Estimation of surface CO_2 flux and observation impact using the CarbonTracker

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Outline

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3. Part II : Impact of Siberian observations on the optimization of surface CO_2 flux
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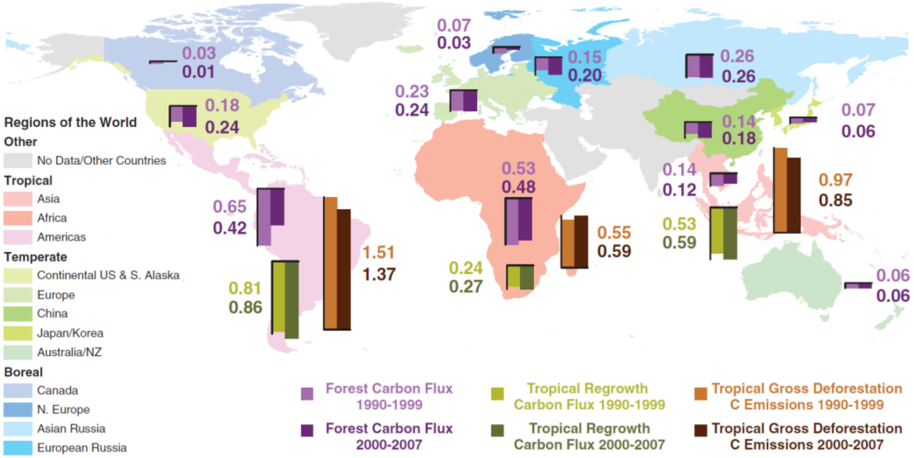
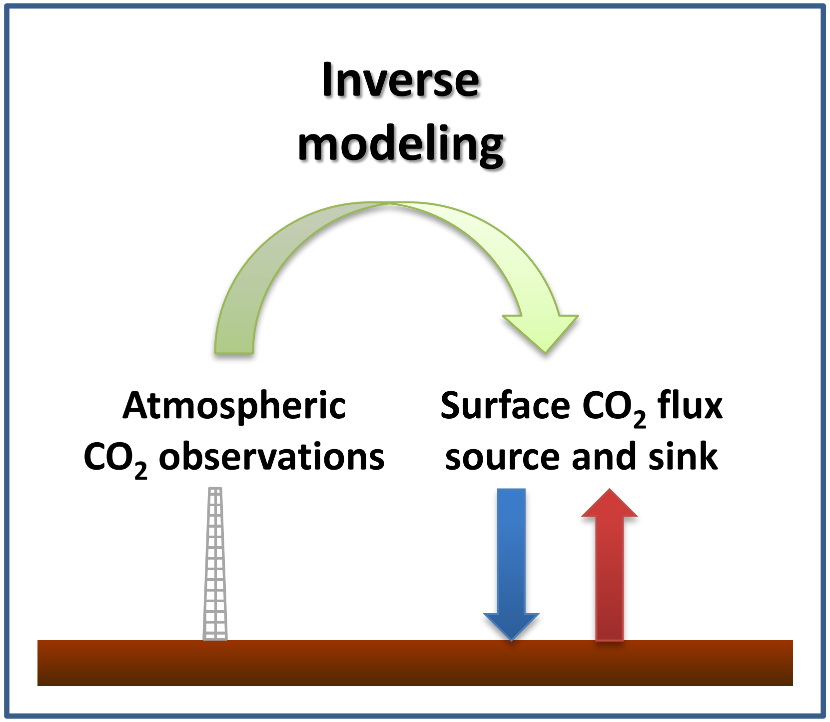
Introduction



(Pan et al., 2009)



