GROUP ON EARTH OBSERVATIONS

Atmospheric Inversions of Global and Regional Terrestrial Ecosystem Carbon Sources and Sinks

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2018-10-25 Kyoto Japan

Outline

1. Overview of Land Sink Inversion efforts in China

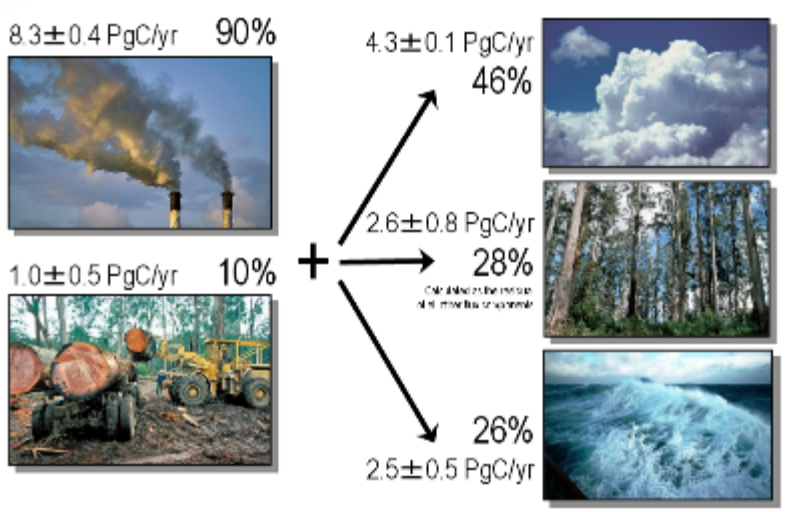
2. A comprehensive estimate for the land sink of China

3. A new Global Carbon Assimilation System (under development)

4. Summary

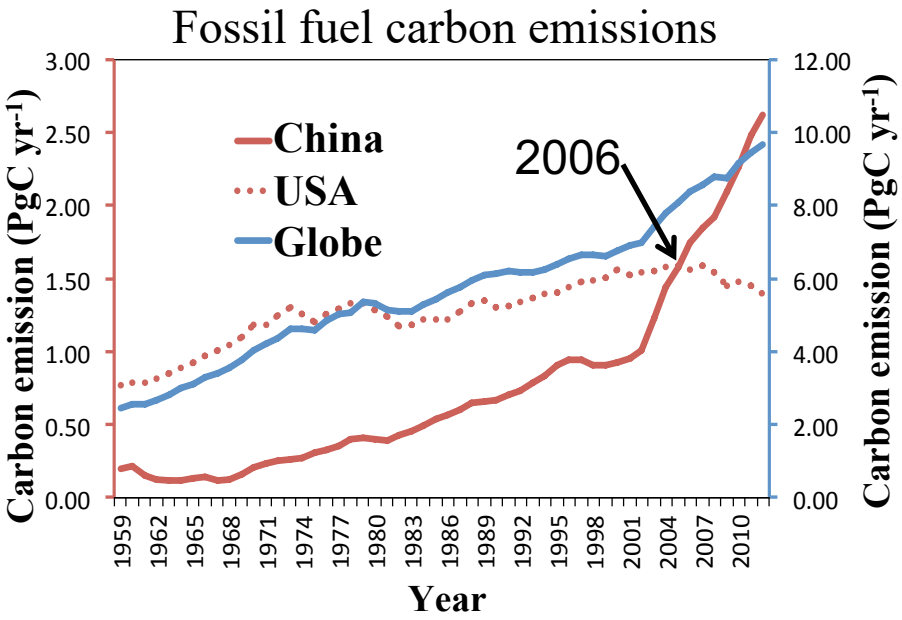
1. Overview of Land Sink Inversion efforts in China

- Terrestrial ecosystem carbon sink play an important role in mitigating the increase of atmospheric CO_2 concentrations.



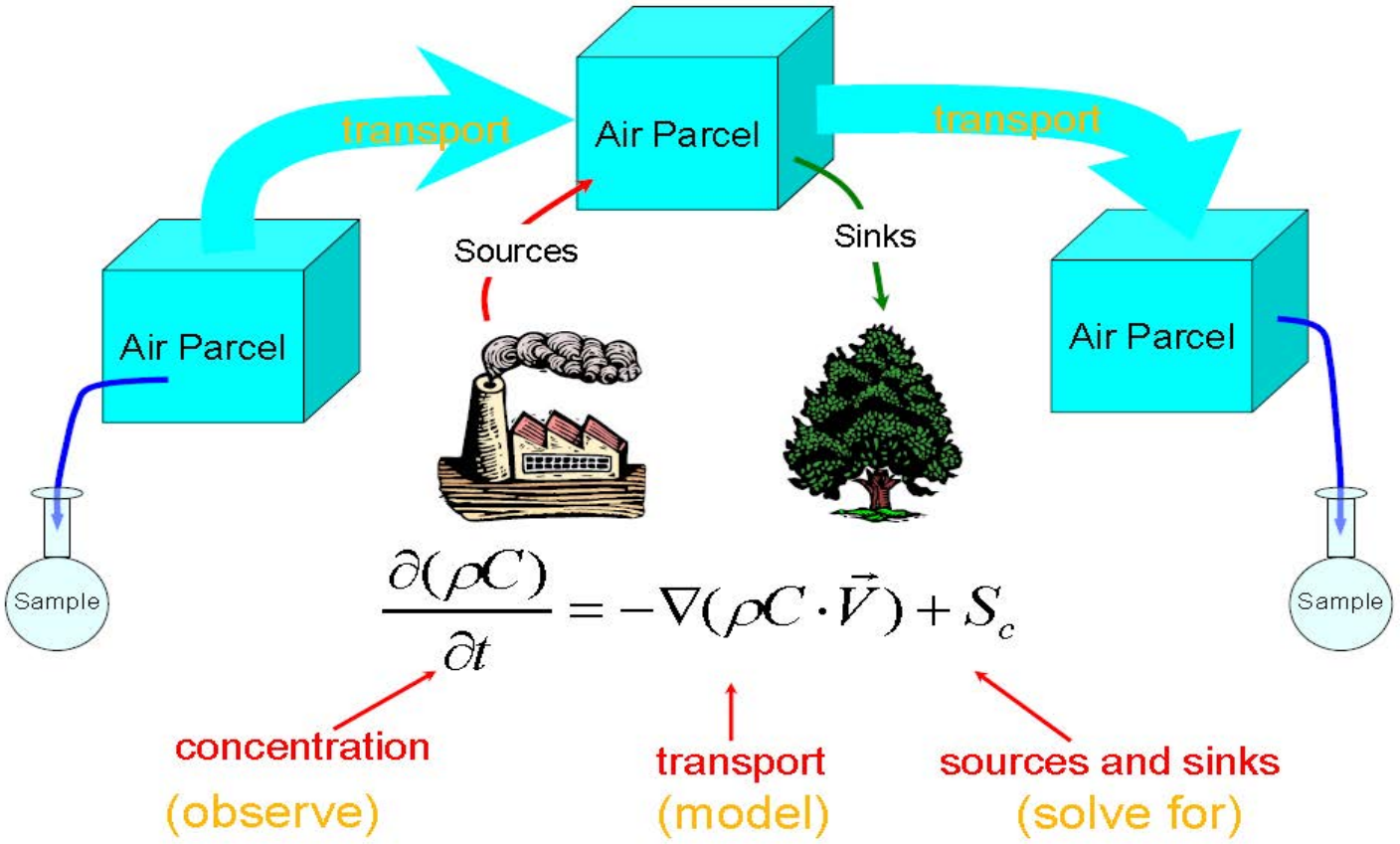
from global carbon budget office

- China is facing a huge international pressure to reduce greenhouse gas emissions, so there is an urgent need to identify its land sink.



1. Overview of Land Sink Inversion efforts in China

Atmospheric inversion is an effective method to estimate global and regional land sinks, which uses **observed CO_2 concentrations** and **atmospheric transport model** to optimize land and ocean carbon fluxes.



Slide modified from Scott Denning

1. Overview of Land Sink Inversion efforts in China

Programs and Institutes

- Since 2010, several programs were started in China
  - The national major scientific research program for Global Change Research
  - The national key R & D projects for "Global change and response"
  - The CAS Strategic Priority Research Program for "Climate Change: Carbon Budget and Relevant Issues"
- Several research institutes work on land sink inversions
  - Nanjing University, Beijing Normal University
  - IAP, CAS
  - IGSNRR, CAS
  - CMA

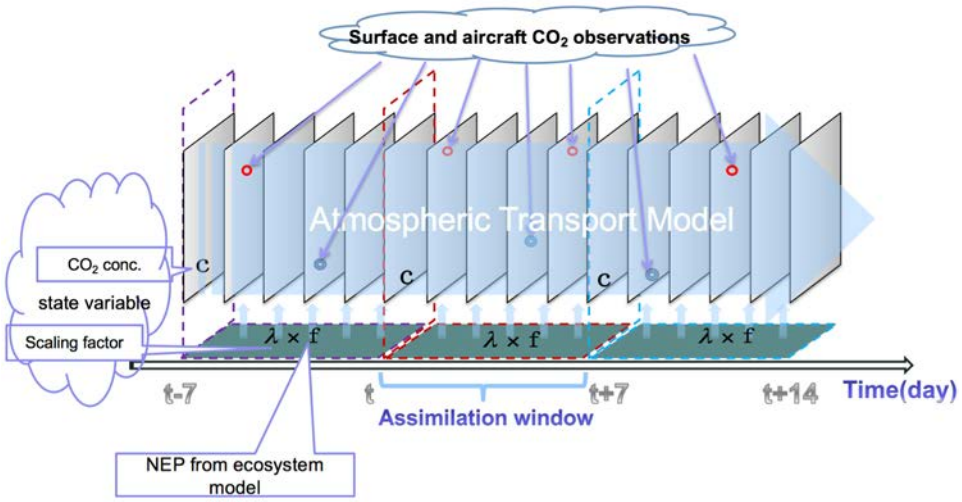
1. Overview of Land Sink Inversion efforts in China

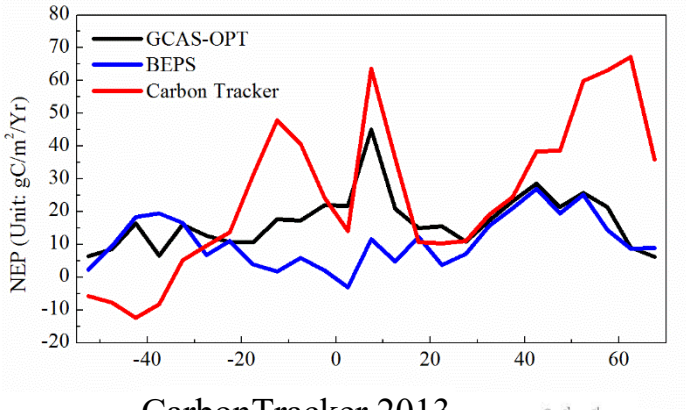
Developed and Introduced Inversion Systems

