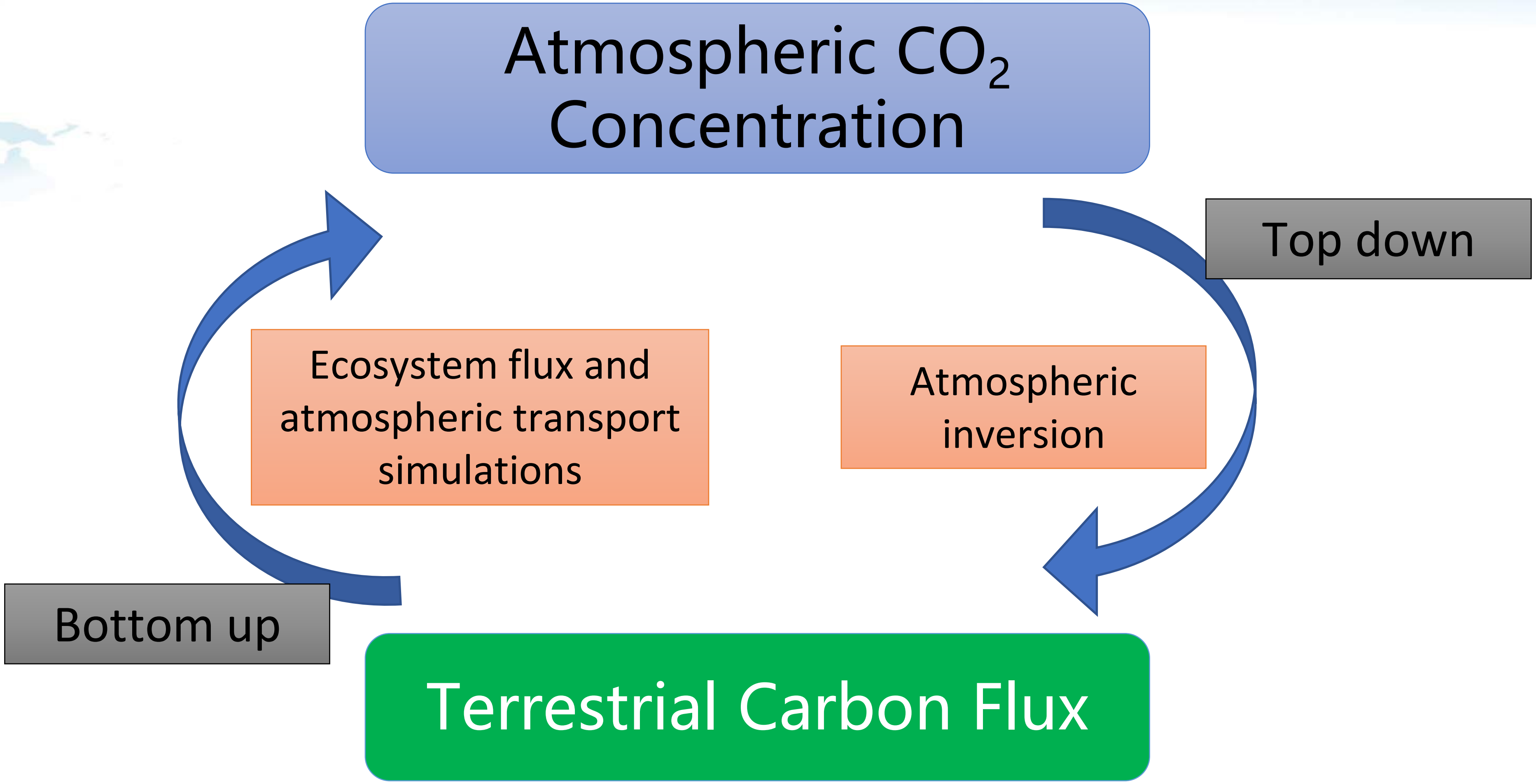
from global carbon budget office

2. The magnitude and distribution of China’s industrial carbon emission are also uncertain.



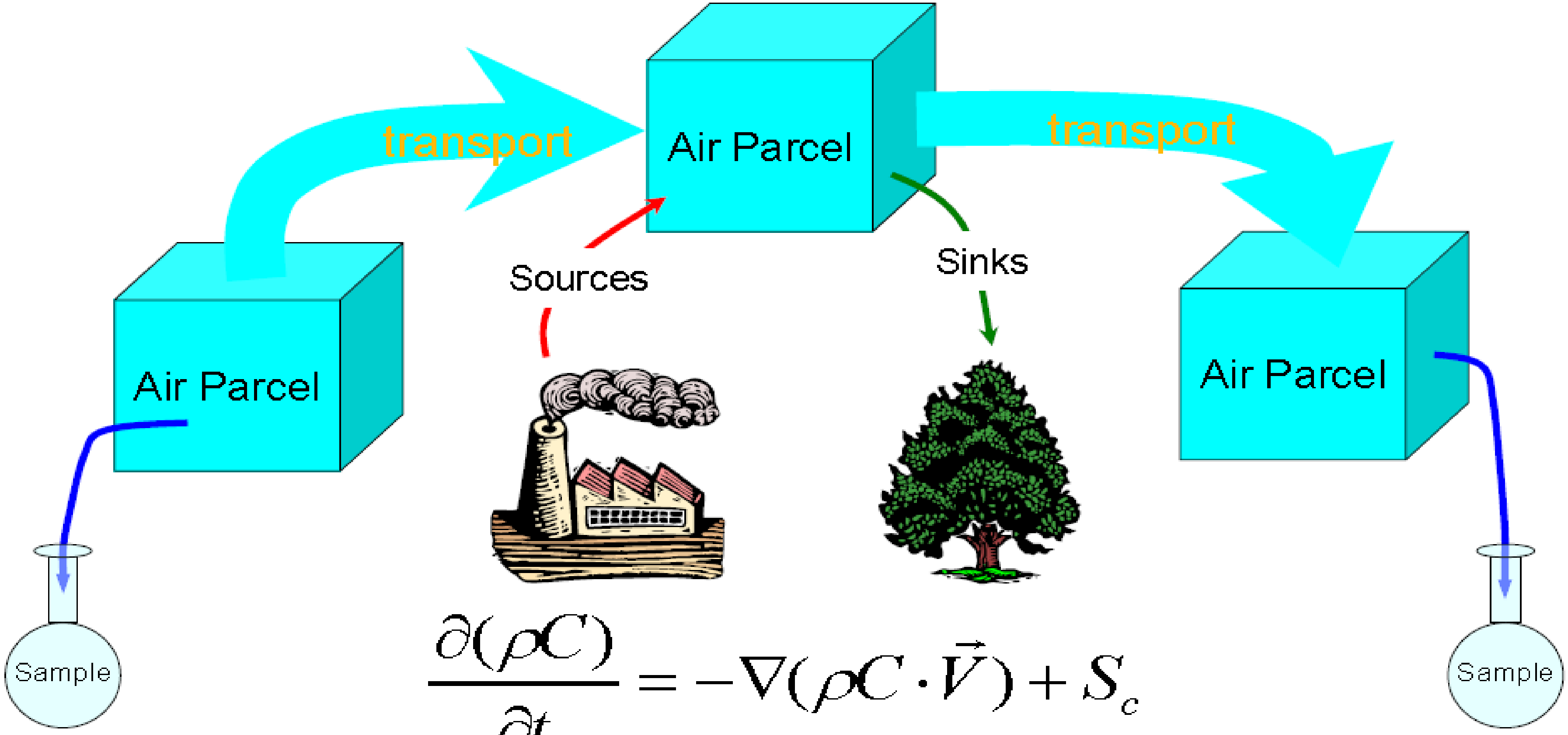
Liu et al., 2015, Nature

Methods for Carbon Flux Estimation



Physical Basis of Atmospheric Inversion

Mass Conservation Principle



$$\frac{\partial(\rho C)}{\partial t} = -\nabla(\rho C \cdot \vec{V}) + S_c$$

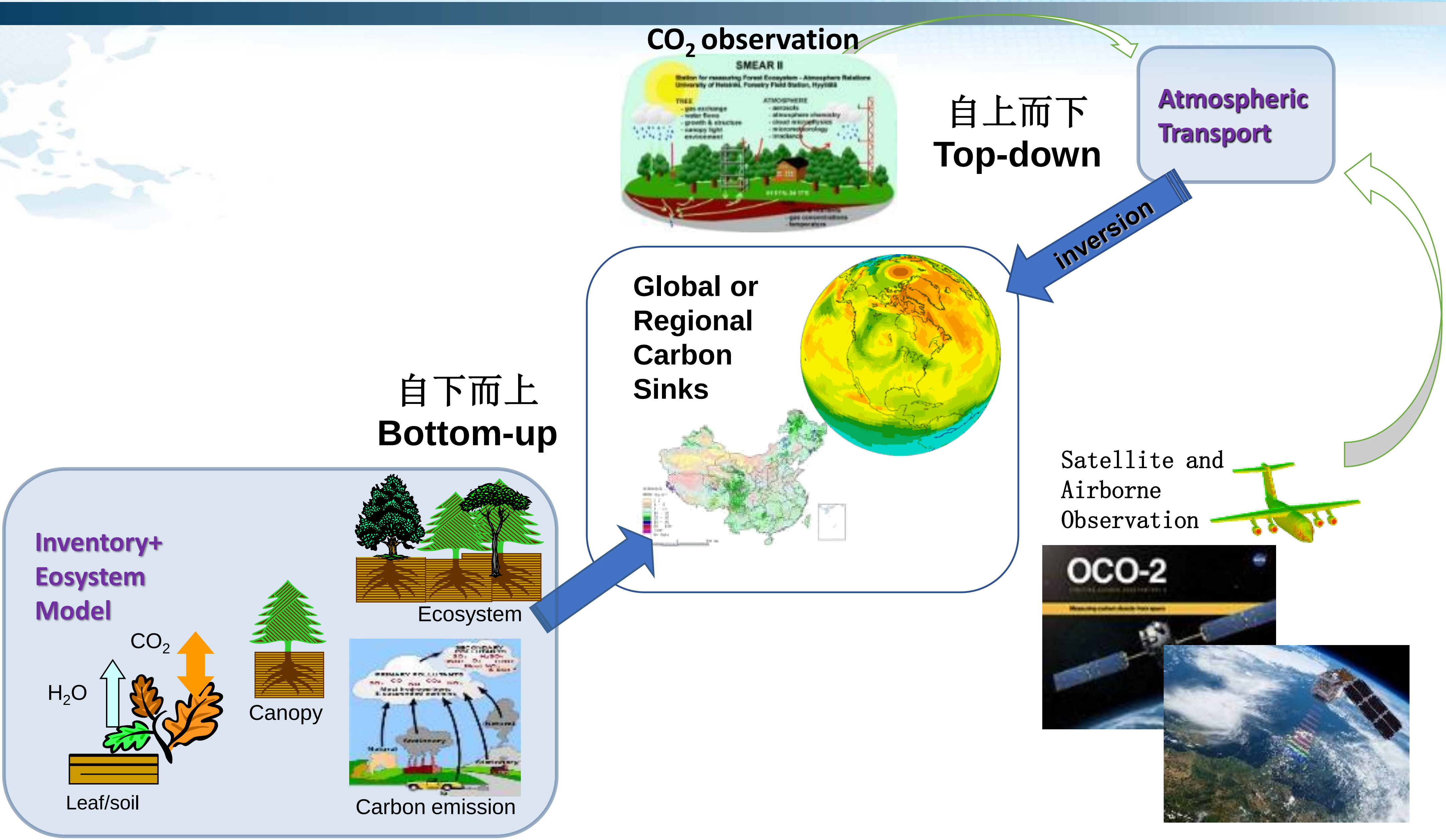
concentration (observe)

transport (model)