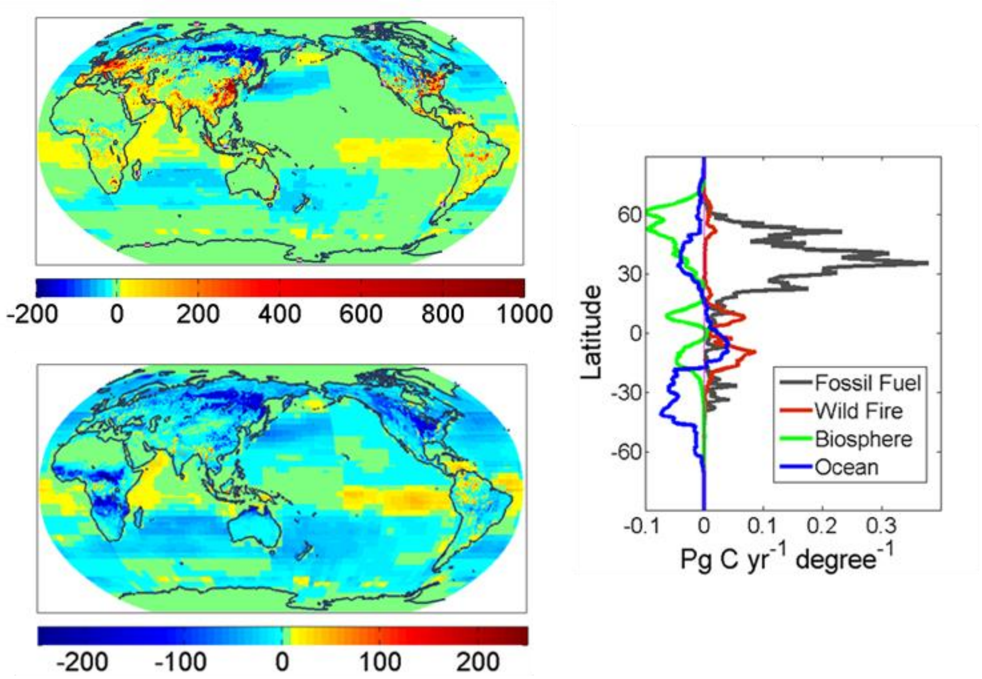
Inverse modeling

Atmospheric CO_2 observations

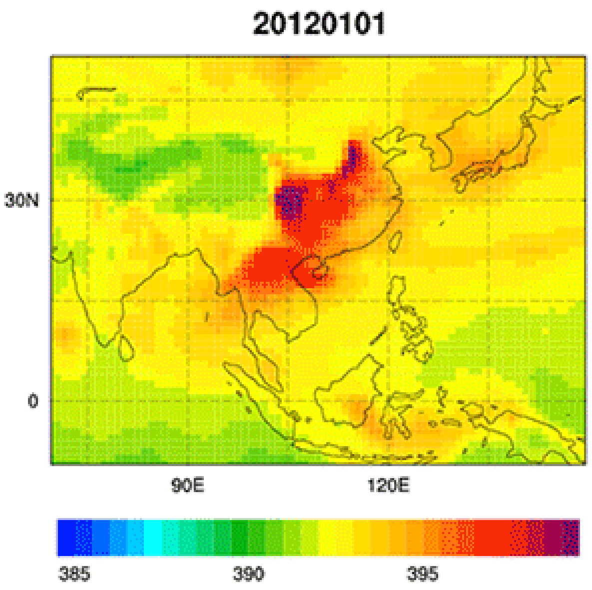
Surface CO_2 flux source and sink

- The terrestrial ecosystem in the Northern Hemisphere (NH) plays an important role in the global carbon balance (Hayes et al., 2011; Le Quéré et al., 2015).
- To estimate surface CO_2 flux, atmospheric CO_2 inversion studies are conducted using atmospheric transport models and atmospheric CO_2 observations (Gurney et al., 2002; Peylin et al., 2013).

Introduction



Spatial distribution of surface CO_2 fluxes



Column CO_2 concentration

(CarbonTracker-Asia; www.nimr.go.kr/2/carbontracker/index.html)

- CarbonTracker is an inverse modeling system that estimates the surface CO_2 flux using an ensemble Kalman filter with atmospheric CO_2 measurements as a constraint.