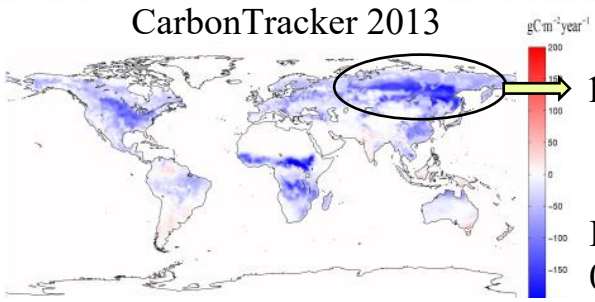
- **A Global Carbon Assimilation System (GCAS)** was joint developed by Nanjing University and Beijing Normal University
- **A Nested Atmospheric inversion system with a focus on China** was developed in Nanjing University
- **A Satellite based and High Resolution Global Carbon Assimilation System (GCAS-II)** is being developed in Nanjing University now
- **A Chinese carbon cycle data-assimilation system (Tan-Tracker)** was developed in IAP, CAS
- CarbonTracker was introduced by CMA and IGSNRR, CAS named as **CarbonTracker-China and CarbonTracker-China CAS**, respectively

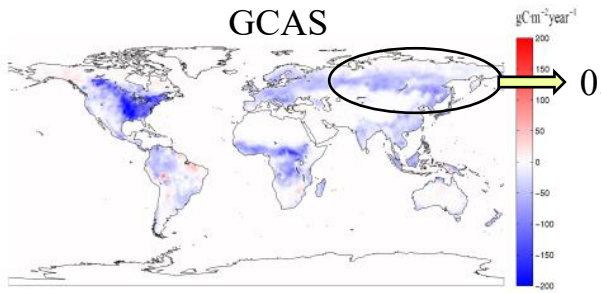
1. Overview of Land Sink Inversion efforts in China

A Global Carbon Assimilation System (GCAS)









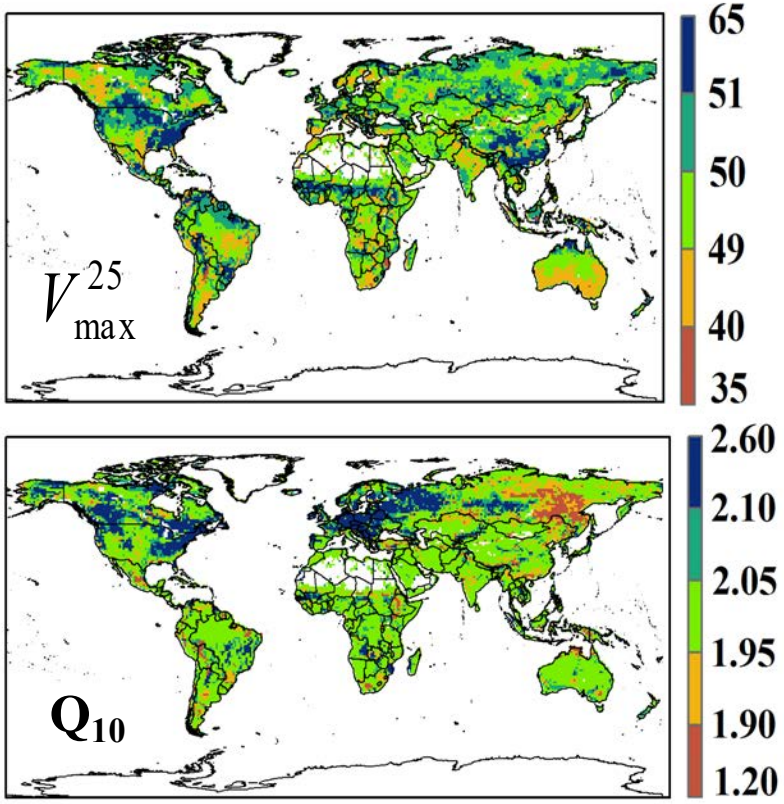
- **Transport Model**: MOZART4, globally, 2.8°×2.8°.
- **Meteorological field**: ERA-interim
- **Priori ecosystem carbon flux**: BEPS
- **Assimilation algorithm**: LETKF; Assimilation window: 1 week
- **Observations**: Obspack
- **Optimized fluxes: terrestrial ecosystem carbon fluxes**

Zhang SP et al., 2014, 2015

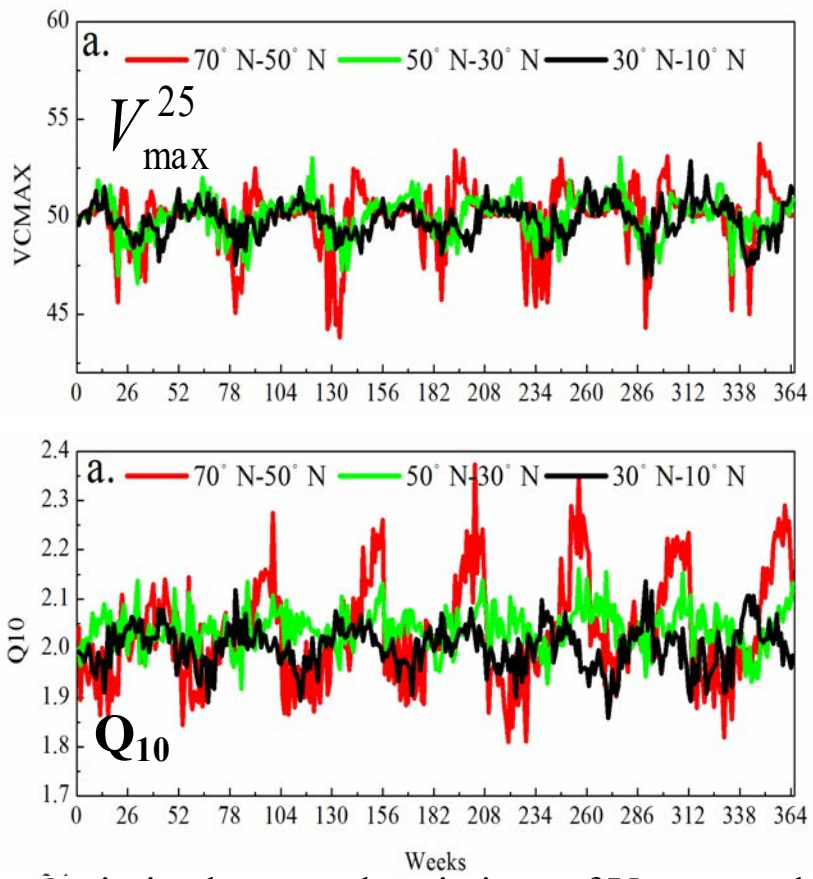
1. Overview of Land Sink Inversion efforts in China

Optimization of ecosystem model key parameters (V_{cmax} and Q_{10})

- Basically, there are higher Vcmax and Q10 over high/mid latitudes.
- The seasonal variabilities in high latitudes are more significant than in low latitudes.



Optimized distributions of Vcmax and Q_{10}

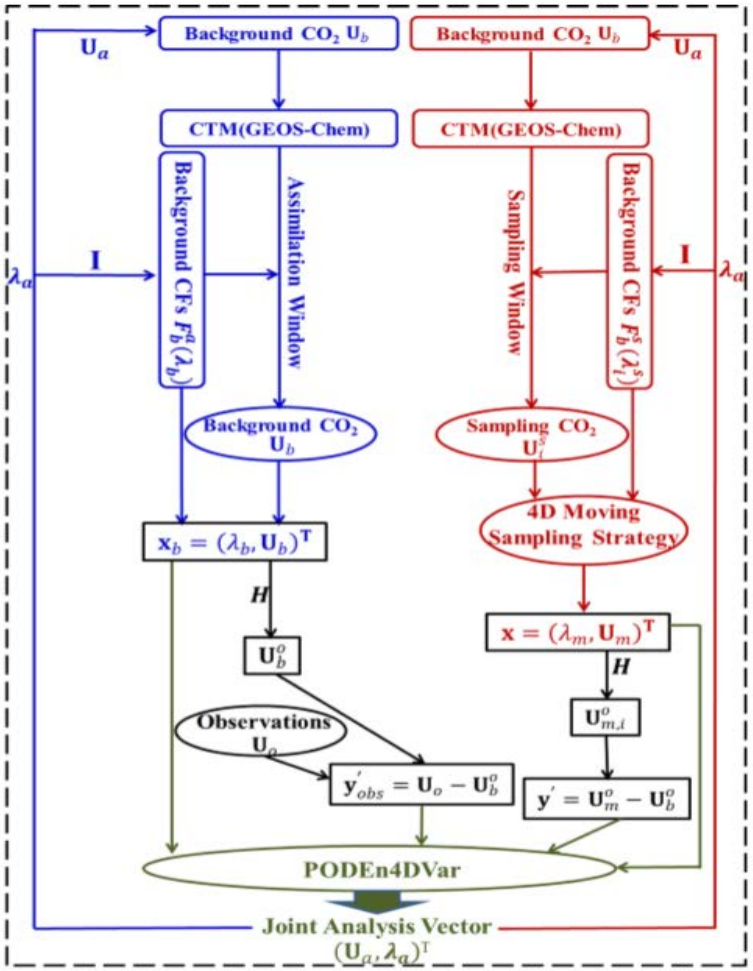


Optimized seasonal variations of Vcmax and Q_{10}

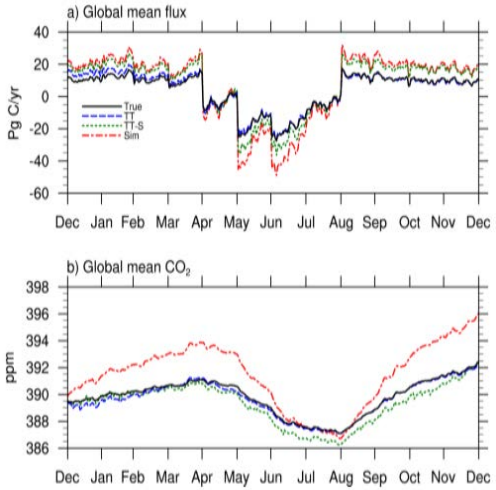
Chen et al., 2017

1. Overview of Land Sink Inversion efforts in China

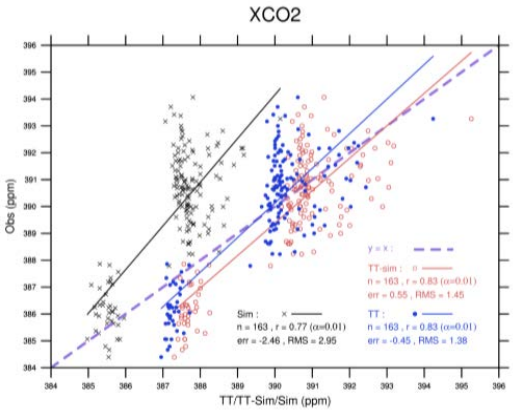
A Chinese carbon cycle data-assimilation system (Tan-Tracker)