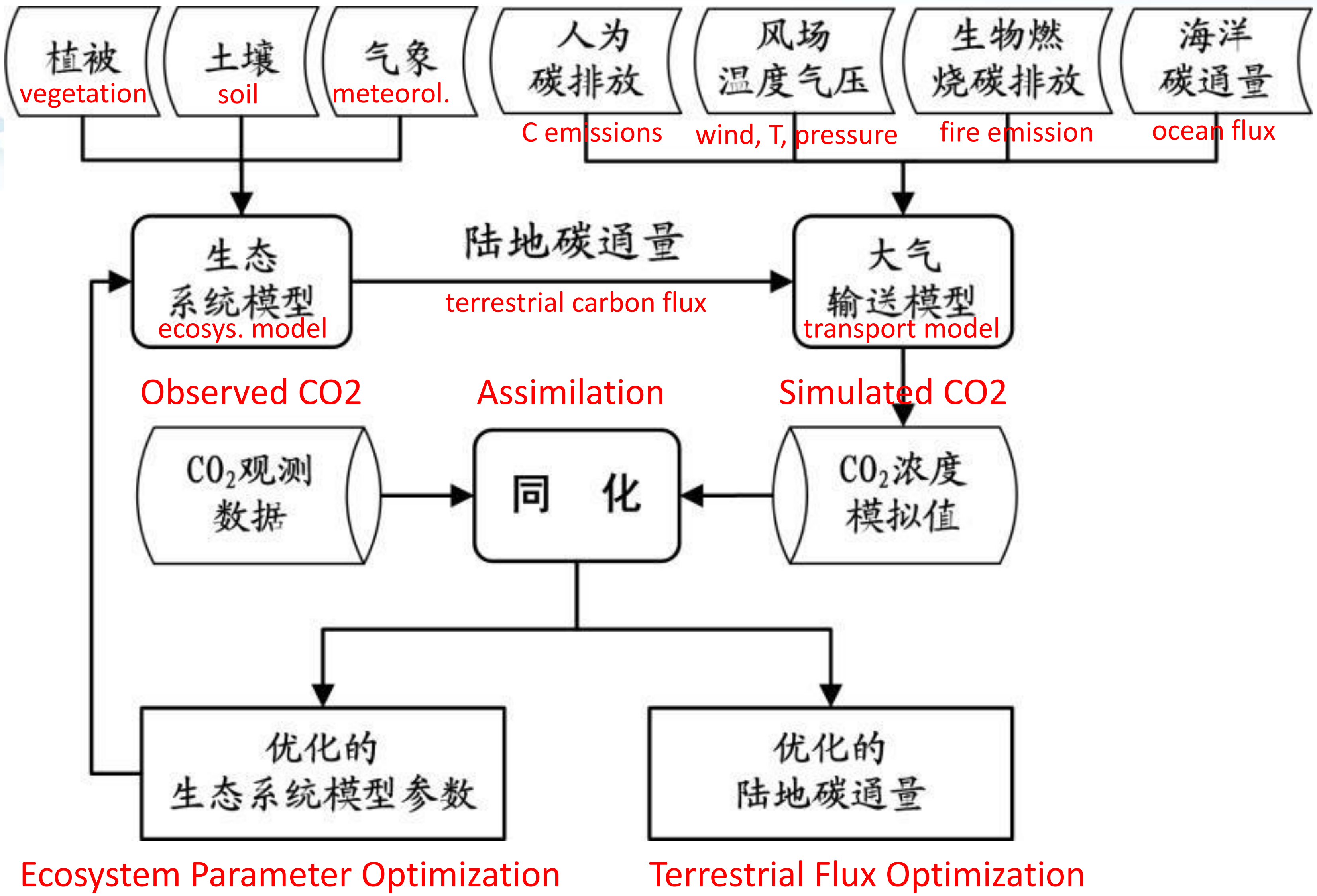
sources and sinks (solve for)

Slide modified from Scott Dennin;

Framework of GCAS



Double Optimization of GCAS



Progress in GCAS

GCAS V1: In situ CO_2 + satellite land surface remote sensing data
Optimization of terrestrial ecosystem fluxes
科技部《全球变化》重大研究计划项目（2010-2014）：
“全球不同区域陆地生态系统碳源汇演变驱动机制与优化计算研究”
PI：Jing M. Chen

GCAS V2： In situ CO_2 + satellite CO_2 column data + ground air pollution data
+satellite land surface remote sensing data
Optimization of terrestrial ecosystem fluxes
+ anthropogenic carbon emission
科技部《全球变化与应对》重点研发项目（2016-2020）：
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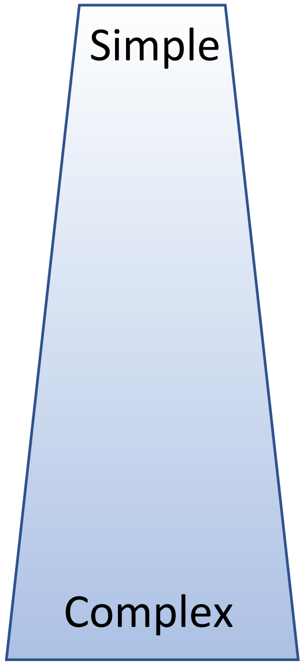
PI：Weimin Ju

Technical Comparison of Major Inversion Systems

System	Country	Ecosystem Model	Land Remote Sensing?	Atms. Transport	Optim. Method	Time Steps	Spatial Res.	同化数据	Optim. By Region
Carbon Tracker	USA	CASA，LUE model	Yes, AVHRR NDVI	TM5	Ensemble Kalman Filter	90 min	Global 3°×2°，US 1°×1°	GLOBALVIEW+	Yes，11 Transcom regions
CCDAS	Europe	BETHY, Enzyme-kinetic model	No	TM2/TM3	4-D variational	1 month	Land model 2°×2°; atmos. Model 8°×10°	SIO/ GLOBALVIEW 2015 soil moisture /VOD/FAPAR	No, By grids
GCAS	China	BEPS, Two-leaf enzyme kinetic + multilayer soil	Yes, GLOBMAP LAI	MOZART	Ensemble Kalman Filter	1 hour	Global 1°×1°	GLOBALVIEW+ /GOSAT/OCO-2	No, By grids

Ecosystem Models Useful for Atm. Inversion

- **LUE Models**
  - Big-leaf： CASA、MODIS GPP模型
  - Two Big-leaf： TL-LUE (He et al., 2013, AFM)
    RTL-LUE (Guan et al., 2021, AFM)
- **Enzyme-Kinetic Models**
  - Big-leaf： BIOME-BGC、SIB2
  - Two Big-leaf： BESS (Ryu et al., 2011, GBC)
  - Two-leaf： BEPS (Chen et al., 1999, EM)



Ecosystem Model in GCAS

Boreal Ecosystem Productivity Simulator (BEPS)

(It has been used for all global ecosystems)

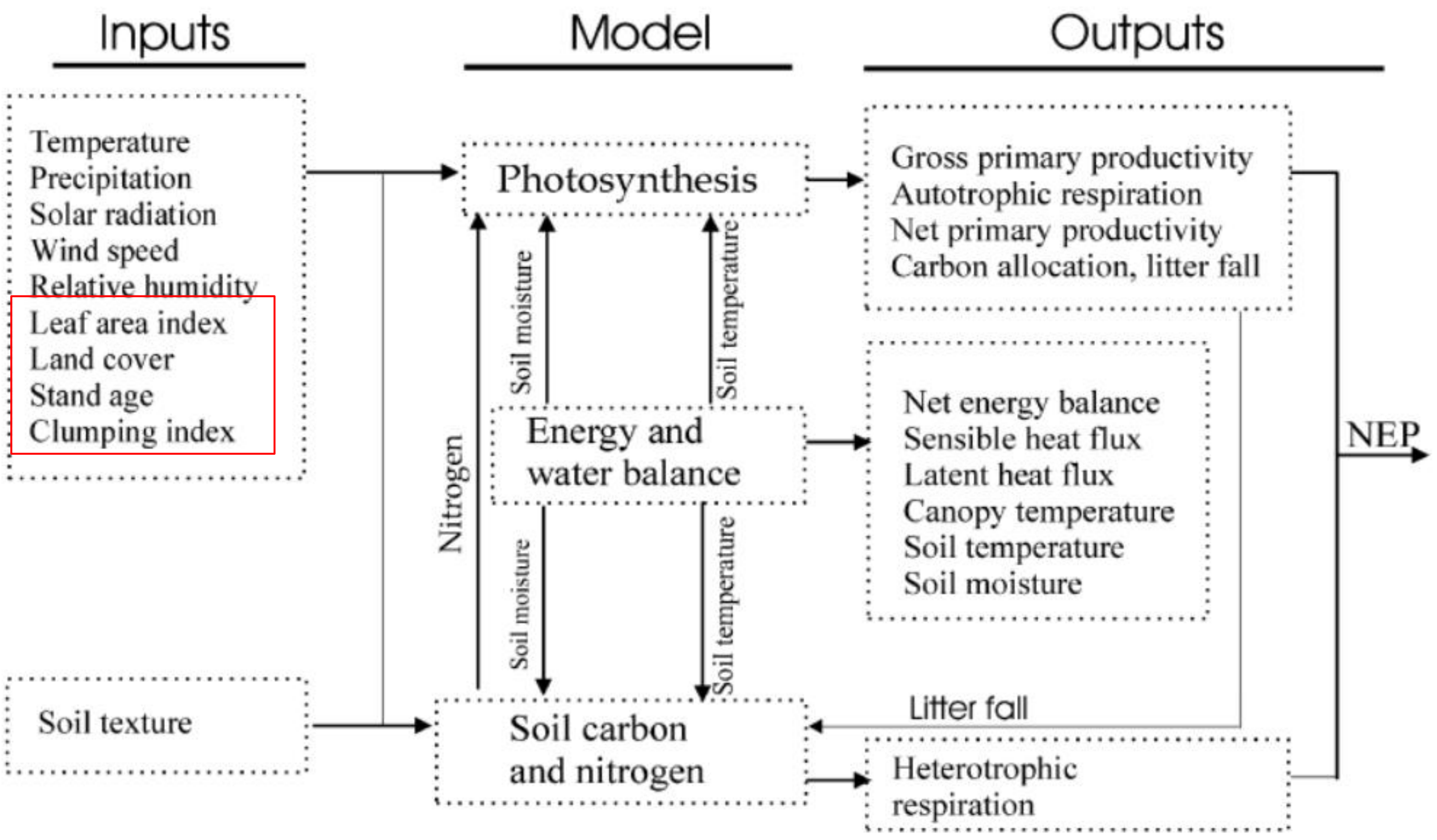


Fig. 1. The major inputs/outputs and information flows in the updated BEPS model.