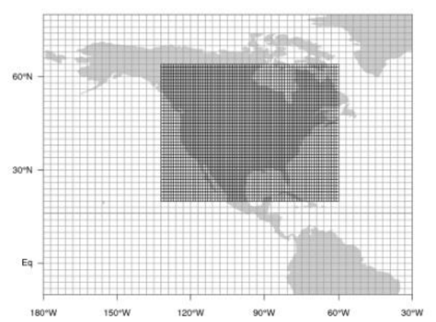
Introduction

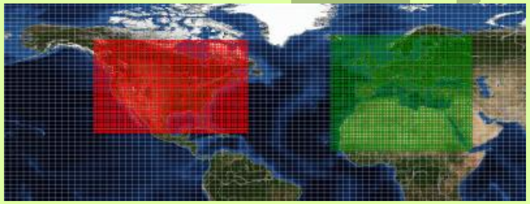
CarbonTracker – NOAA
(Peters et al., 2005, 2007;
Peylin et al., 2013)

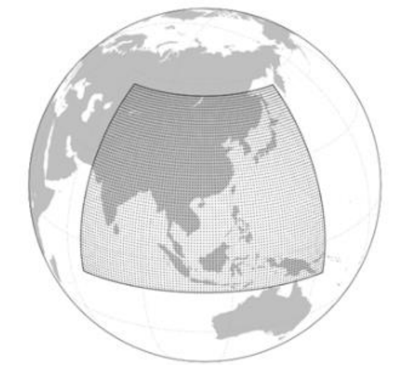
CarbonTracker – Europe
(Peters et al., 2010;
Peylin et al., 2013;
Le Quéré et al., 2014)

CarbonTracker – Asia
(Kim et al., 2012, 2014a, 2014b)

CarbonTracker – China
(Zhang et al., 2014a, 2014b)







- Since the original CarbonTracker release, a series of improvements has been made with subsequent releases.

Part I

Influence of CO_2 observations on the optimized CO_2 flux

Motivation

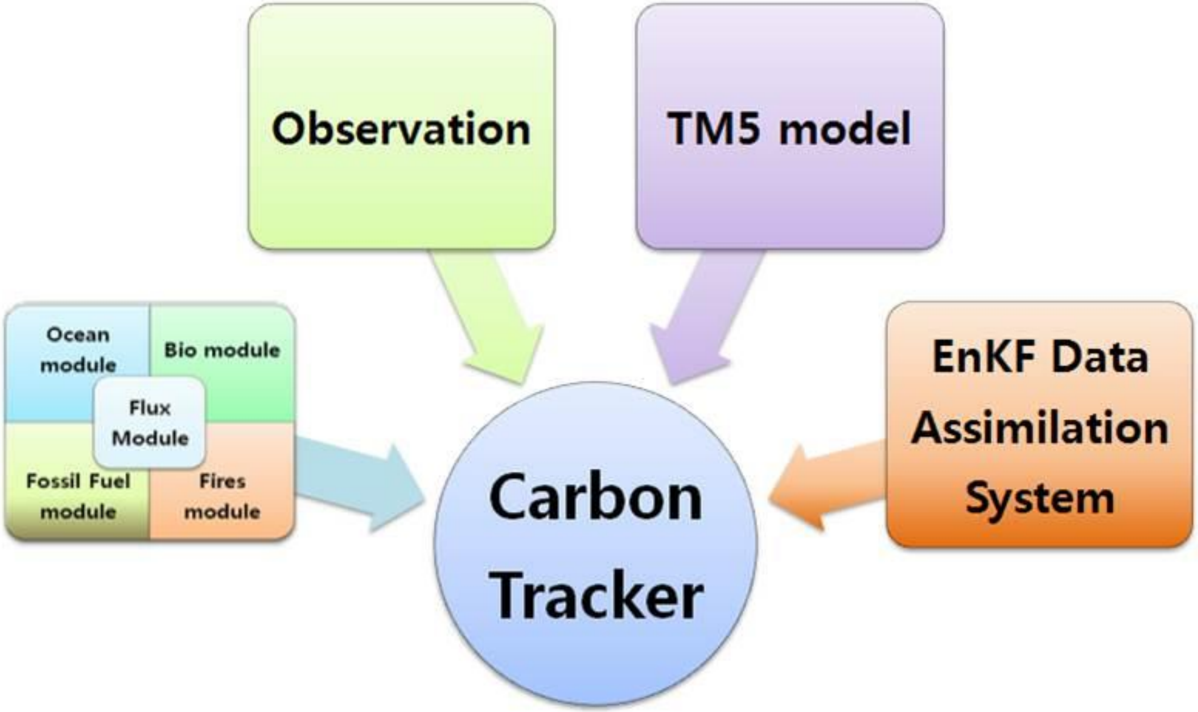
- Atmospheric CO_2 observations can be used to quantitatively estimate the source and sink of surface CO_2 fluxes (Gurney et al., 2002; Ciais et al., 2010; Peylin et al., 2013).