Flowchart of Tan-Tracker



OSSEs test



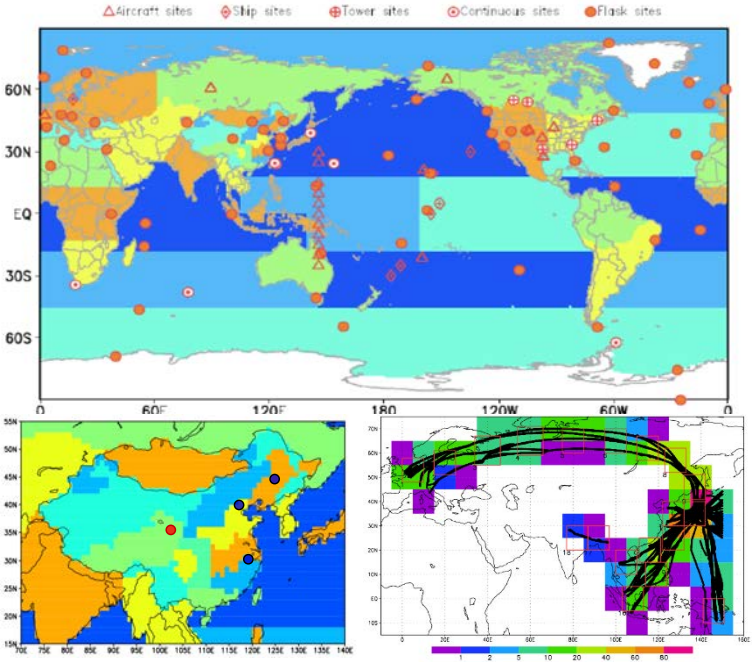
Comparisons of XCO_2

- **Advantages**: advanced data-assimilation method, efficient computing performance, and optimize CO_2 concentrations and CO_2 fluxes at the same time.
- It has well performance in the idea experiment.
- It can use XCO_2 data to infer the surface carbon flux

Tian et al., 2014

1. Overview of Land Sink Inversion efforts in China

A Nested Atmospheric inversion system with a focus on China



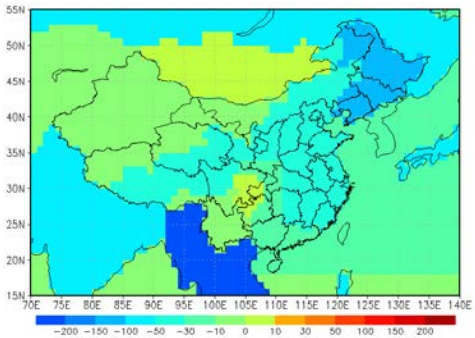
Regions: 43 regions in globe, and 13 small regions in China

Transport model: TM5, global 3°×2 °

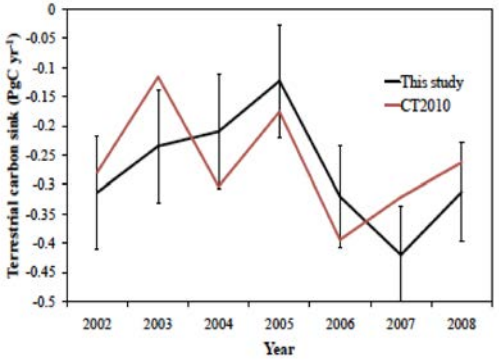
Inversion method:

$$J = \frac{1}{2}(\mathbf{M}s - c)^T R^{-1}(\mathbf{M}s - c) + \frac{1}{2}(s - s_p)^T Q^{-1}(s - s_p)$$

$$s_{post} = \left(\mathbf{M}^T R^{-1}\mathbf{M} + Q^{-1}\right)^{-1}\left(\mathbf{M}^T R^{-1}c + Q^{-1}s_p\right),$$

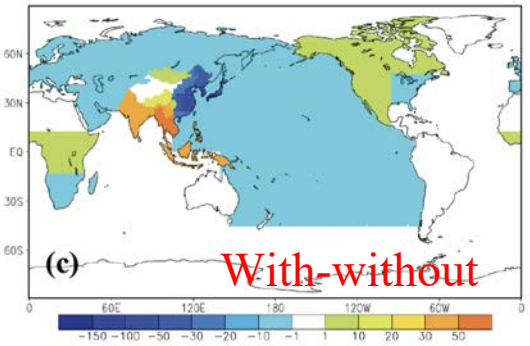


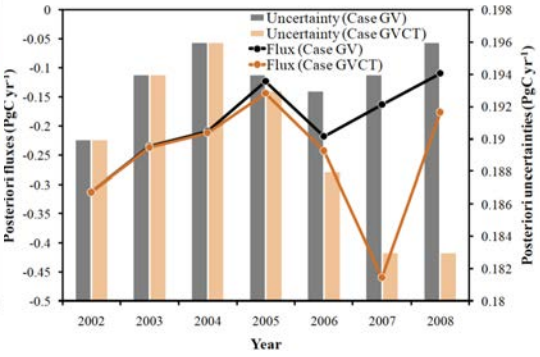
Inverted mean distribution of terrestrial and ocean carbon fluxes (averaged for 2002–2008).



Inter-annual variations

Jiang et al., 2013



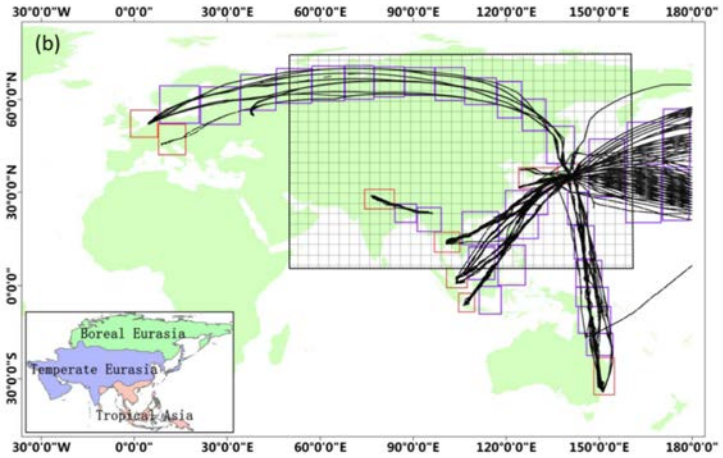


Impact of CONTRAIL aircraft CO_2 measurements on the inverted land sink of China

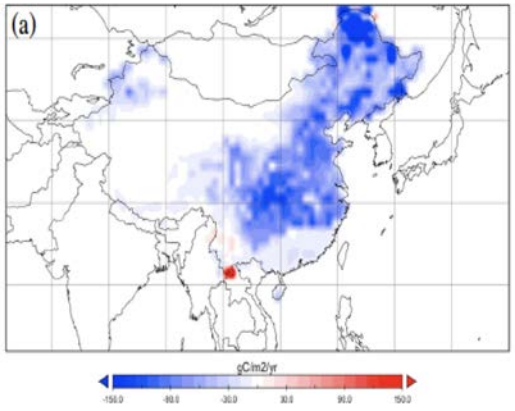
Jiang et al., 2014

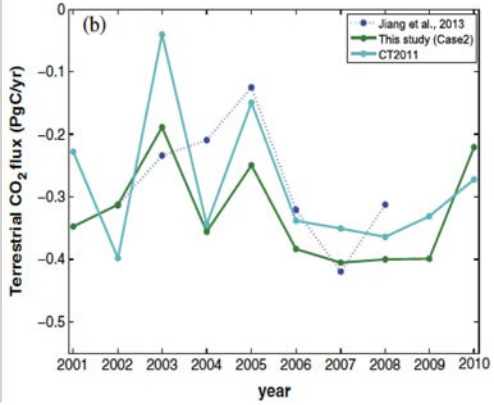
1. Overview of Land Sink Inversion efforts in China

CarbonTracker-China CAS

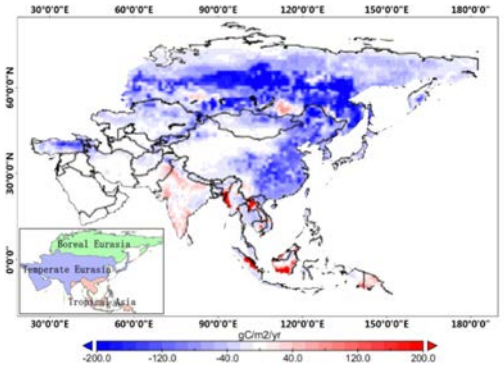


Basically the same as CT in US, but move the nested domain from north America (CT) to East Asia, and use more data over east Asia

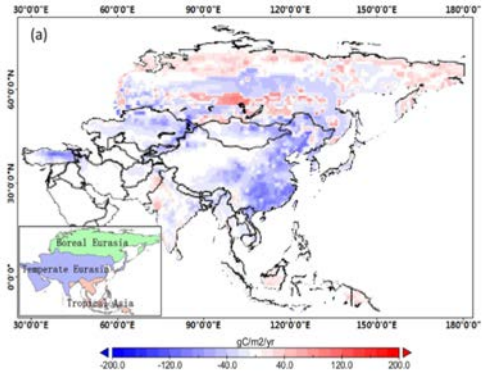




Mean and inter-annual terrestrial biosphere CO_2 flux in China during 2001–2010



Inverted carbon flux over Asia during 2006–2010



Impact of CONTRAIL data

Zhang HF et al., 2014a, b

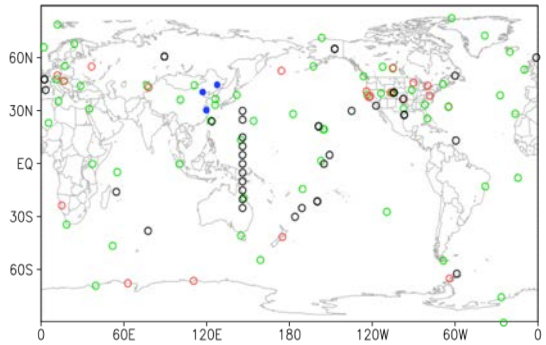
2. A comprehensive estimate for the land sink of China

Top-down estimate

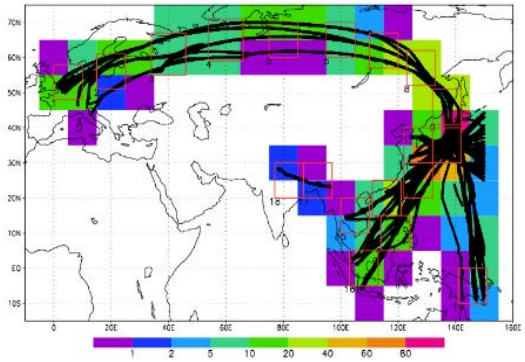
- **Methods**
  - A Nested Atmospheric inversion system with a focus on China (BNI)
  - CarbonTracker-China CAS (CTC)

- **Data and Experiment**

	BNI	CTC
Case 1	130 sites from GLOBALVIEW datasets	99 sites from Obspack and WDCGG
Case 2	Based on Case 1 and add 3 additional sites	
Case 3	Based on Case 2, further add CONTRAIL aircraft CO_2 observations	