Liu et al., 1997; Chen et al., 1999; Ju et al., 2006

Ecosystem Model in GCAS

GCAS V1: In situ CO_2 + satellite land surface remote sensing data
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GCAS V2： In situ CO_2 + satellite CO_2 column data + ground air pollution data
+satellite land surface remote sensing data
Optimization of terrestrial ecosystem fluxes
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Leaf-level Photosynthesis Model

Farquhar's Enzyne-Kinetic Model

$$W_c = V_m \frac{C_i - \Gamma}{C_i + K}$$

$$W_j = J \frac{C_i - \Gamma}{4.5C_i + 10.5\Gamma}$$

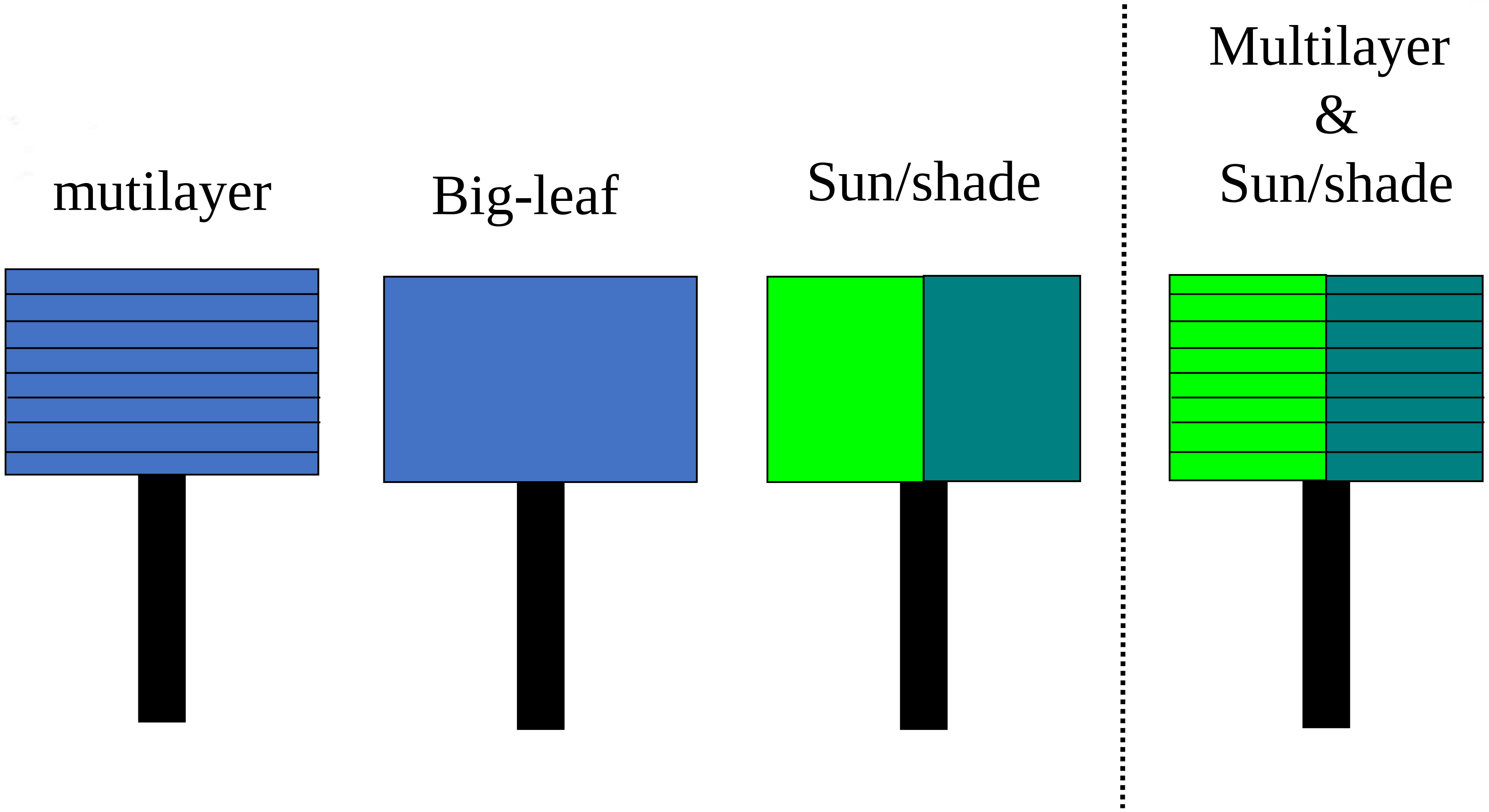
$$GPP = \min(W_c, W_j) - R_d$$

Sunlit Leaf

Shaded Leaf

W_c and W_j are temperature/nutrient-limited and light-limited gross photosynthesis rates

Scaling from Leaf to Canopy



EK and LUE Models to be Compared

Two-leaf EK Model

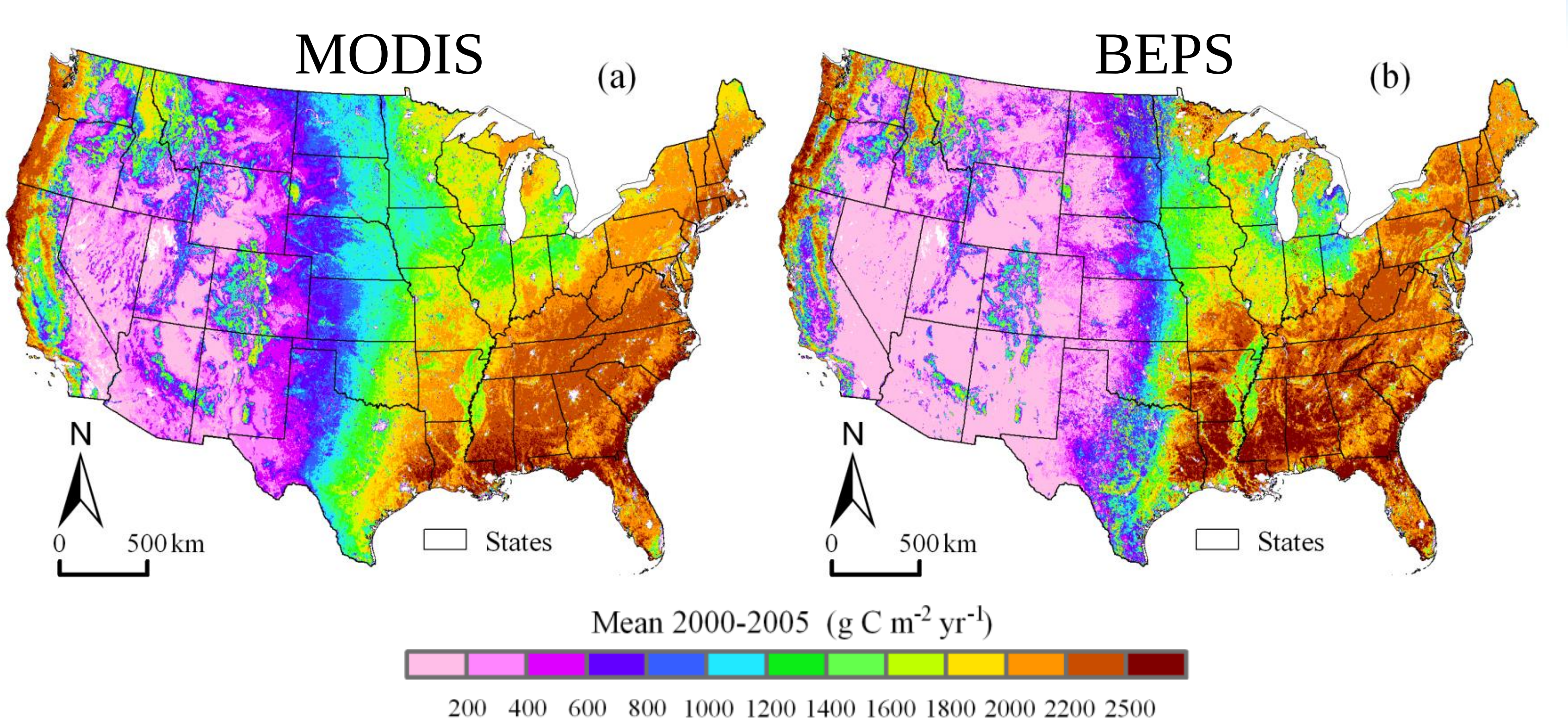
(Norman, 1993; du Pury and Farquhar, 1997; Wang and Leuning, 1998; Chen et al., 1999)

$$GPP = GPP_{sun} L_{sun} + GPP_{shaded} L_{shaded}$$

Big-leaf Light Use Efficiency Model

$$GPP = \varepsilon(\varepsilon_{\max}, T_a, VPD, \ldots\ldots)APAR$$

Spatial Distributions of Modelled GPP



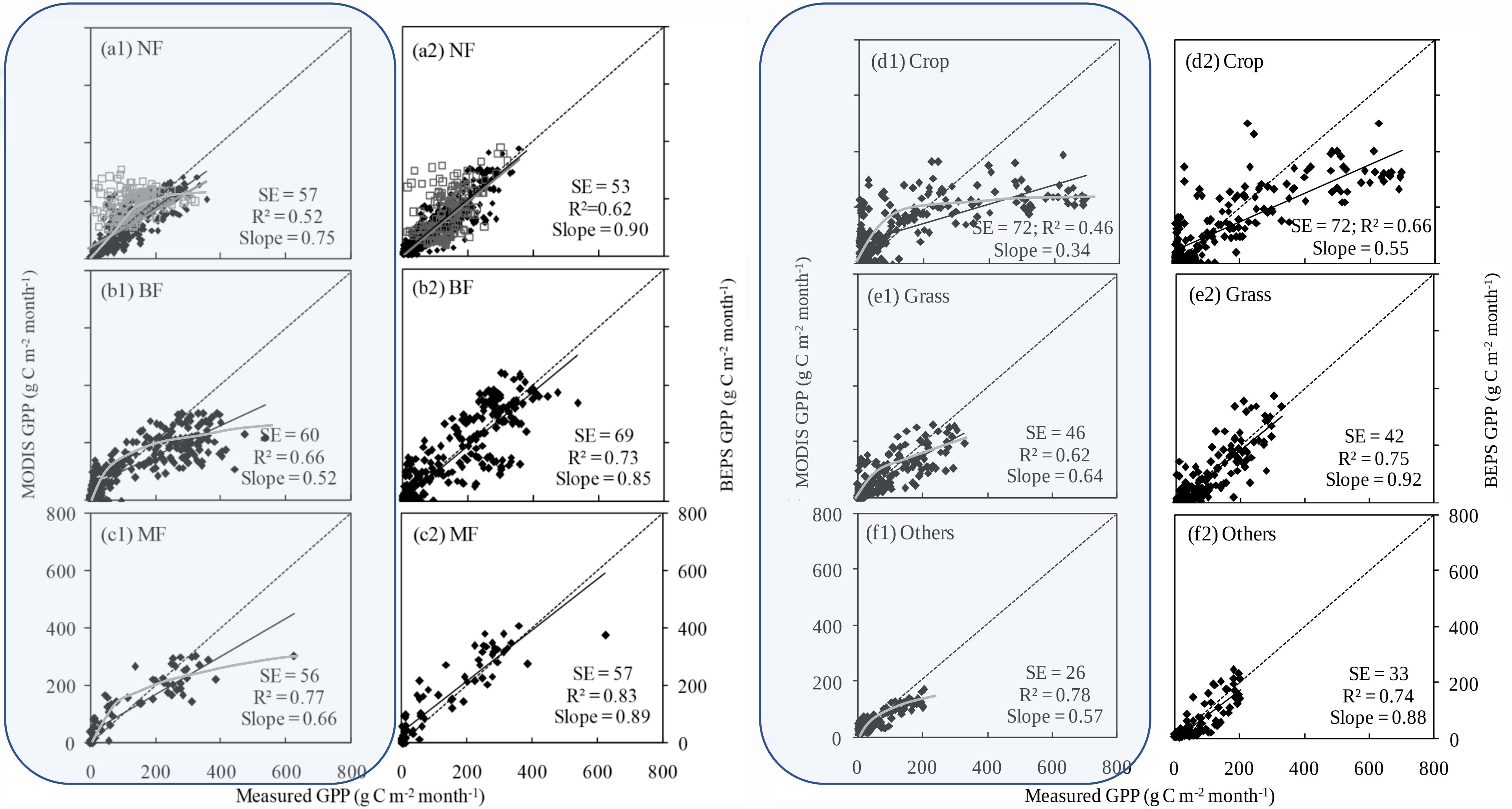
Big-leaf LUE Model
8-day Time Steps
1 km Resolution
2000-2005 average: 6.46 Pg C yr^{-1}