- Various state-of-the-art data assimilation schemes based on linear estimation theories (Talagrand 1997) have been used in atmospheric CO_2 inversion studies.

- The influence matrix (Cardinali et al., 2004) of the linear statistical analysis scheme can diagnose the impact of individual observations on the analysis in observational space.

- In part I, to estimate the impact of CO_2 observations on the analyzed surface CO_2 fluxes, both self sensitivity and information content are calculated in the CarbonTracker.

Method : CarbonTracker



- CarbonTracker consists of **4 modules**.
- Flux module includes 4 prior fluxes : **Biosphere**, **Ocean**, **Fossil Fuel**, **Fires** flux.
- TM5 is **transport model** for calculating atmospheric CO_2 concentration using fluxes.
- Surface carbon flux is optimized in **data assimilation** process with CO_2 concentration **observations**.

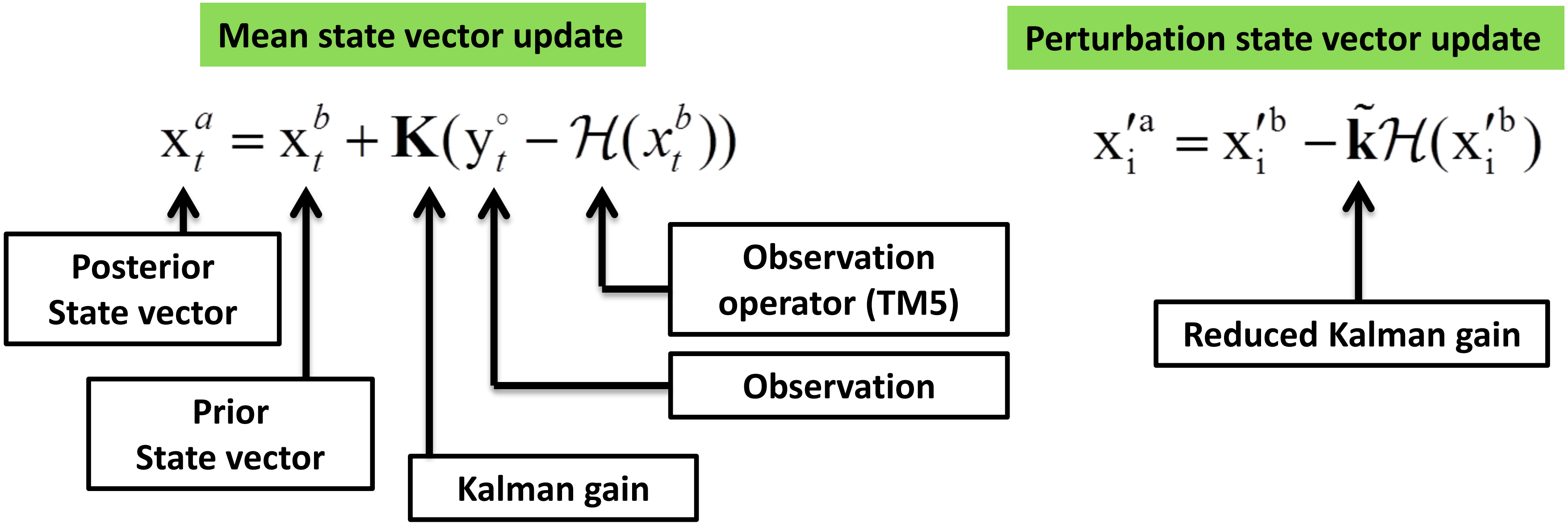
Method : Data assimilation process

- **Flux calculation with scaling factor**

$$F(x,y,t)=\lambda_r\cdot F_{bio}(x,y,t)+\lambda_r\cdot F_{ocn}(x,y,t)+F_{ff}(x,y,t)+F_{fire}(x,y,t)$$

- ➢ Background fluxes on 1˚×1˚ grid are calculated by multiplying four *a priori* fluxes with prior scaling factors.
- ➢ Optimized fluxes are calculated by multiplying four prior fluxes by posterior scaling factors.