Published global CO_2 data and 3 additional sites in China

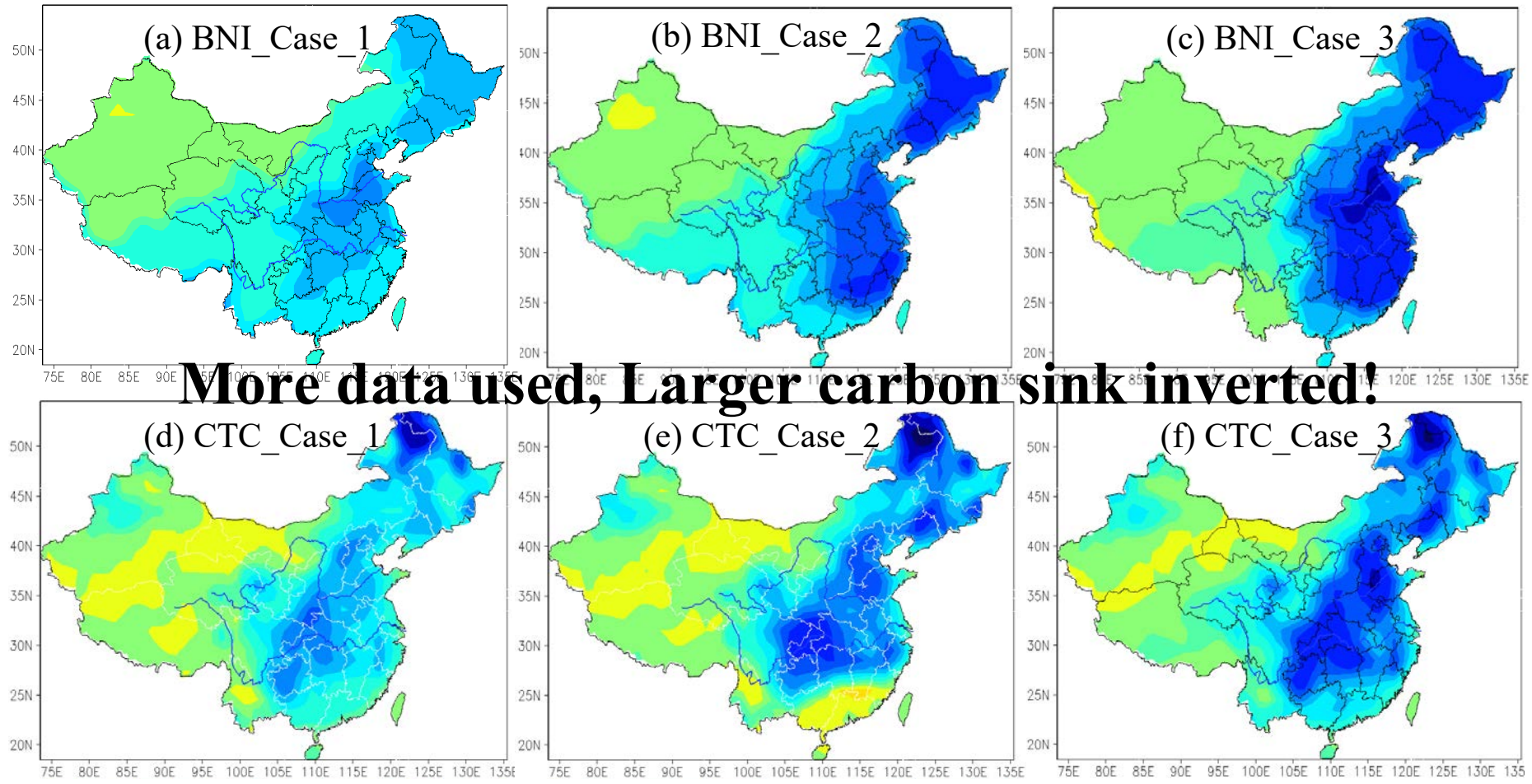


CONTRAIL Aircraft Observations

Jiang et al., 2016

2. A comprehensive estimate for the land sink of China

Distributions of the inverted land sinks in China

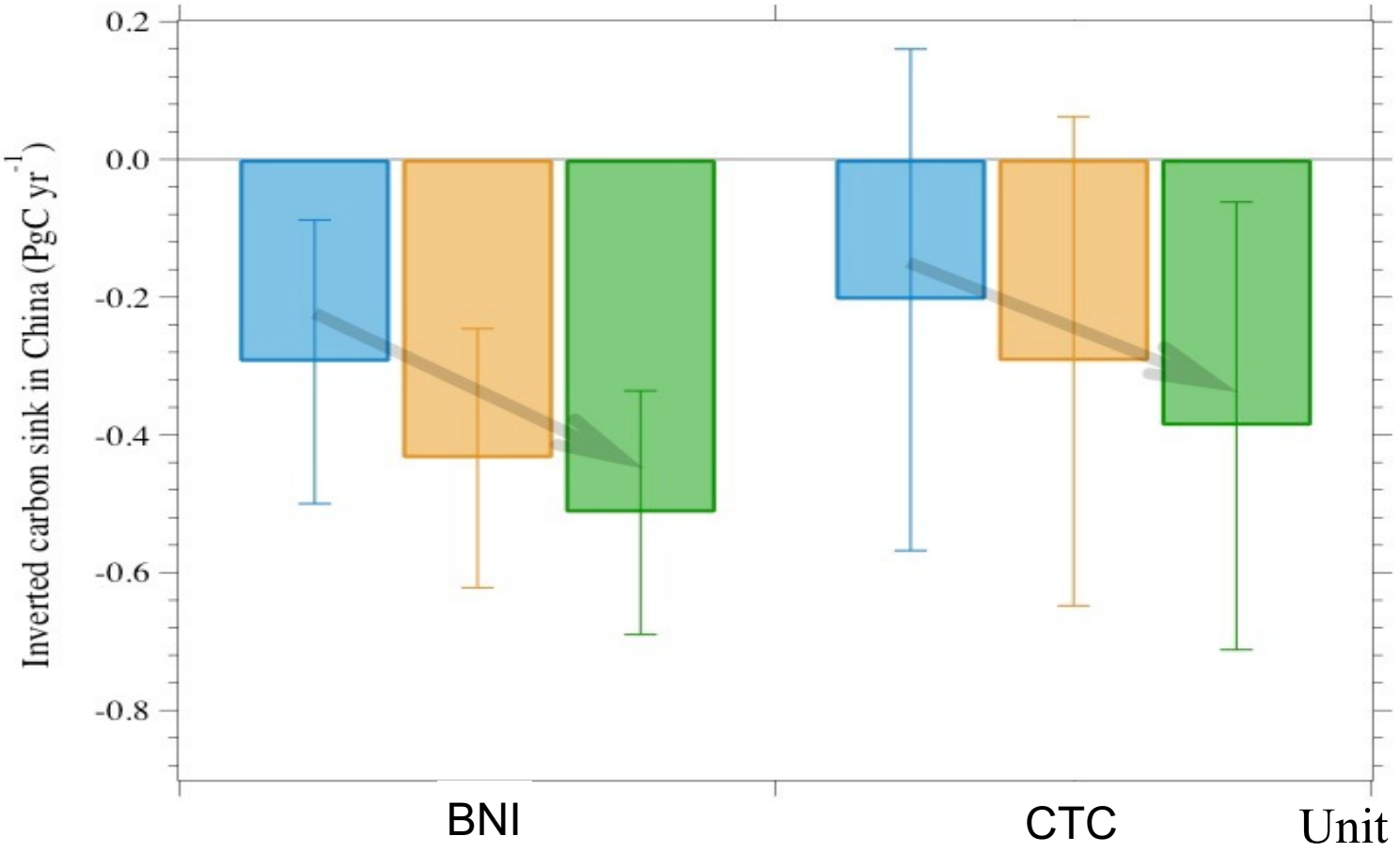


More data used, Larger carbon sink inverted!

Jiang et al., 2016

2. A comprehensive estimate for the land sink of China

Inverted land sink of China during 2006-2009



Unit : PgC yr^{-1}

Blue: use published data, only one site (wlg) in China **0.25±0.28**

Orange: add three additional sites of China **0.36±0.27**

Green: further add CONTRAIL aircraft observations **0.45±0.25**

2. A comprehensive estimate for the land sink of China

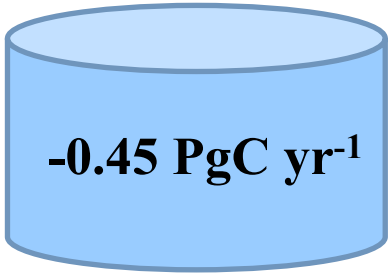
Bottom-up estimate:

Carbon accumulated in China's terrestrial ecosystems during 2000s

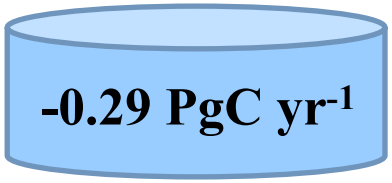
Category		Method	Area (1e6 ha)	Carbon balance (PgC yr^{-1})	Period	Ref.
Vegetation	Forest stands	Inventory	149	0.174	1999-2008	Zhang et al., 2013
		Inventory	156	0.115	2000-2007	Guo et al., 2013
		Inventory	149	0.104	1999-2008	Pan et al., 2011
	Forest ave.		**151**	**0.13±0.04**		
	Economic forests	Inventory	21	0.000	1999-2008	Zhang et al., 2013
		Inventory	21	0.000	1999-2008	Guo et al., 2013
	Economic Forest ave.		**21**	**0.000**		
	Bamboo	Inventory	5.1	0.013	1999-2008	Zhang et al., 2013
		Inventory	5.1	0.005	1999-2008	Guo et al., 2013
	Bamboo ave.	**Inventory**	**5.1**	**0.009±0.006**		
	Woodlands	**Inventory**	**5.4**	**-0.002±0.001**	1999-2008	Zhang et al., 2013
	Shrub	**Inventory**	**49.5**	**0.019±0.013**	1999-2008	Zhang et al., 2013
	Tree on non-forest lands			**-0.001±0.001**	1999-2008	Zhang et al., 2013
	Grass	**Inventory**	**331**	**0.007±0.003**	1980s,1990s	Piao et al., 2009
	Subtotal			**0.17±0.06**		
Soil	Forest	InTEC model	155	0.068±0.034	1999-2008	This study
		Inventory	156	0.060±0.030	2000-2007	Pan et al., 2011
	Forest ave.		**155**	**0.064±0.030**		
	Shrub	Statistic model	215	0.039±0.009	1980s,1990s	Piao et al., 2009
		Process model	141	0.012±0.005	1981-2000	Tian et al., 2011
	Shrub ave.			**0.026±0.019**		
	Crop	**Aggregate**	**130**	**0.021±0.004**	**1980s,1990s**	**Huang et al., 2010**
	Grass	**Aggregate**	**331**	**0.005±0.002**	**1980s,1990s**	**Huang et al., 2010**
	Subtotal			**0.12±0.06**		
	Total			**0.29±0.12**		