Two-leaf EK Model
Hourly Time Steps
1 km Resolution
2000-2005 average: 6.04 Pg C yr^{-1}

Zhang, Chen et al., (2012, RSE)

Comparison with Measured Monthly GPP Derived from Eddy Covariance Data

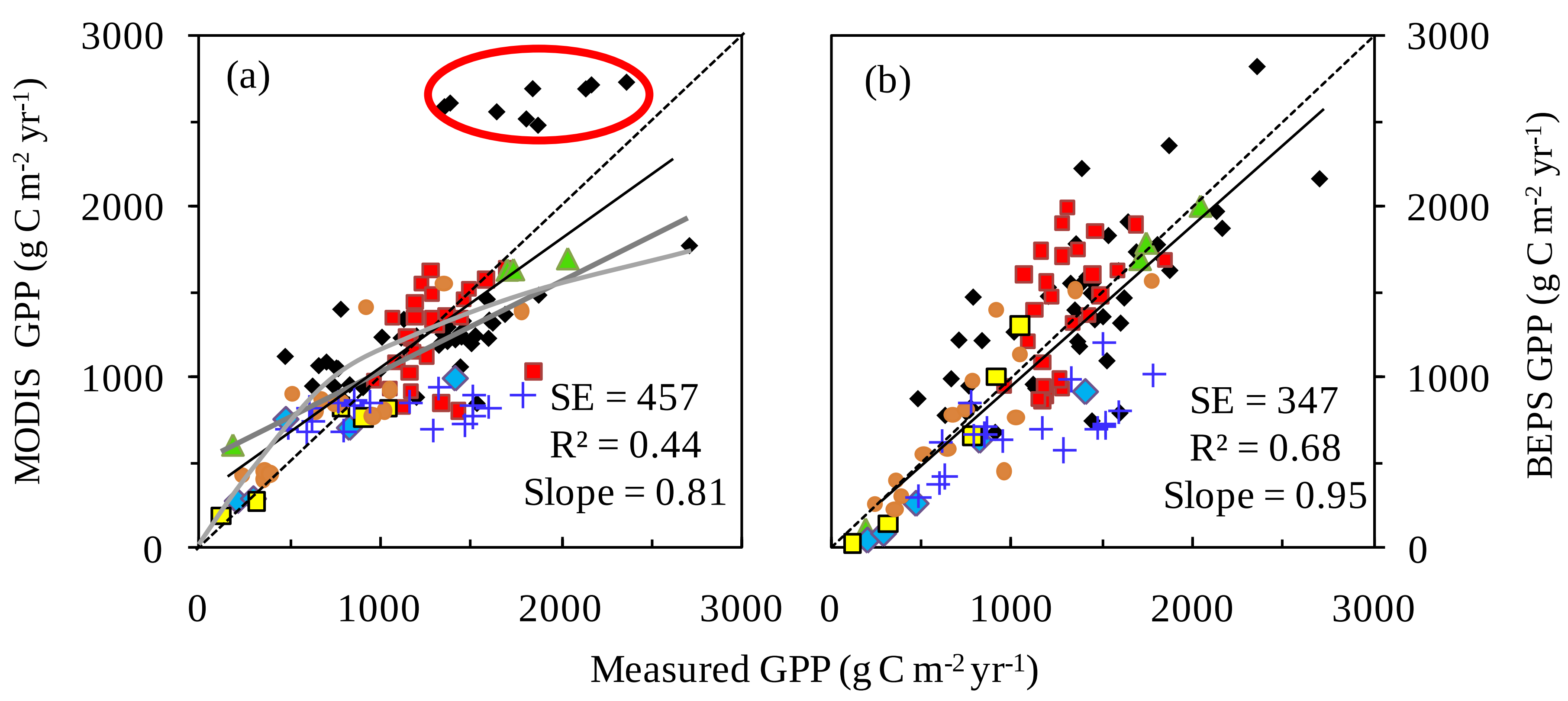
(40 sites, 120 site-years, different PFTs)



Zhang, Chen et al., (2012, RSE)

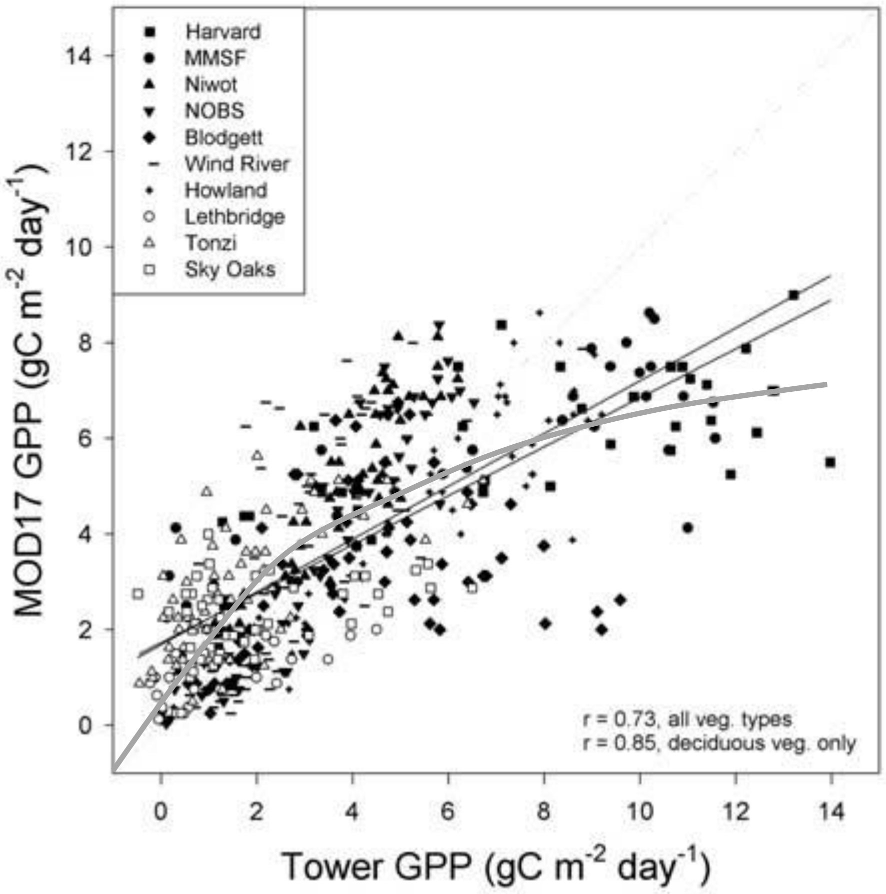
Comparison with Measured Yearly GPP Derived from Eddy Covariance Data

(40 sites, 120 site-years, different PFTs)



Zhang, Chen et al., (2012, RSE)

Similar Comparisons Found in Previous Studies



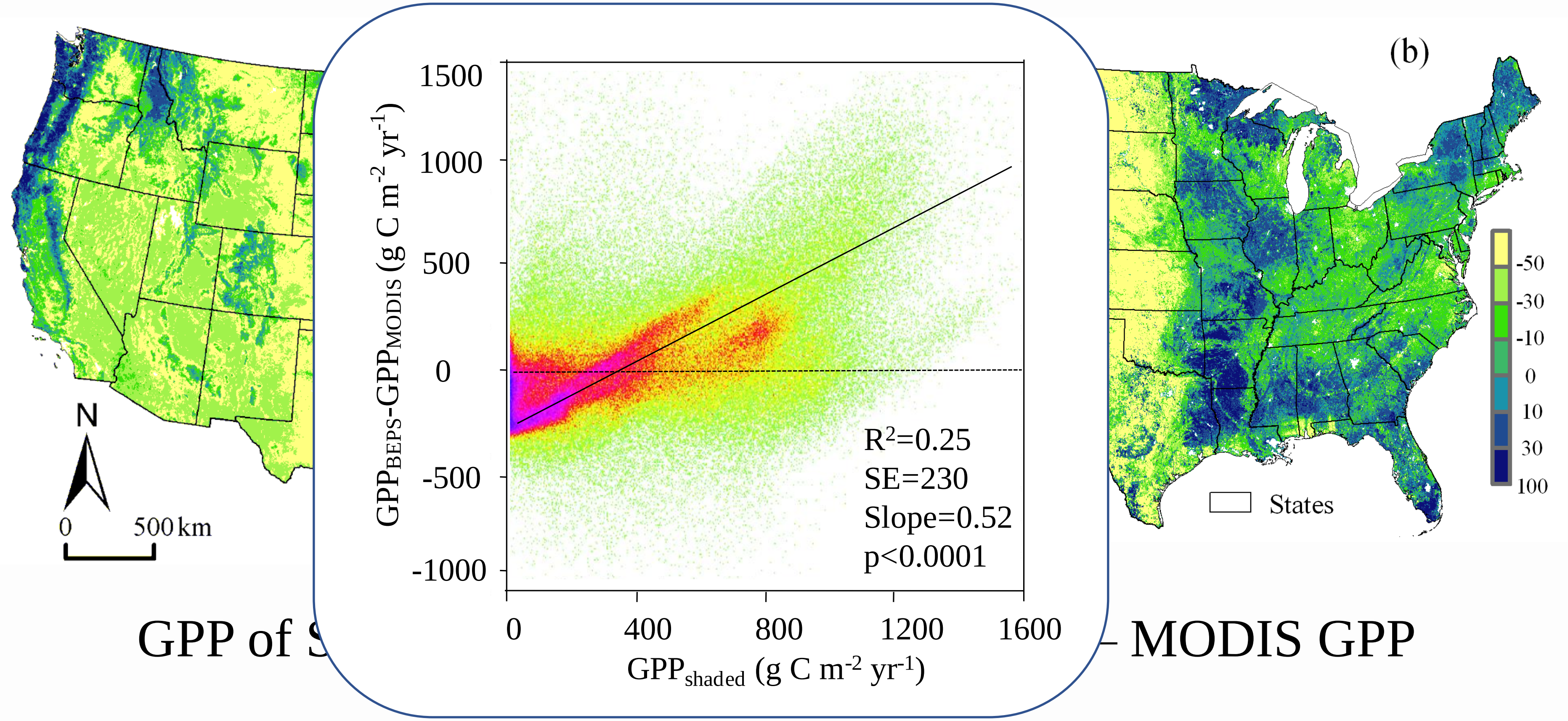
See also:

Sims *et al*. (2006, *JGR*)

Janhan and Gan (2009, *JGR*)

Rahman *et al*. (2005, *JGR*)

Shaded GPP is mostly responsible for the difference between MODIS and BEPS GPP

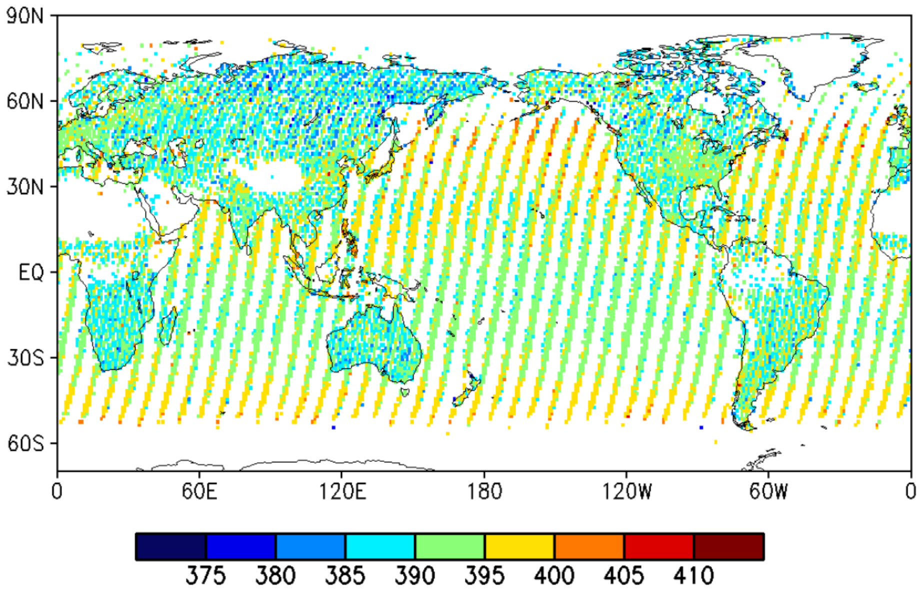


GPP of S ... – MODIS GPP

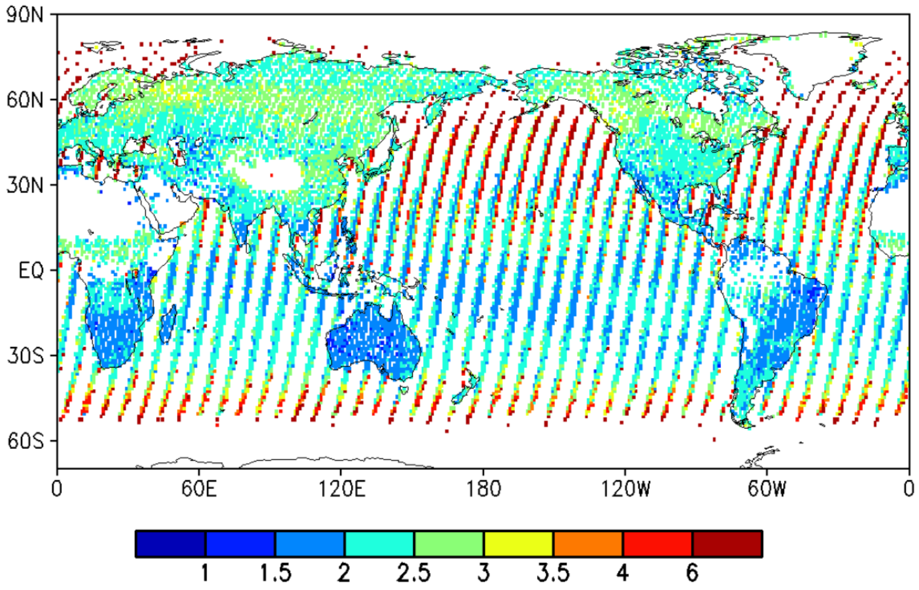
Zhang, Chen et al., (2012, RSE)

Global Terrestrial Carbon Flux Optimization by GCAS

- Data： GOSAT ACOS v7.3
- Period： 2009-05-01 to 2015-12-31， Assimilation window： 1 week
- Prior flux： Land by BEPS； Ocean from pCO_2-Clim prior；
- Anthropogenic emission： CDIAC; biomass emission： GFEDv4



Mean CO_2 concentration



Mean uncertainty

CO2 Concentration Improved by Assimilation

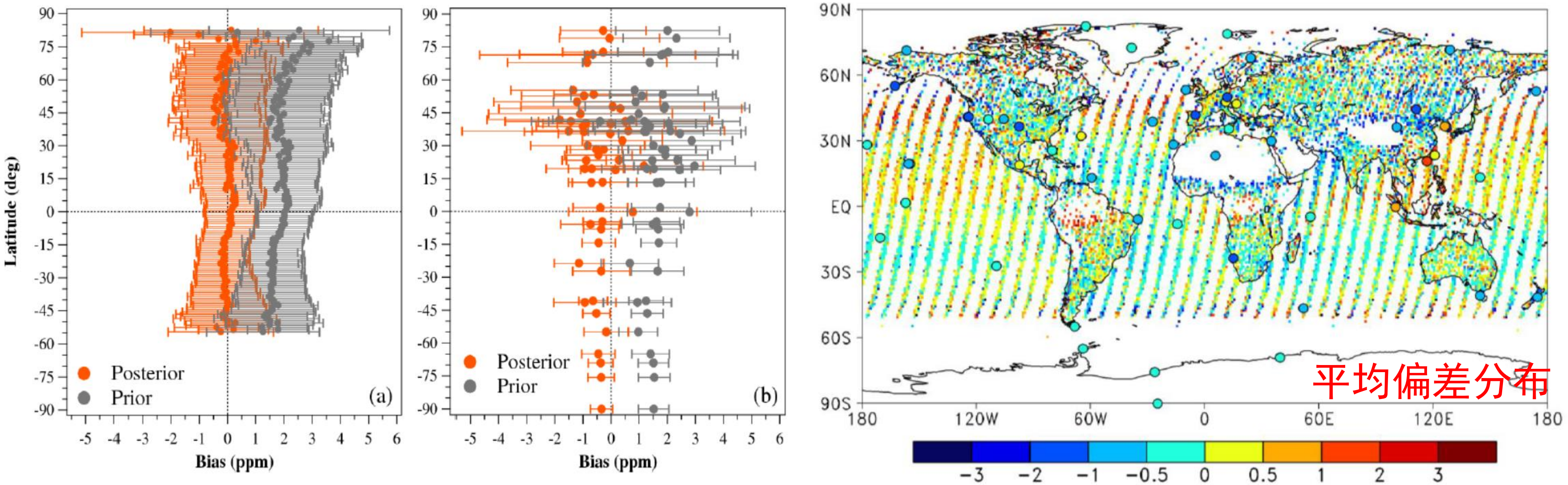
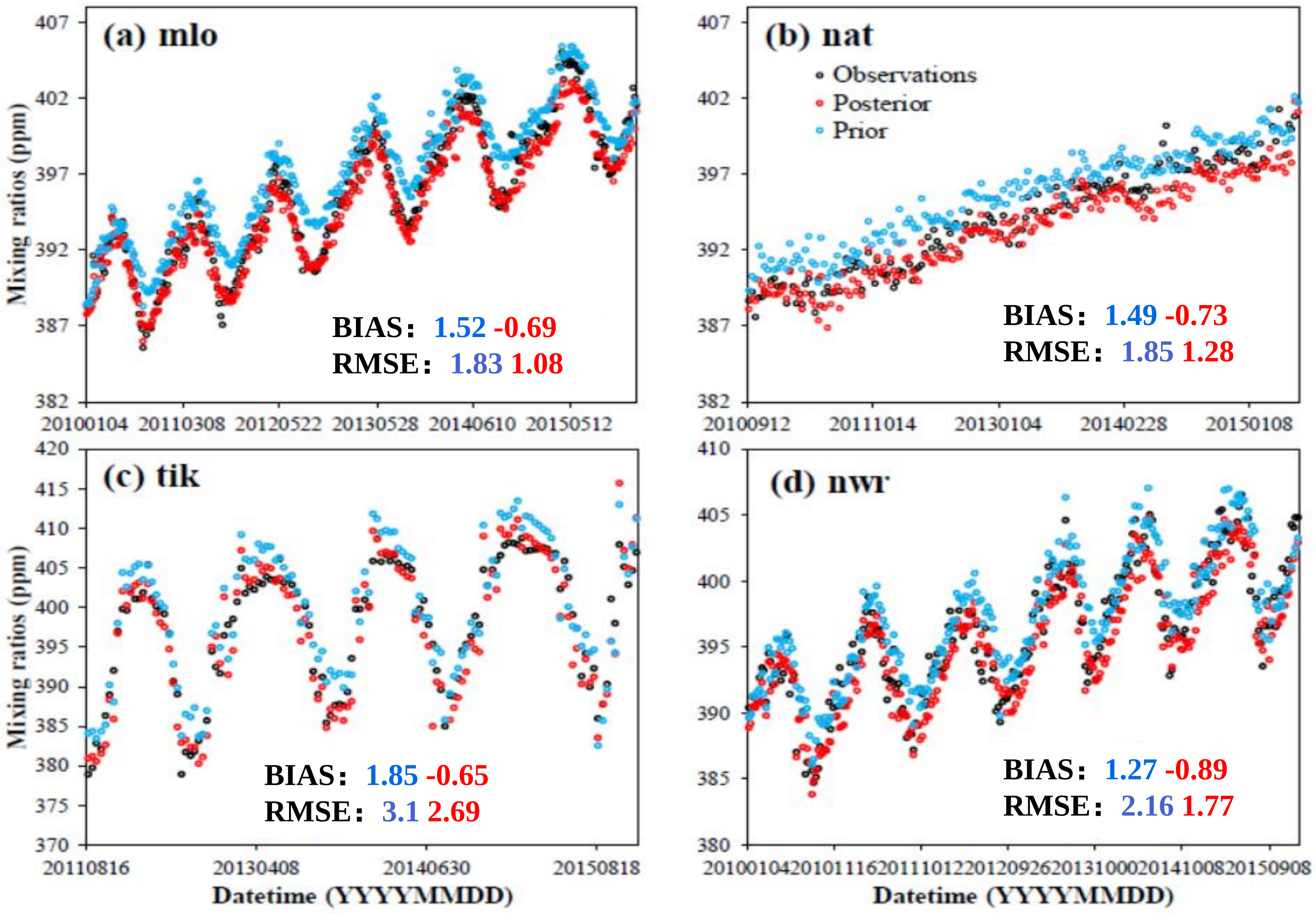