- **Equations used in data assimilation process (Whitaker and Hamill 2002)**



Mean state vector update

$$\mathrm{x}_t^a=\mathrm{x}_t^b+\mathbf{K}(\mathrm{y}_t^{\circ}-\mathcal{H}(x_t^b))$$

Perturbation state vector update

$$\mathrm{x}_{\mathrm{i}}'^{\mathrm{a}}=\mathrm{x}_{\mathrm{i}}'^{\mathrm{b}}-\tilde{\mathbf{k}}\mathcal{H}(\mathrm{x}_{\mathrm{i}}'^{\mathrm{b}})$$

Method : Influence matrix calculation

Analysis sensitivity w.r.t. the observations (Cardinali et al., 2004)

$$\mathbf{S}^{\mathrm{o}} = \frac{\partial \mathbf{y}^{\mathrm{a}}}{\partial \mathbf{y}^{\mathrm{o}}} = \mathbf{K}^{\mathrm{T}}\mathbf{H}^{\mathrm{T}} = \mathbf{R}^{-1}\mathbf{H}\mathbf{P}^{\mathrm{a}}\mathbf{H}^{\mathrm{T}}$$

Analysis sensitivity w.r.t. the observations (self-sensitivity) in EnKF framework (Liu et al., 2009)

$$\mathbf{S}^{\mathrm{o}}_{jj} = \frac{\partial \mathbf{y}^{\mathrm{a}}_{j}}{\partial \mathbf{y}^{\mathrm{o}}_{j}} = \left(\frac{1}{m-1}\right)\frac{1}{\sigma_j^2}\sum_{i=1}^{m}(\mathbf{H}\mathbf{X}^{\mathrm{a}}_{i})_j \times (\mathbf{H}\mathbf{X}^{\mathrm{a}}_{i})_j \qquad 0 \le \mathbf{S}^{o}_{jj} \le 1$$

Information content : the amount of information extracted from observations

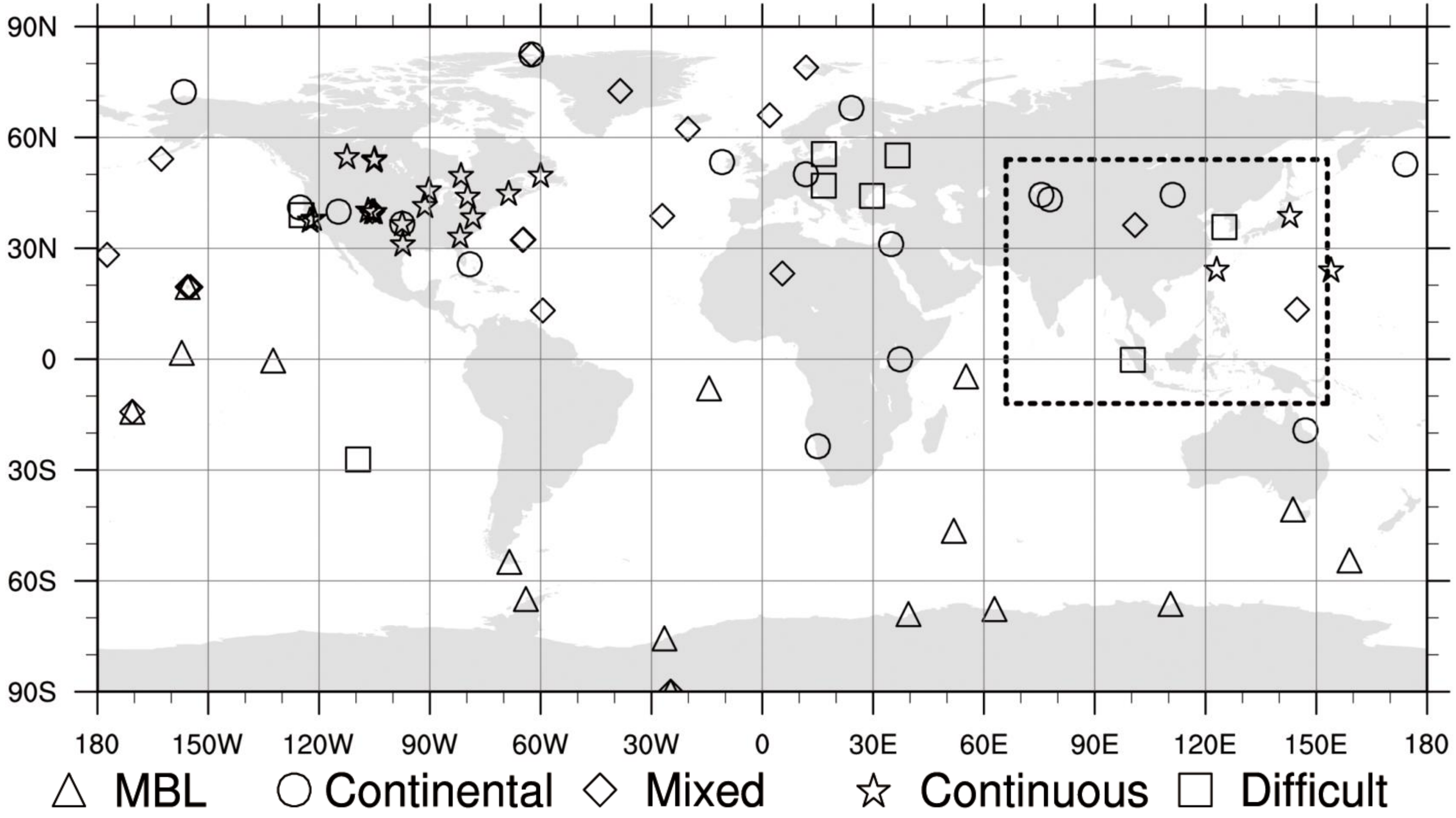
$$GAI = \frac{\mathrm{tr}(\mathbf{S}^{\mathrm{o}})}{p}$$