2. A comprehensive estimate for the land sink of China

Top-down estimate



Bottom-up estimate



$$\begin{aligned} \textit{Land sink}_{\text{top-down}} = {} & \textbf{inverted } \mathbf{CO_2}\textbf{ sink} \\ & - \text{fossil fuel RCC transferred to global atmosphere} \\ & - \text{fossil fuel RCC deposited to land surface} \\ & - \text{biogenic RCC transferred to global atmosphere} + \text{net import} \end{aligned} \quad (1)$$

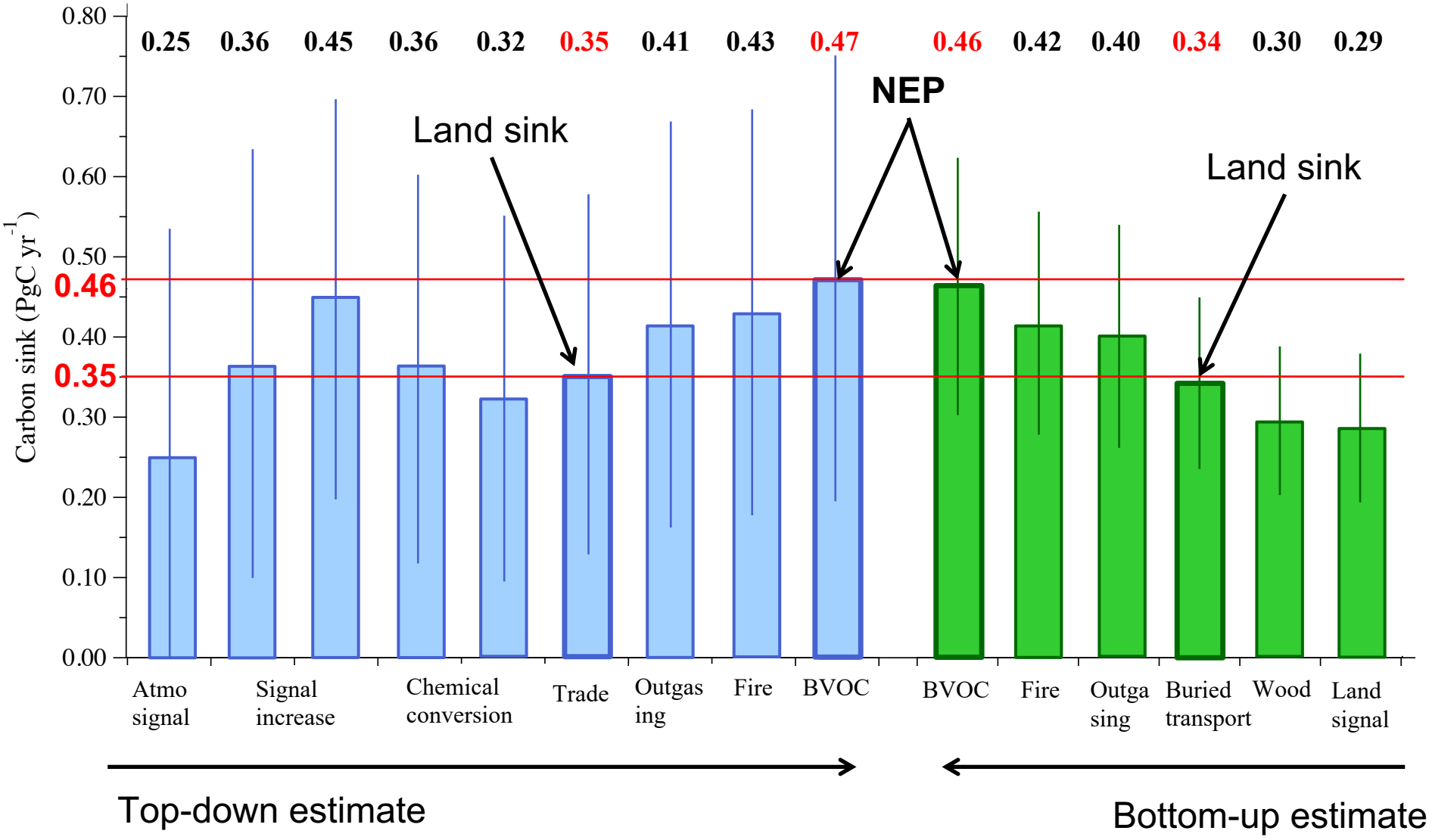
$$\begin{aligned} \textit{Land sink}_{\text{bottom-up}} = {} & \textbf{carbon stock change} + \text{accumulation in products} \\ & + \text{burial in aquatic sediments} + \text{delivery to ocean} \end{aligned} \quad (2)$$

$$\begin{aligned} \textit{NEP} = {} & \textbf{land sink} + \text{biomass burning} + \mathrm{CO_2}\text{ outgassing} + \text{biogenic RCC emission} \\ & - \text{biogenic RCC deposition} \end{aligned} \quad (3)$$

RCC： VOC+CO

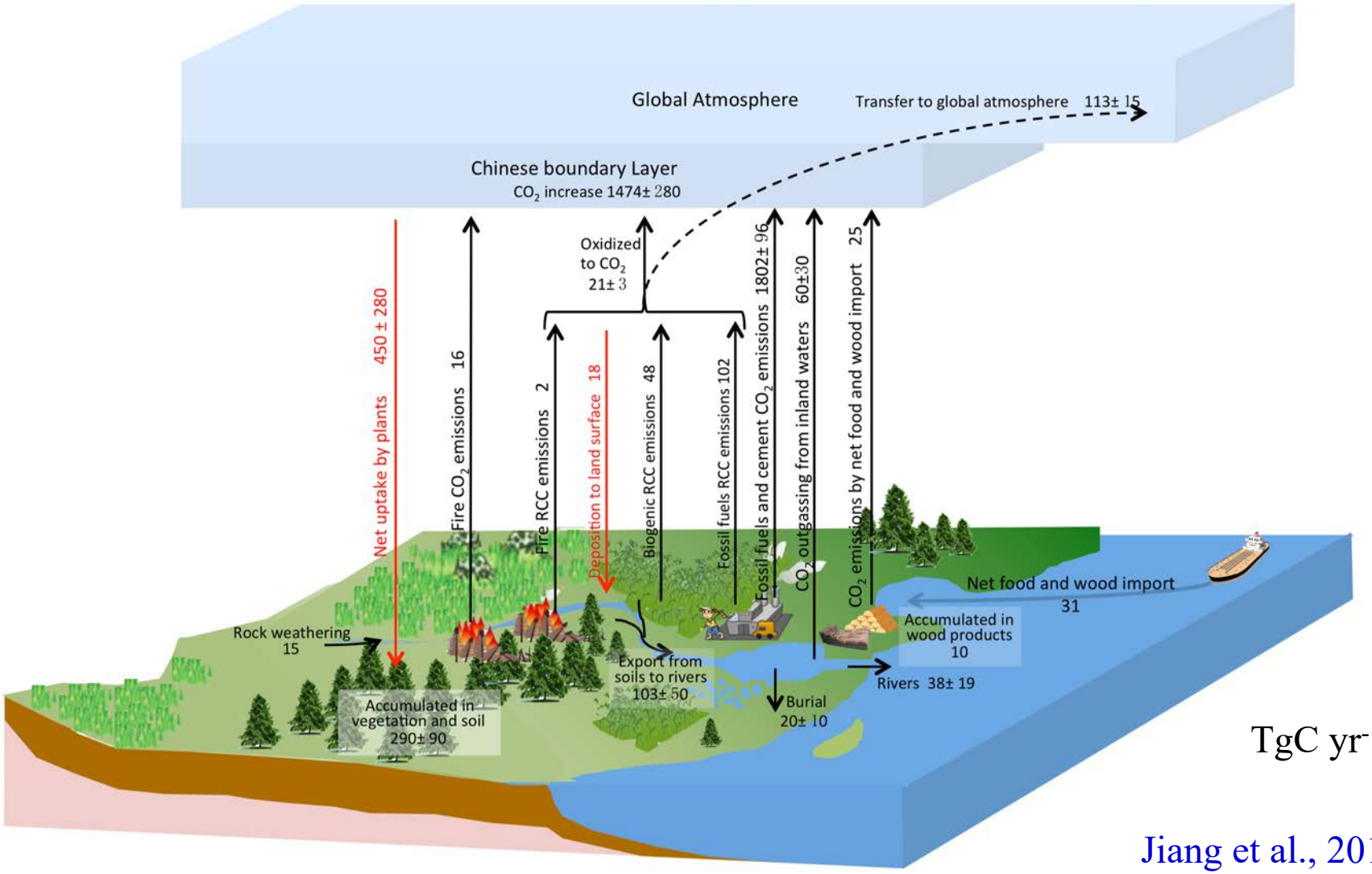
2. A comprehensive estimate for the land sink of China