Table1. Statistics of the simulated surface CO_2 and XCO_2 concentrations against the surface flask observations and GOSAT retrievals, respectively

	BIAS (ppm)*		RMSE (ppm)		CORR	
	Prior	Posterior	Prior	Posterior	Prior	Posterior
XCO_2	1.8±1.3	-0.0±1.1	2.2	1.1	0.95	0.96
Surface CO_2	1.6±1.8	-0.5±1.8	2.4	1.9	0.96	0.96

*mean ± standard deviation

Validation Using in situ Data



CO_2 Annual Growth Rate Is Improved

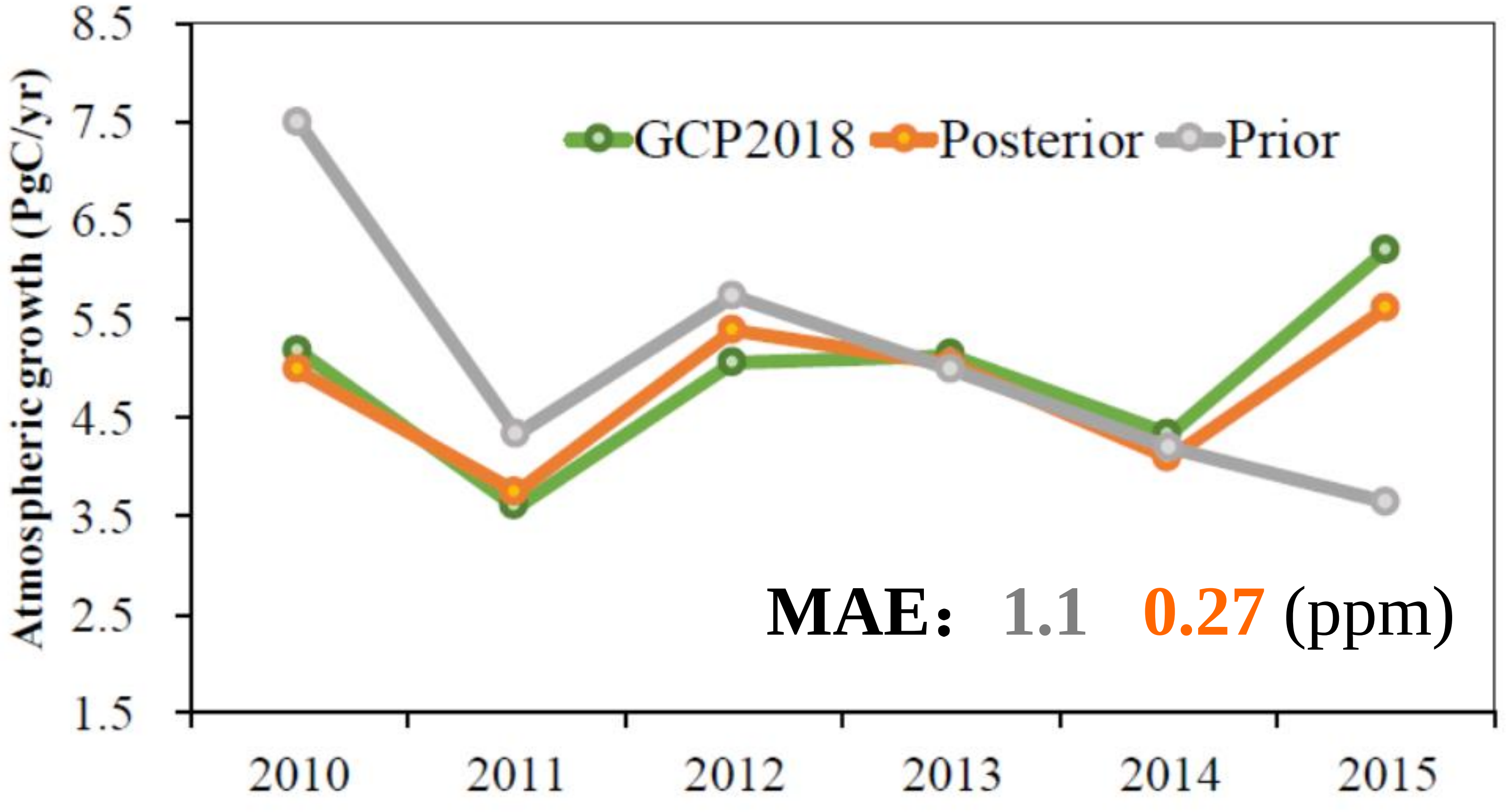
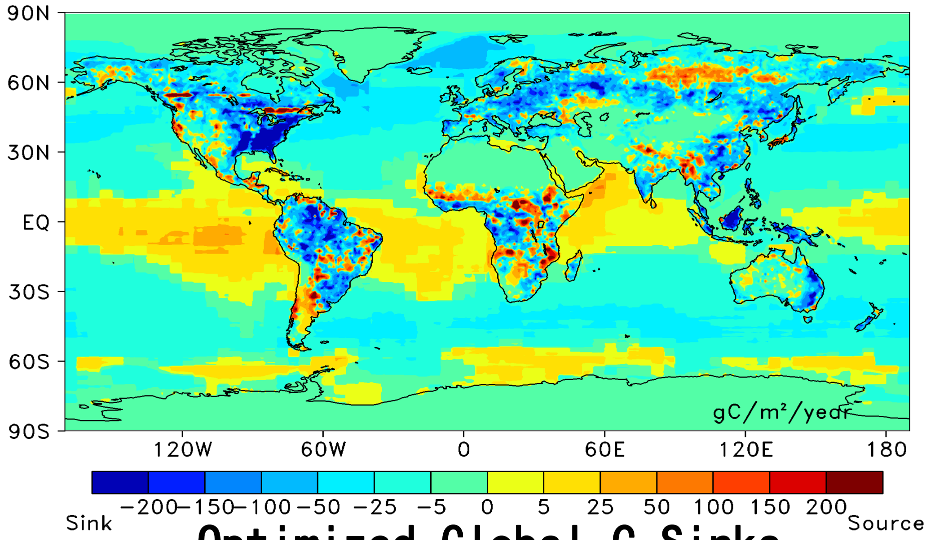
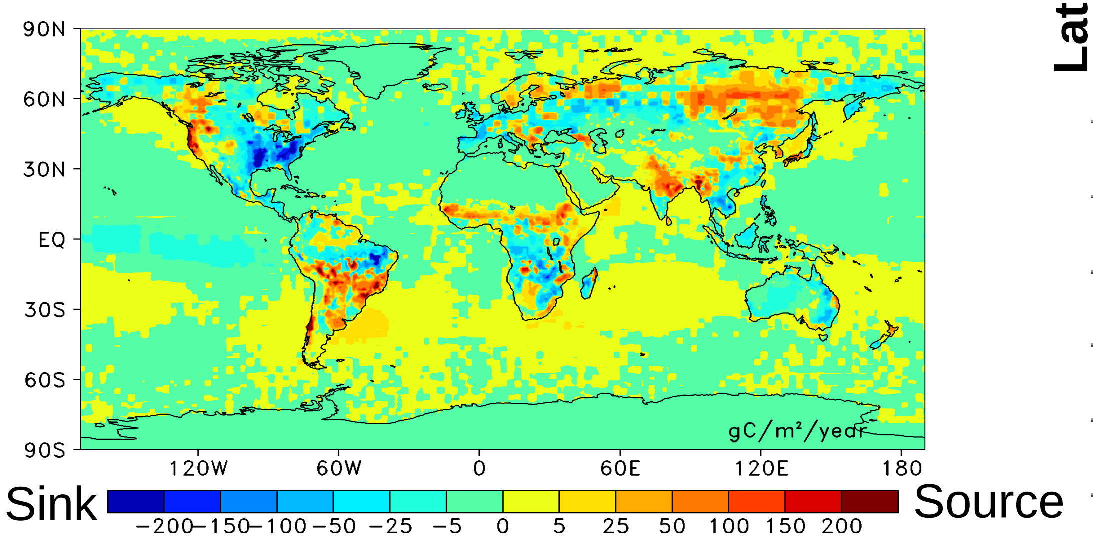


Figure 8. Interannual variations of the atmospheric CO_2 growth rates

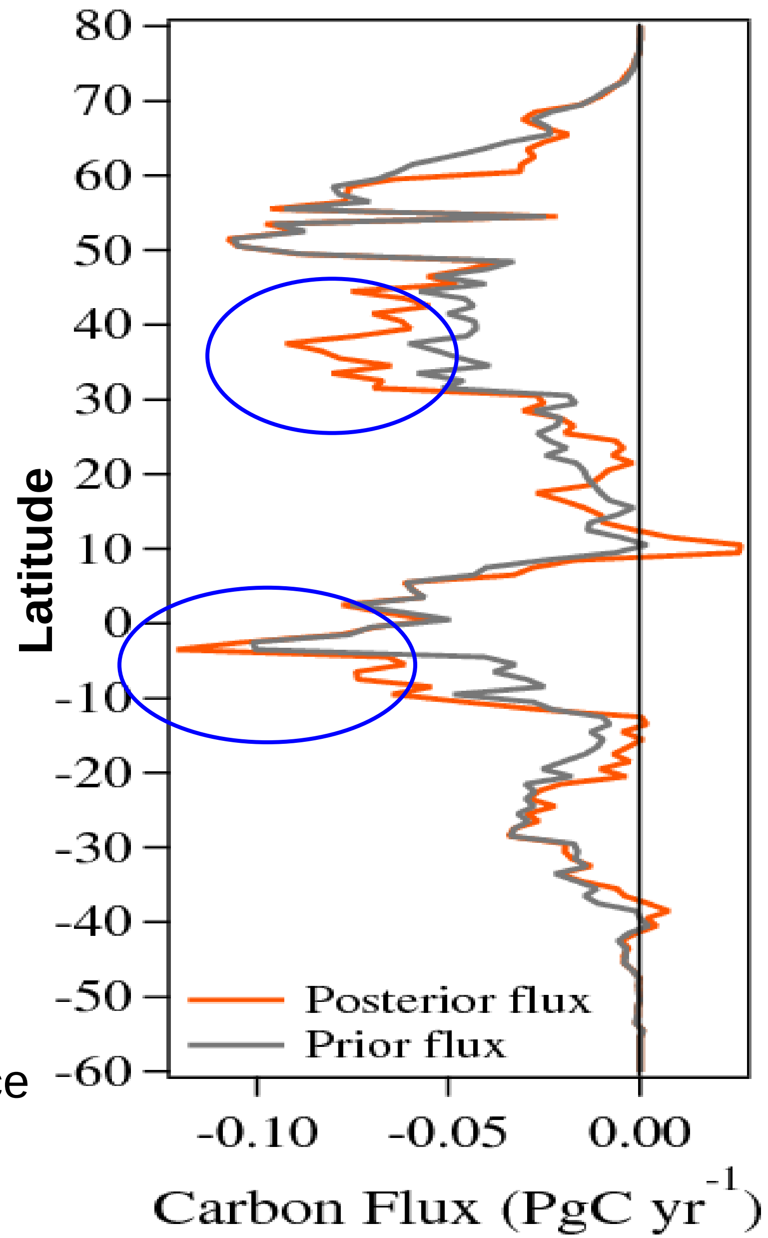
Optimized Global Carbon Sink/Source Distribution