Globally averaged observation influence

$$PAI = \frac{\sum_{j\in I}\mathbf{S}^{\mathrm{o}}_{jj}}{p_I}$$

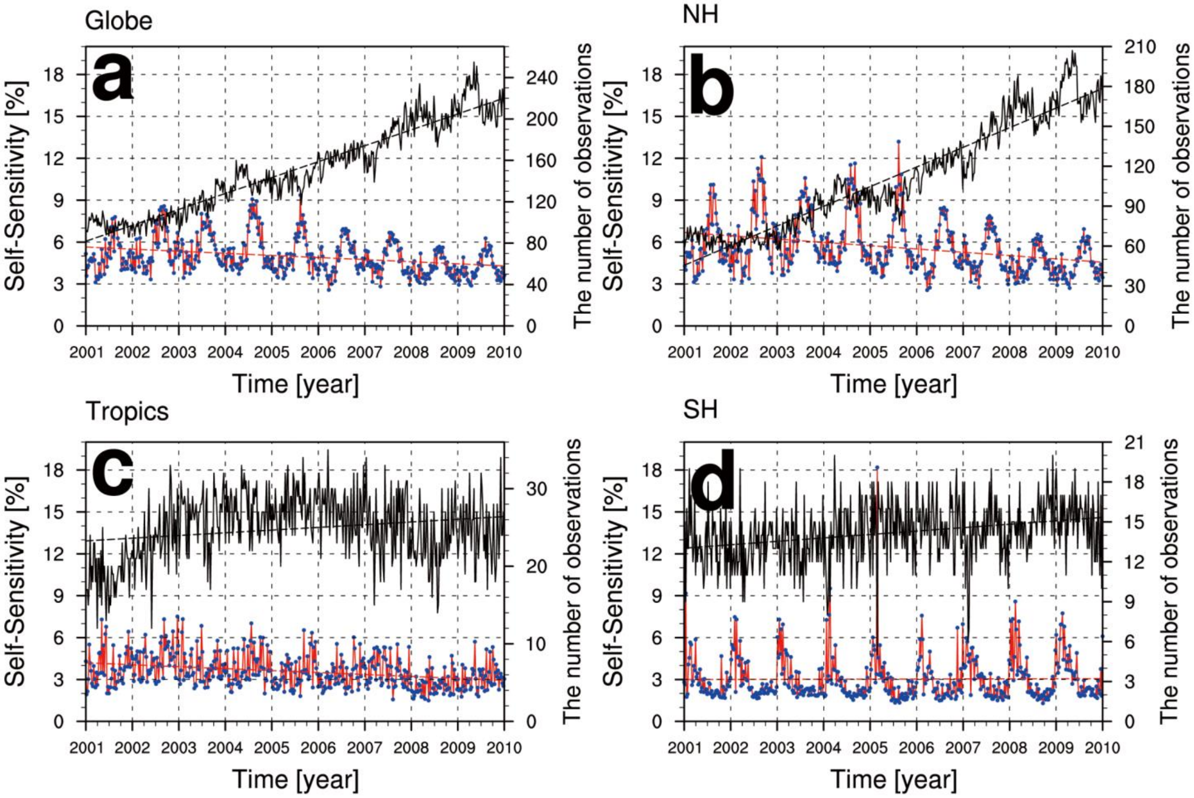
Partial influence for any selected subset of observations