Terrestrial carbon balance in China



2. A comprehensive estimate for the land sink of China

Regional Carbon Cycle in China during 2006 to 2009



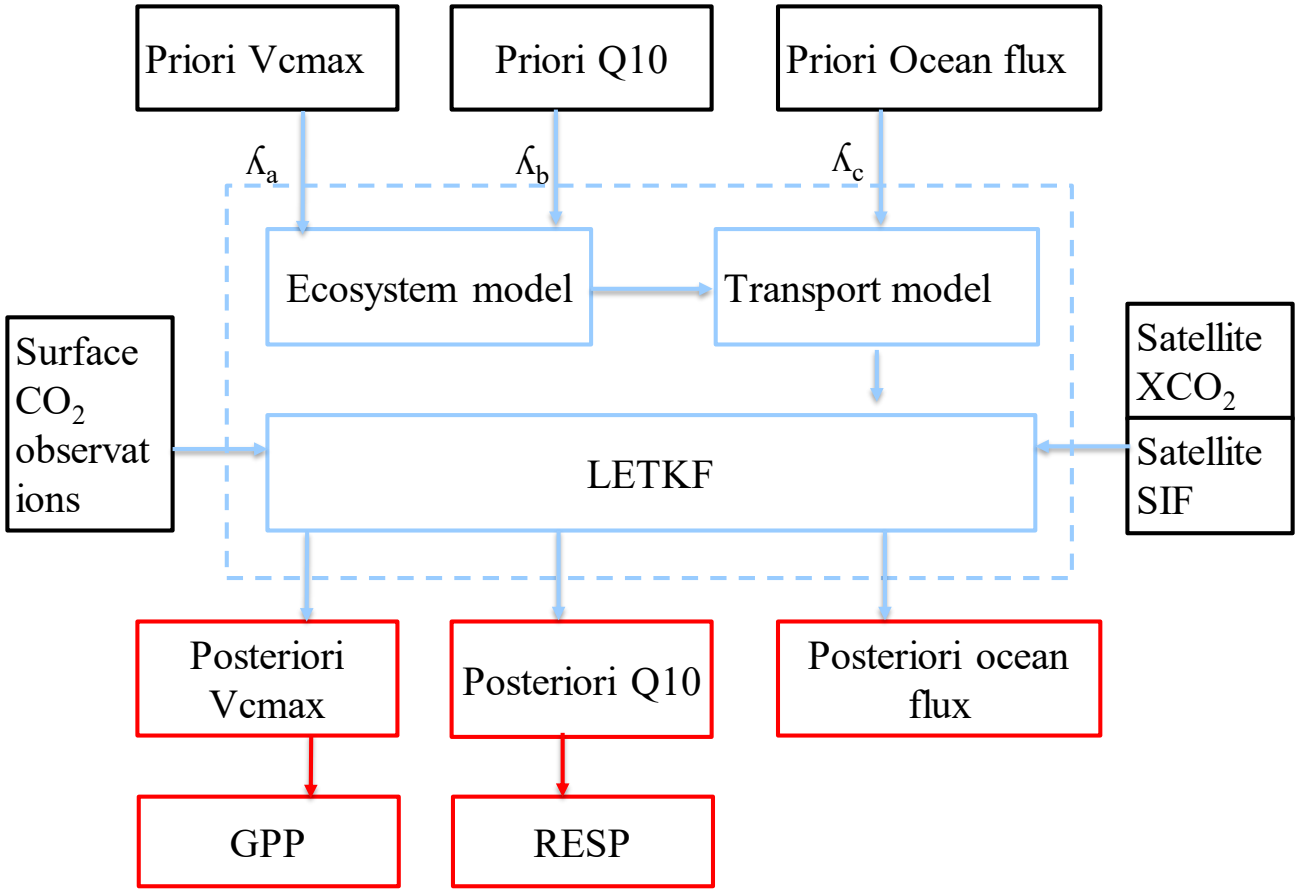
TgC yr^{-1}

Jiang et al., 2016

3. A new Global Carbon Assimilation System

A satellite based and high resolution global carbon assimilation system (under development)

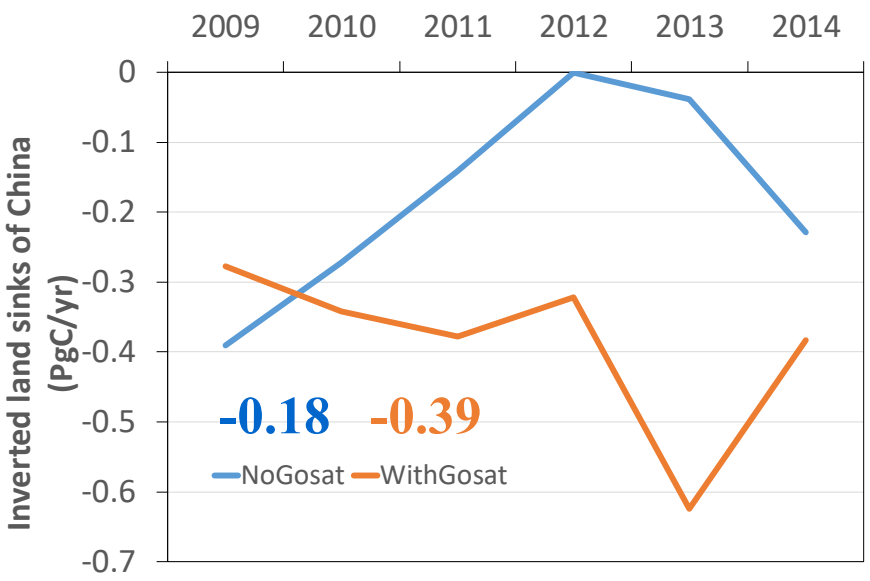
- Supported by the national key R & D projects for "Global change and response" (2016-2021)
- Leaded by Nanjing University

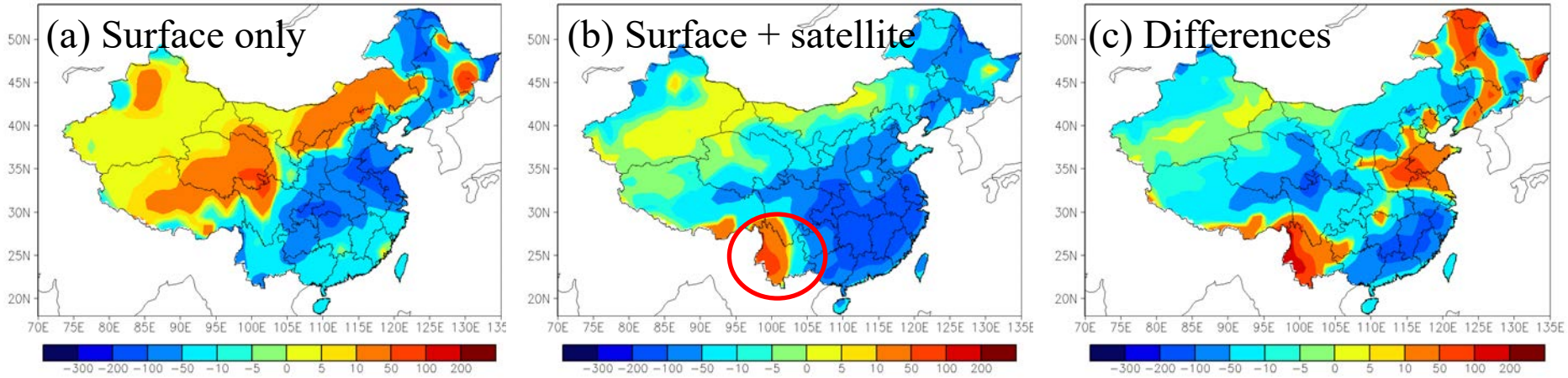


3. A new Global Carbon Assimilation System

Terrestrial carbon fluxes in China during 2009 - 2014 constrained by both surface and satellite CO_2 observations

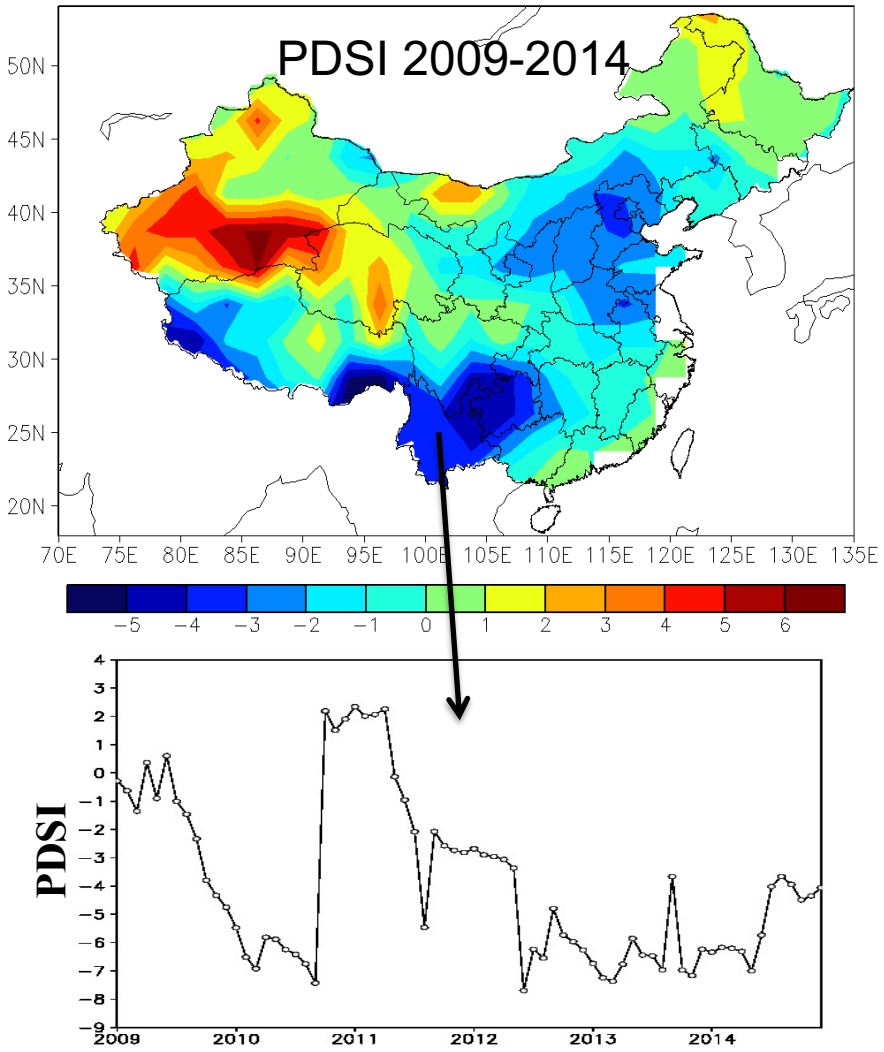
- Surface only, decrease trend, weakest in 2012; satellite added, increase trend, peak in 2013.
- Carbon sink over Southeast and South China, and western and northern grassland areas are significantly increased; those in southwest China, North China Plains and Northeast forest area are significantly reduced.





Distributions of the mean inverted carbon flux in China during 2009-2014

3. A new Global Carbon Assimilation System



- From the autumn of 2009 to the spring of 2014, Southwest China (mainly Yunnan province) has occurred many years of extreme drought, which may lead to a carbon source in this area.
- After adding satellite XCO_2, the inversion results show a significant increase of carbon source in this area, **indicating that the satellite XCO_2 data may help to understand the changes of regional carbon sinks caused by extreme climate events.**

PDSI gridded data from Aiguo Dai, hosted at NCAR-RDA

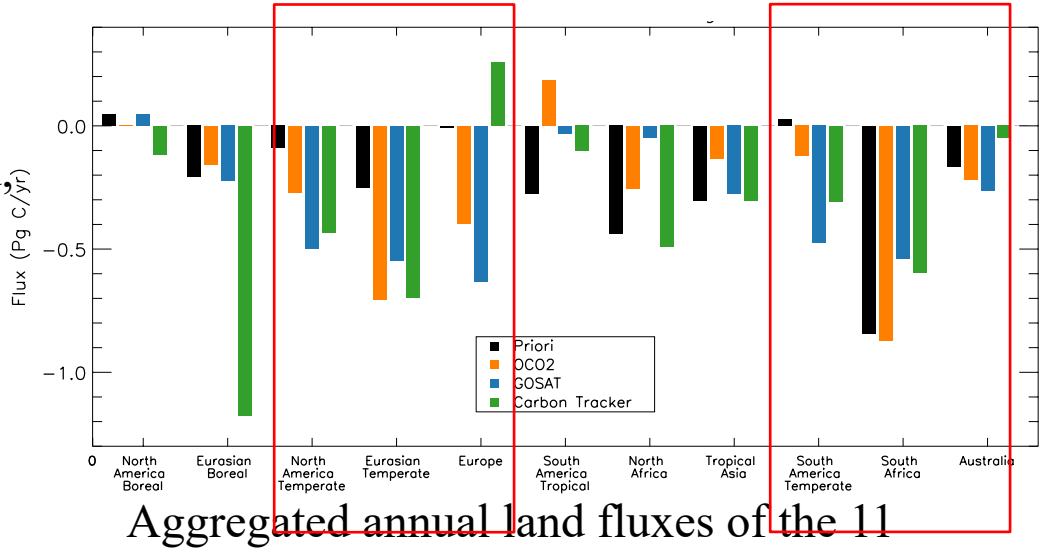
3. A new Global Carbon Assimilation System

Comparisons of Terrestrial Ecosystem Carbon Flux as inferred from GOSAT and OCO-2 XCO_2 retrievals

- Study period: 2015
- Data: GOSAT and OCO-2 XCO_2 Version 7.3 Level 2 Lite products, no surface data was assimilated.