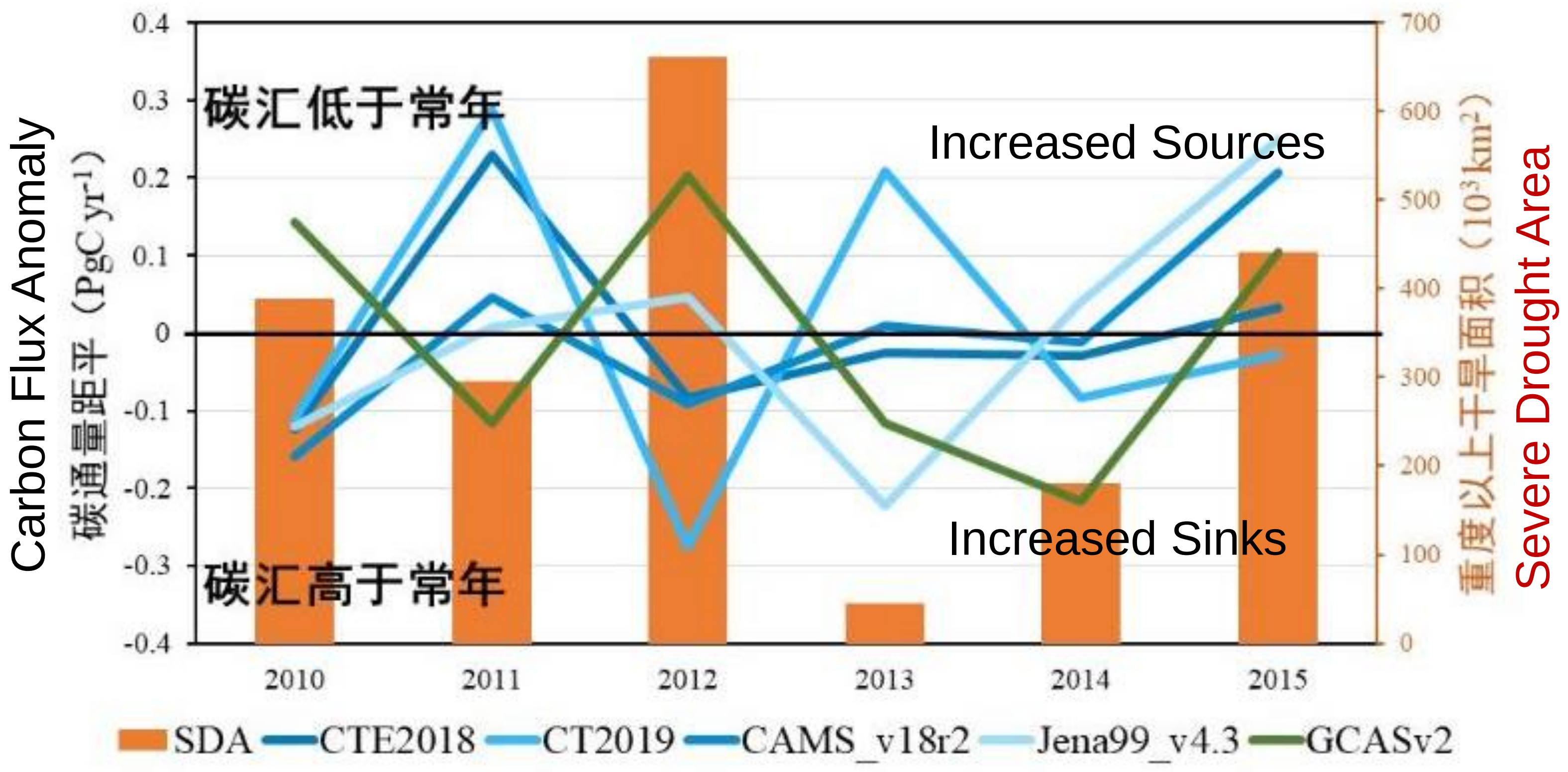
Optimized Global C Sinks



Difference between Prior and Posterior Fluxes



Response of Optimized Flux to Drought in Europe



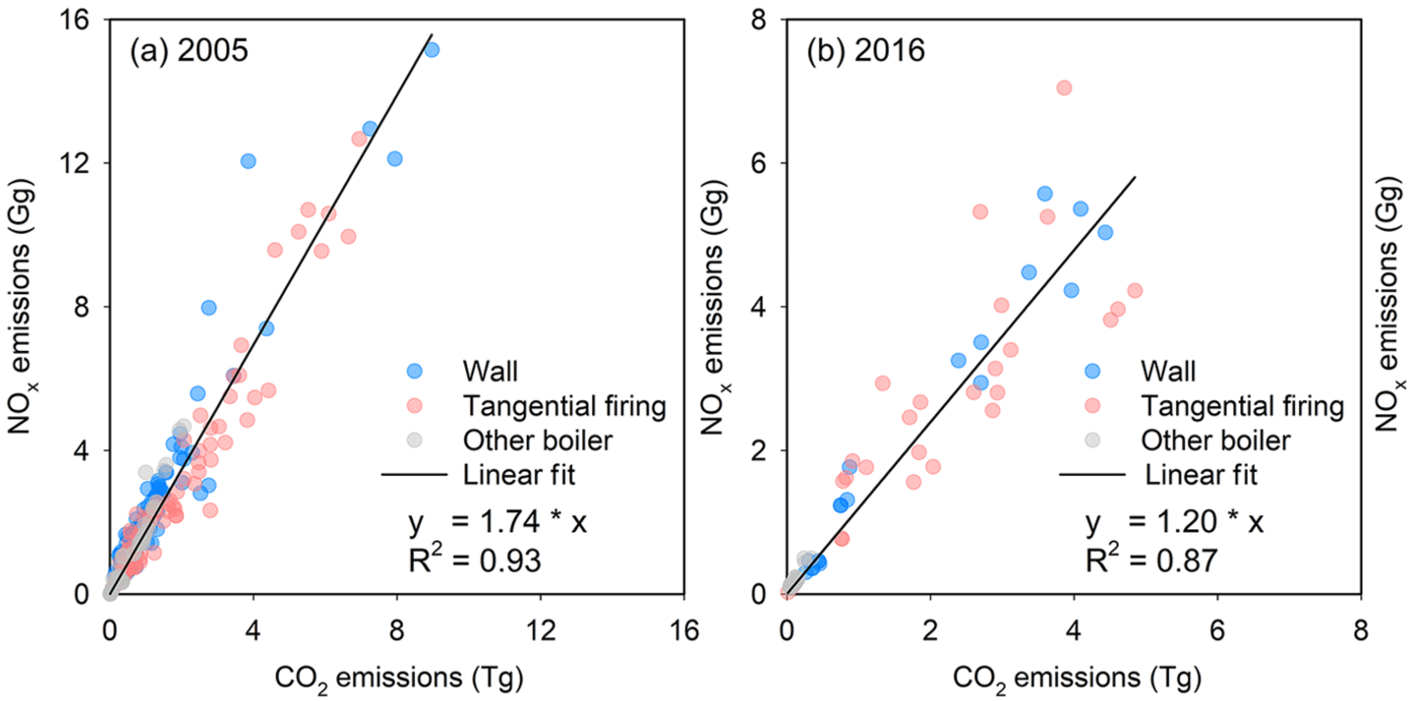
GCAS seams to be the only model that responded well to severe drought

Optimization of China's Carbon Emission

Good relationships between Nox and CO_2 emissions

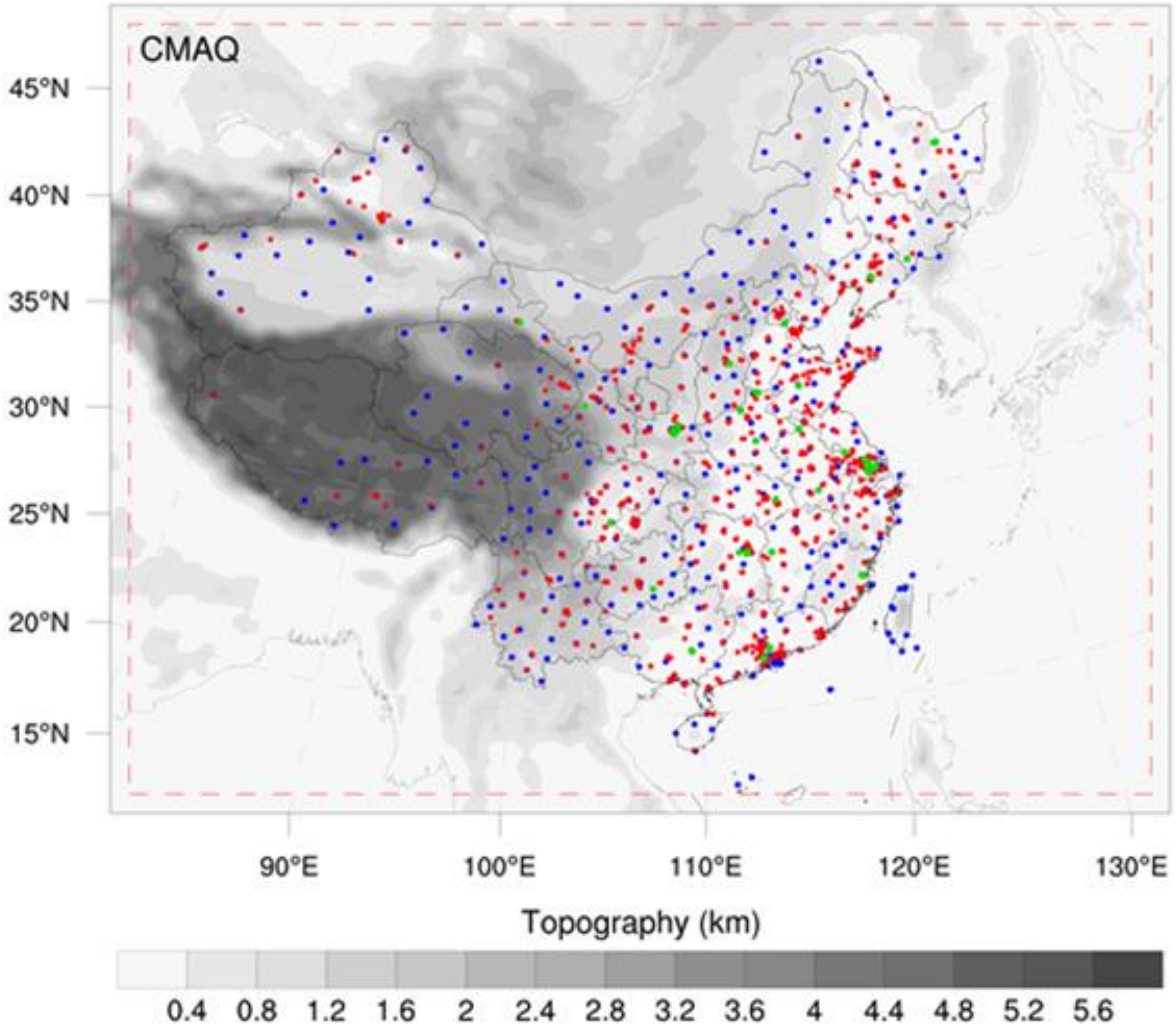
$$CO2_{t,s}^{top-down} = NOx_{t,s}^{top-down} \times \frac{CO2_{t,s}^{bottom-up}}{NOx_{t,s}^{tbottom-up}},$$