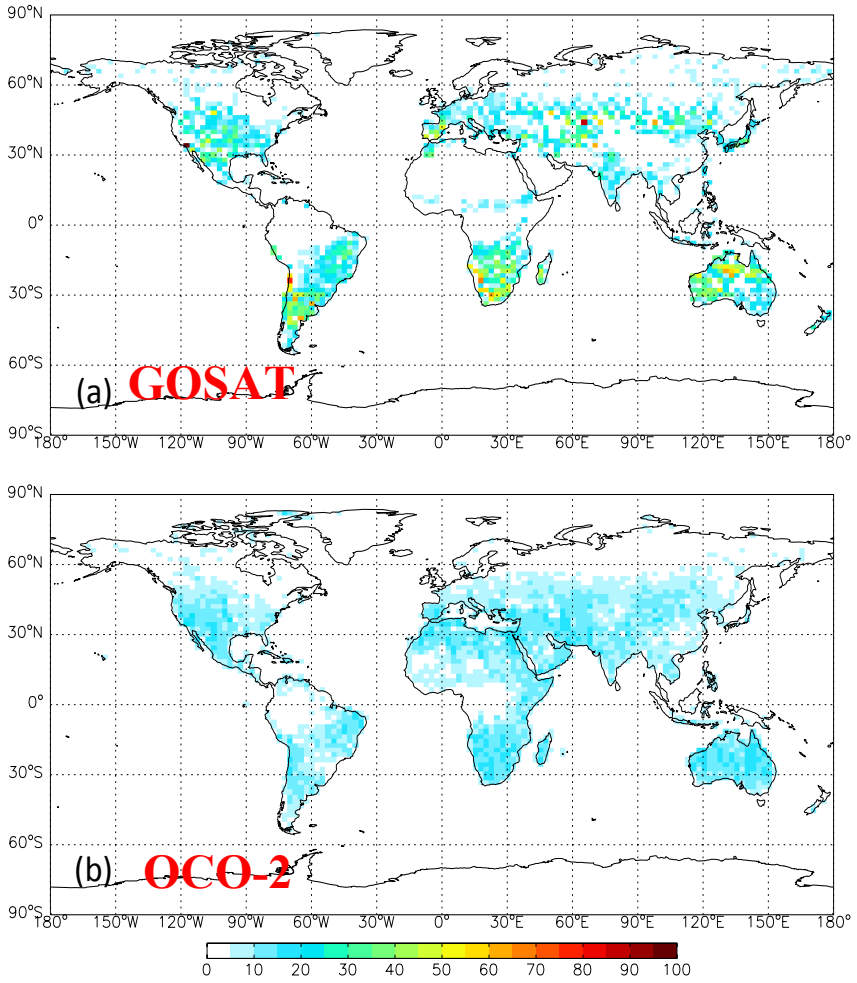
	Priori	OCO-2 Exp.	GOSAT Exp.	CT2016	GCP2017
Fossil fuel	9.83	9.83	9.83	9.83	9.83
fire	2.2	2.2	2.2	2.2	1.52[a)]
Land sink	-2.5	-2.94	-3.48	-3.9	-2.55[b)]
Land sink + fire	-0.5	-0.74	-1.28	-1.7	-1.03
Ocean Sink	-2.41	-2.43	-2.45	-2.41	-2.57
Global net flux	7.12	6.66	6.1	5.72	6.23[c)]

- The global net flux estimated using GOSAT data is much closer to the annual CO_2 growth rate
- In temperate regions, the inferred land sinks are significantly increased, while those in tropical regions are decreased
- In most regions, the land sinks inverted using GOSAT data are stronger than those using OCO-2 data

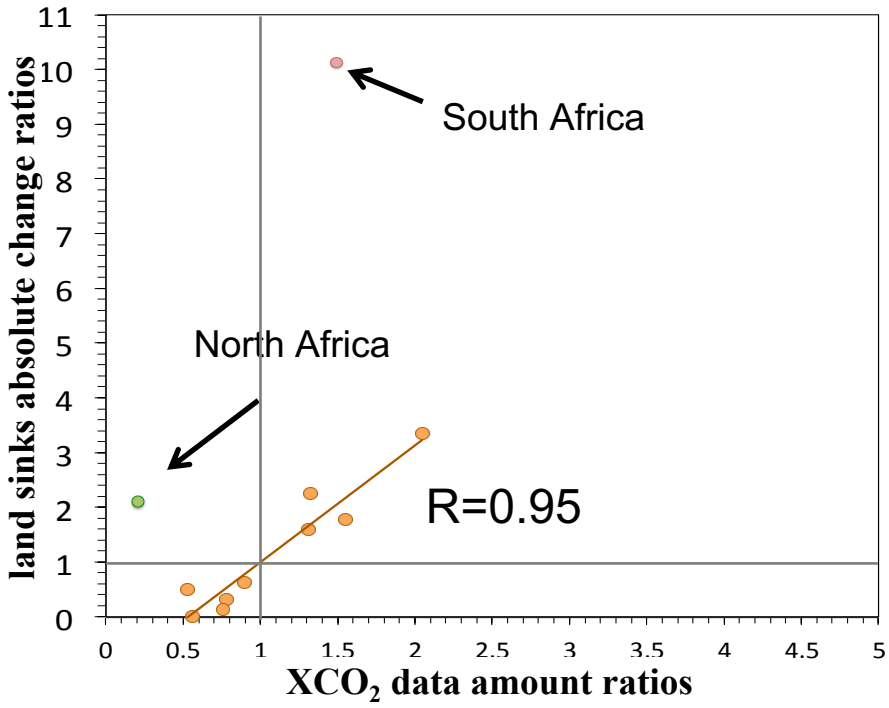


Aggregated annual land fluxes of the 11 TRANSCOM land regions

3. A new Global Carbon Assimilation System



Coverage and frequency of ACOS XCO_2

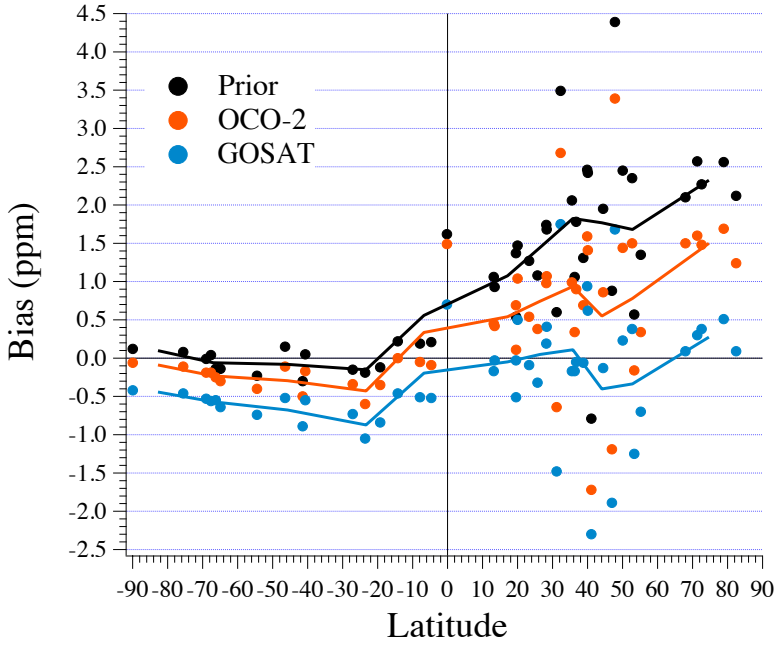


A liner relationship was found between the XCO_2 data amount ratios of GOSAT to OCO-2 and the land sinks absolute change ratios caused by GOSAT to OCO-2 for 11 TRANSCOM land regions.

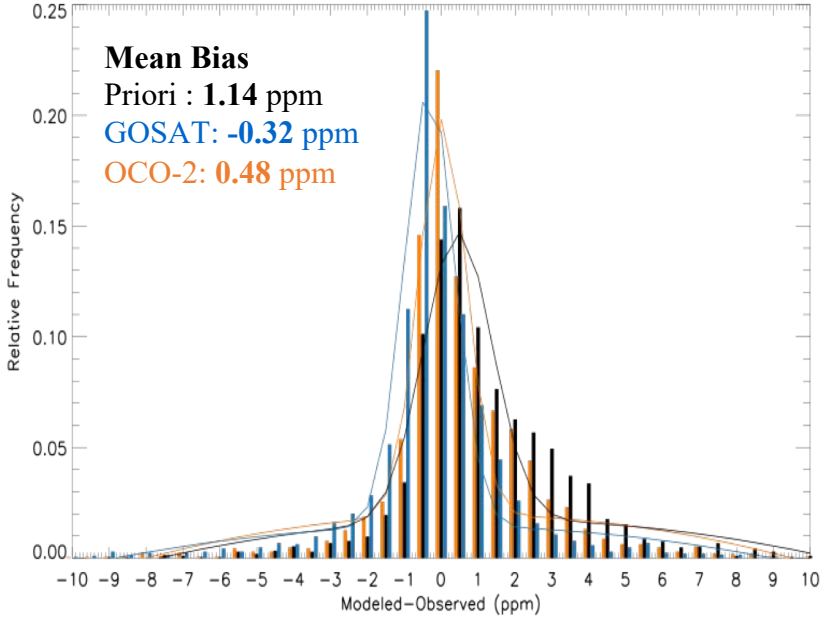
The different performances of GOSAT and OCO-2 in different regions are mainly related to the spatial coverage and data amount of XCO_2 in these regions.