t is time; S is type of fossil fuel



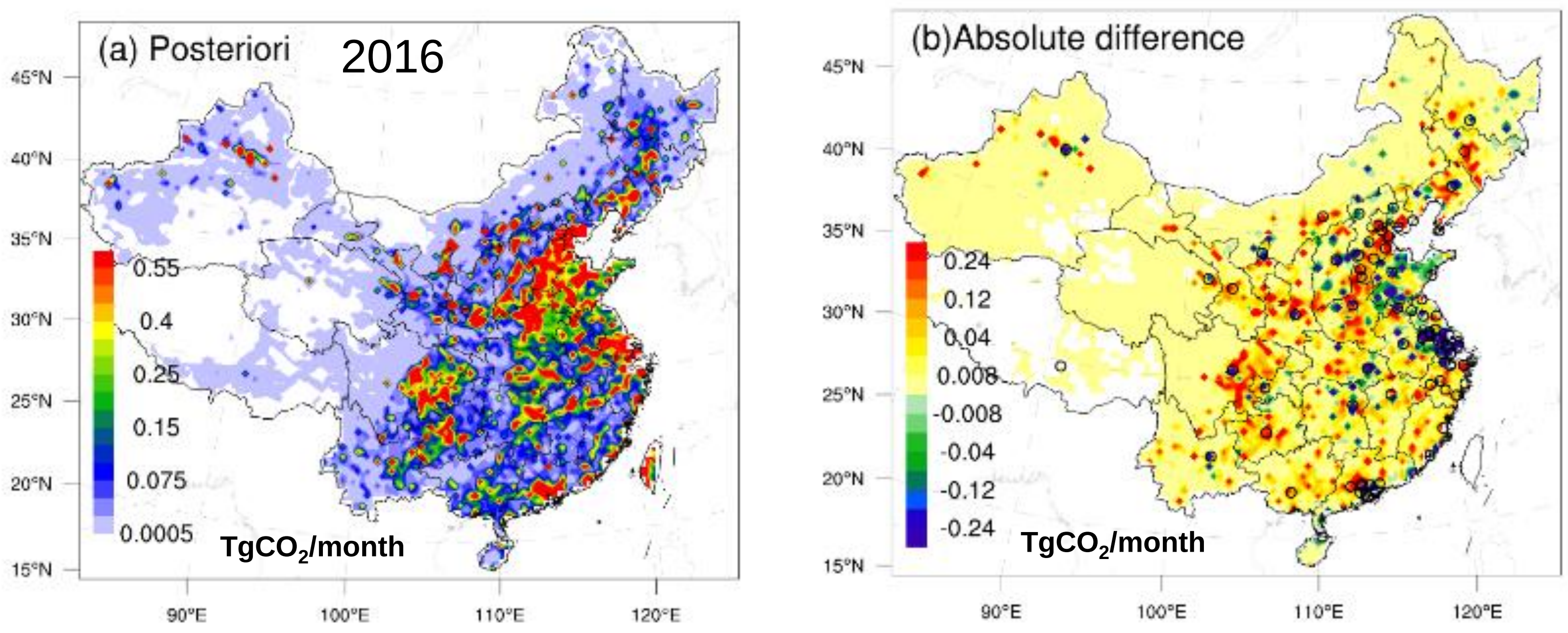
Liu et al., 2020, ACP

NOx and Weather Stations



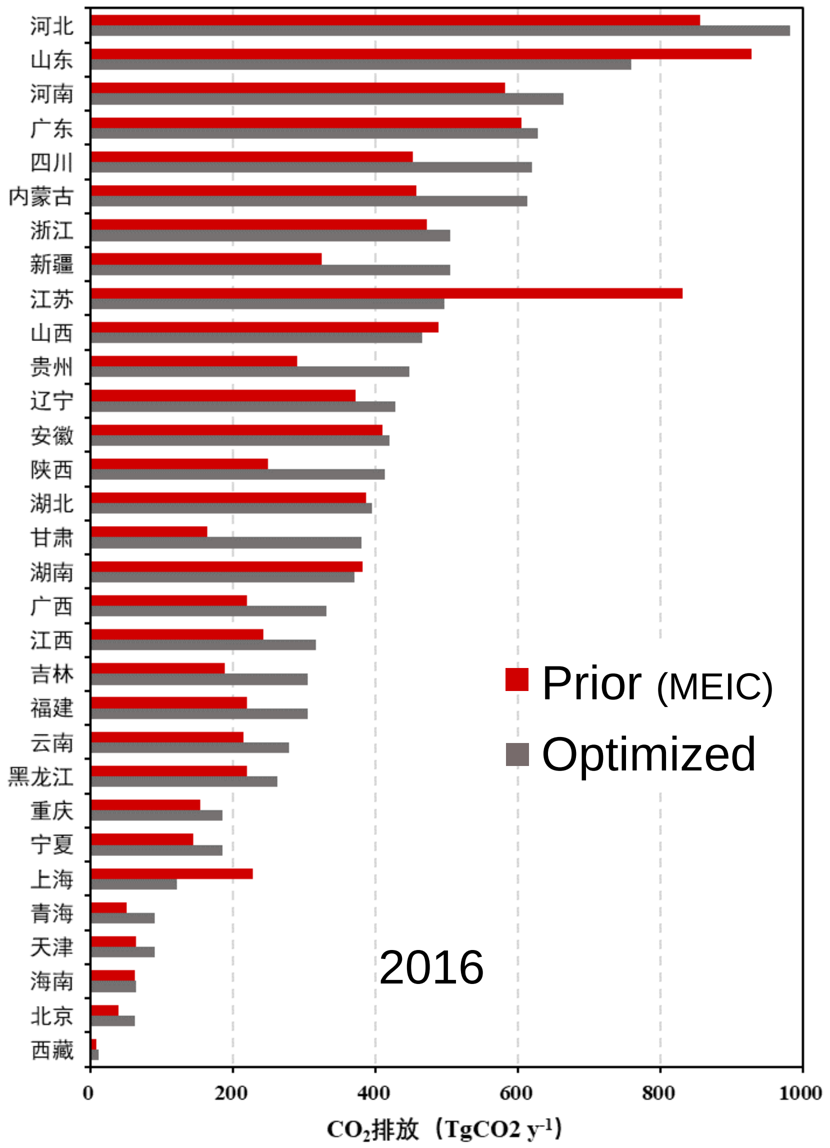
- NOx Assimilaton Sites，1385
- NOx Validation Sites，119
- Weather Stations，400

Optimized China's Anthropogenic Carbon Emission

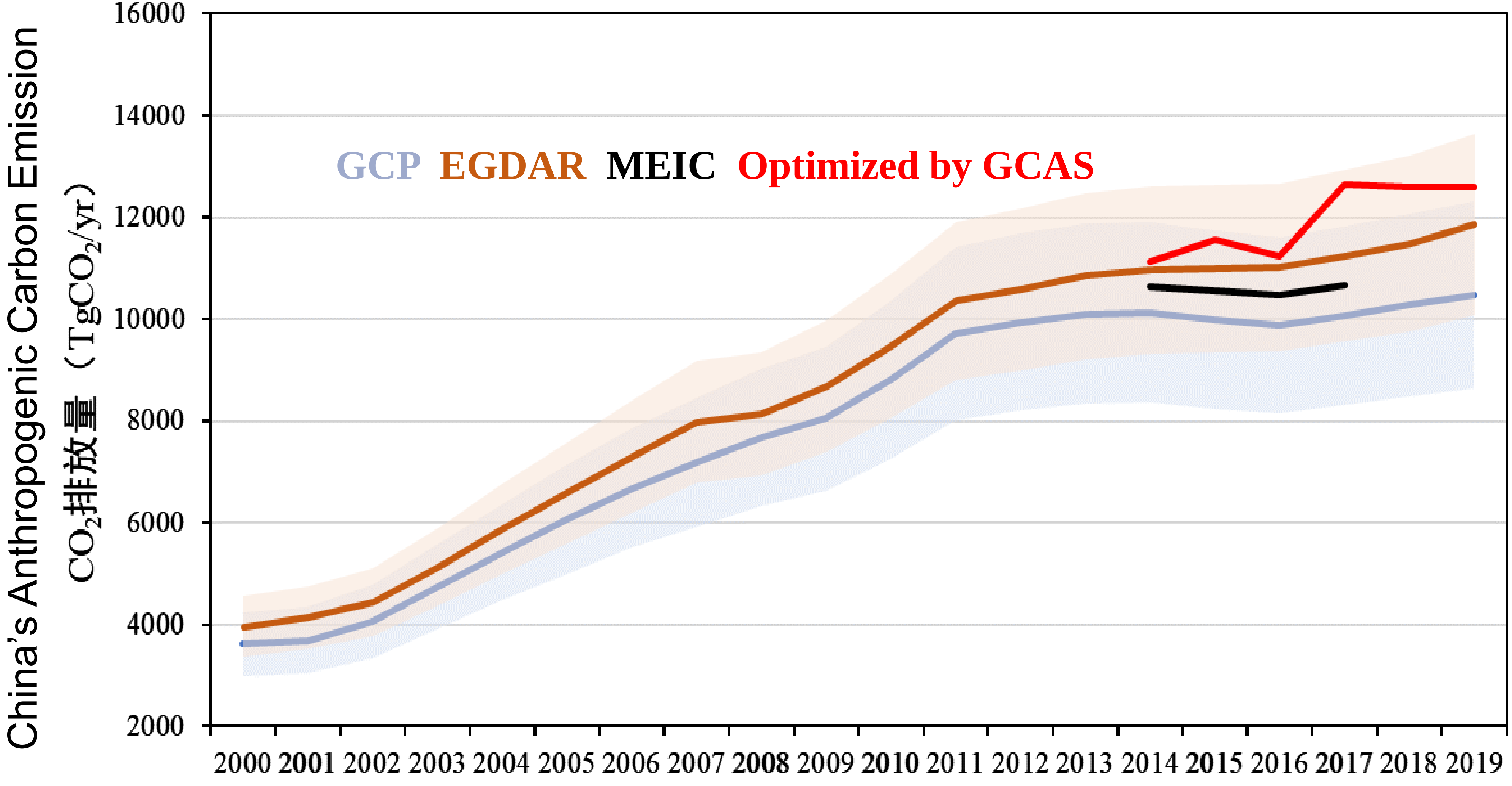


- Optimized flux is 6% higher than the Multi-Scale Emission Inventories of China (MEIC)
- Western regions show increased emissions while some eastern regions show decreasing emissions. Scaling emissions with GDP and population could be the main reason for the biases in MEIC.

Optimized Carbon Flux by Province



Comparison of Various Estimates



Summary

- GCAS is further developed to assimilate satellite CO_2 column and surface air pollution data for land and anthropogenic carbon flux optimization;
- Optimized land fluxes using GOSAT CO_2 column data responded well to severe drought impacts on the land carbon flux;
- Air NO_x data are shown to be useful for optimizing anthropogenic carbon fluxes over China, although the results are yet to be validated

Thank You

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