3. A new Global Carbon Assimilation System

Evaluation with independent 47 sites of surface flask CO_2 observations



Biases in different latitudes



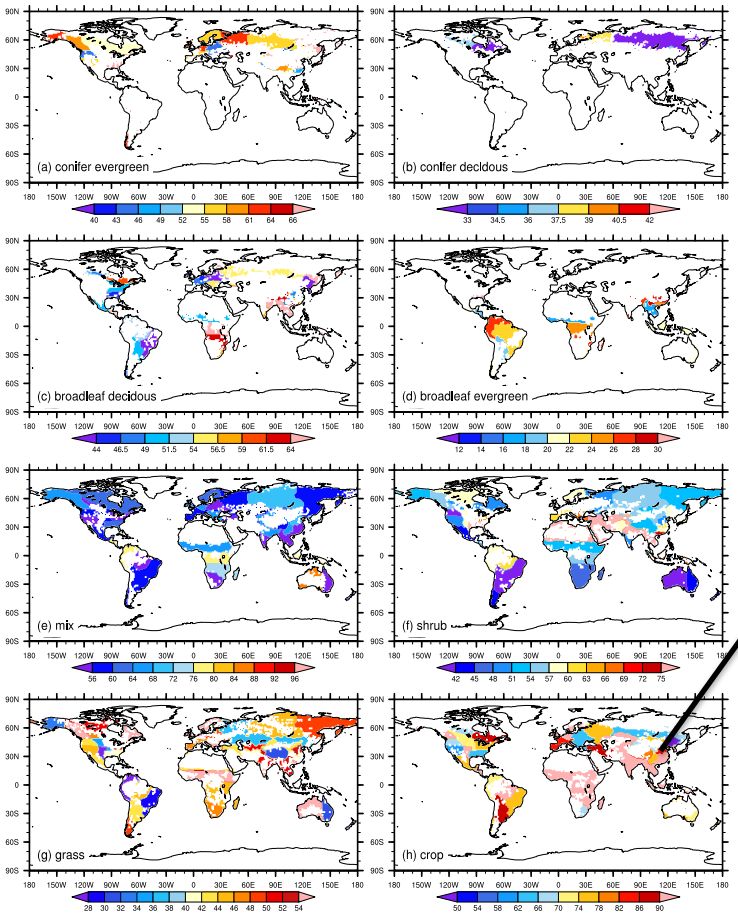
Distribution of the biases

- The deviations in most northern hemisphere sites are significantly reduced (improved), while in the southern hemisphere, the biases increase (overestimated), especially for GOSAT.
- On average, GOSAT result has smaller bias than OCO-2.

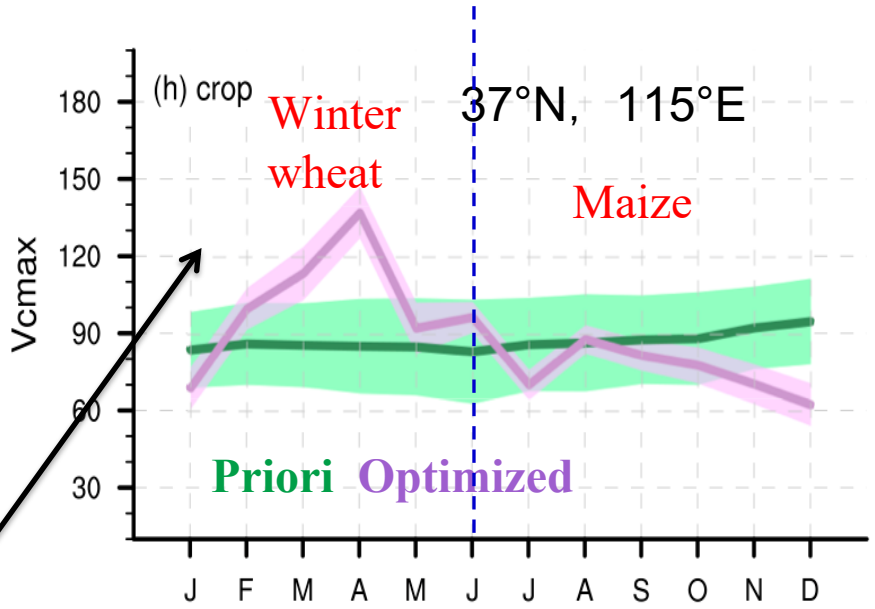
3. A new Global Carbon Assimilation System

A preliminary result of the optimization of ecosystem model key parameter (Vcmax) using satellite SIF data

BEPS + LETKF + OCO-2 v8 757 nm SIF (2015)



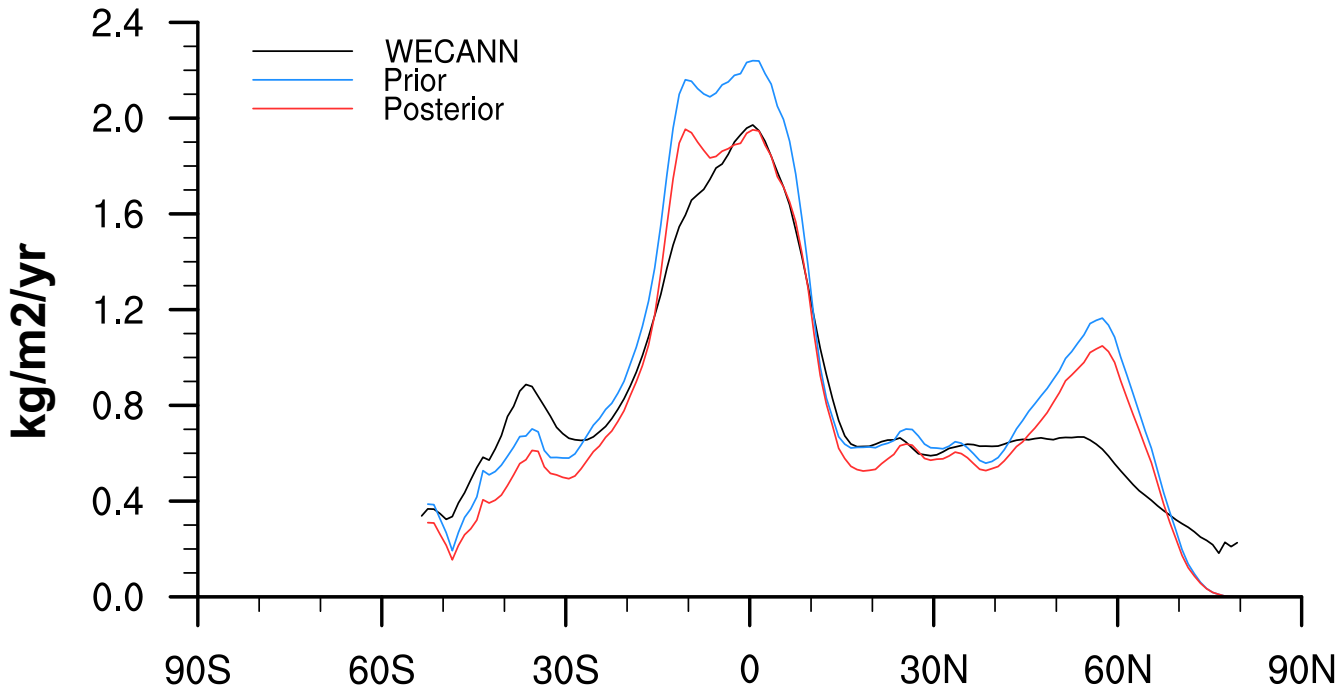
Optimized results



- This monthly variations clearly represent a two-seasons planting of a year.
- In north China plain, most areas plant two seasons every year.

3. A new Global Carbon Assimilation System

Evaluation of simulated GPP results with WECANN retrievals



- In low latitudes, the simulated GPP with optimized Vcmax is much closer to WECANN retrievals
- In high latitude of northern hemisphere, there still have large differences.

https://avdc.gsfc.nasa.gov/pub/data/project/WECANN

4. Summary

- China has made remarkable efforts on atmospheric inversion studies. We have achieved a closed estimate for the land sink in China and drawn a regional carbon cycle map.
- Due to lack of enough surface CO_2 observations, the inversions using published CO_2 data may underestimate the land sink of China, which may also affect the inversions of land sink in Asia.
- CONTRAIL aircraft observations and satellite XCO_2 data could help to improve the land sink inversions in China and Asia.


Thank you for your attention!!
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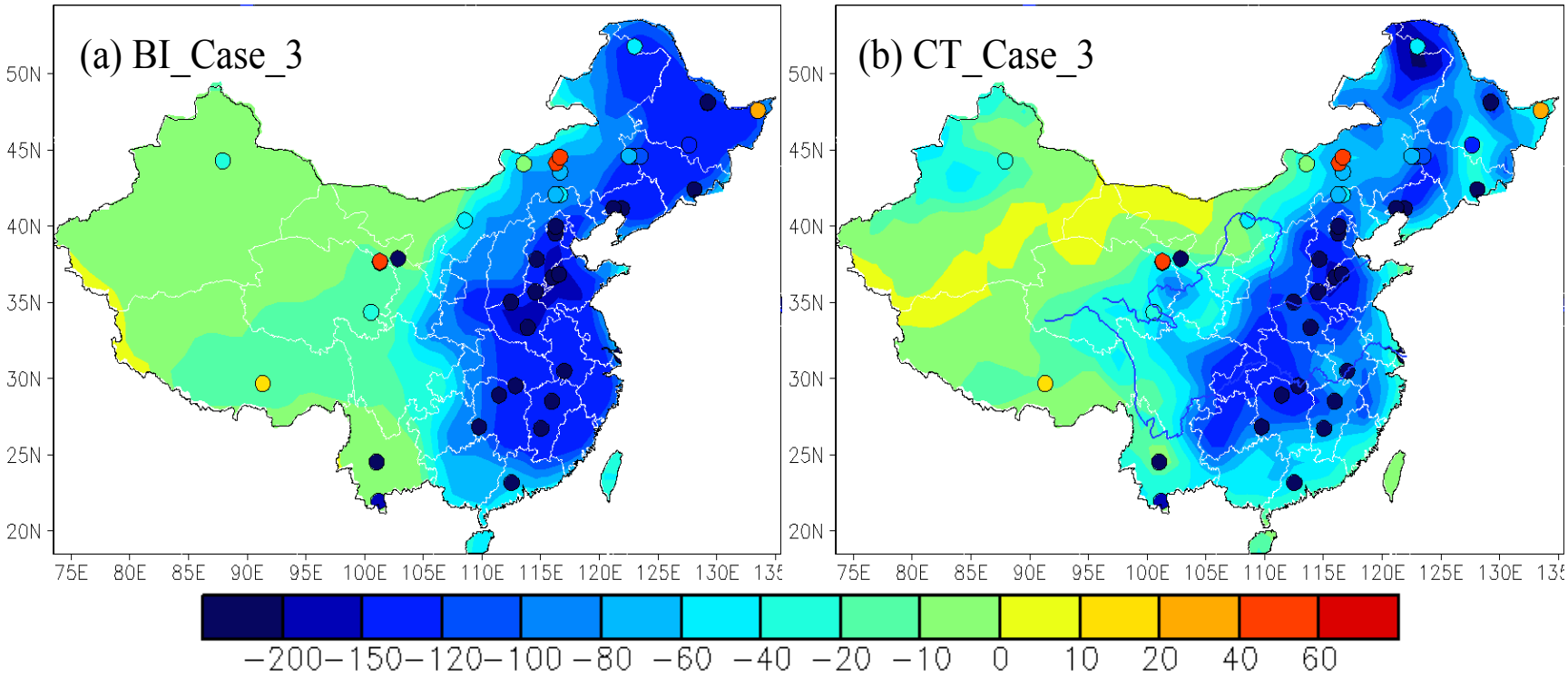
Surface observations in China

Compared with ChinaFlux



反演的陆地生态系统碳源汇空间分布格局与ChinaFlux观测的空间分布格局基本一致。

2006年东亚地区观测站气团的5天后向轨迹