Method : Experiment set-up



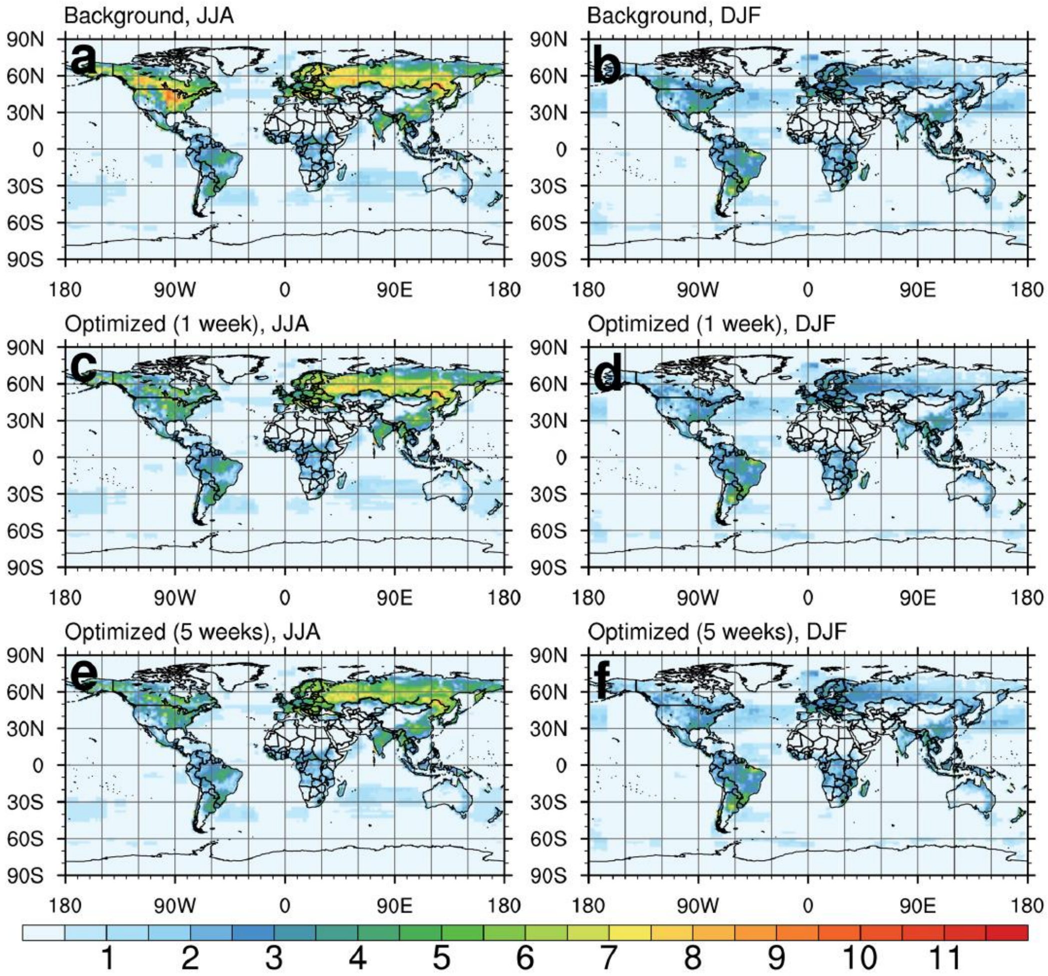
Experimental period	2000. 1. 1. ~ 2009. 12. 31.
Assimilation weeks of lag	5 week
The number of ensemble	150

Results : Average self-sensitivity



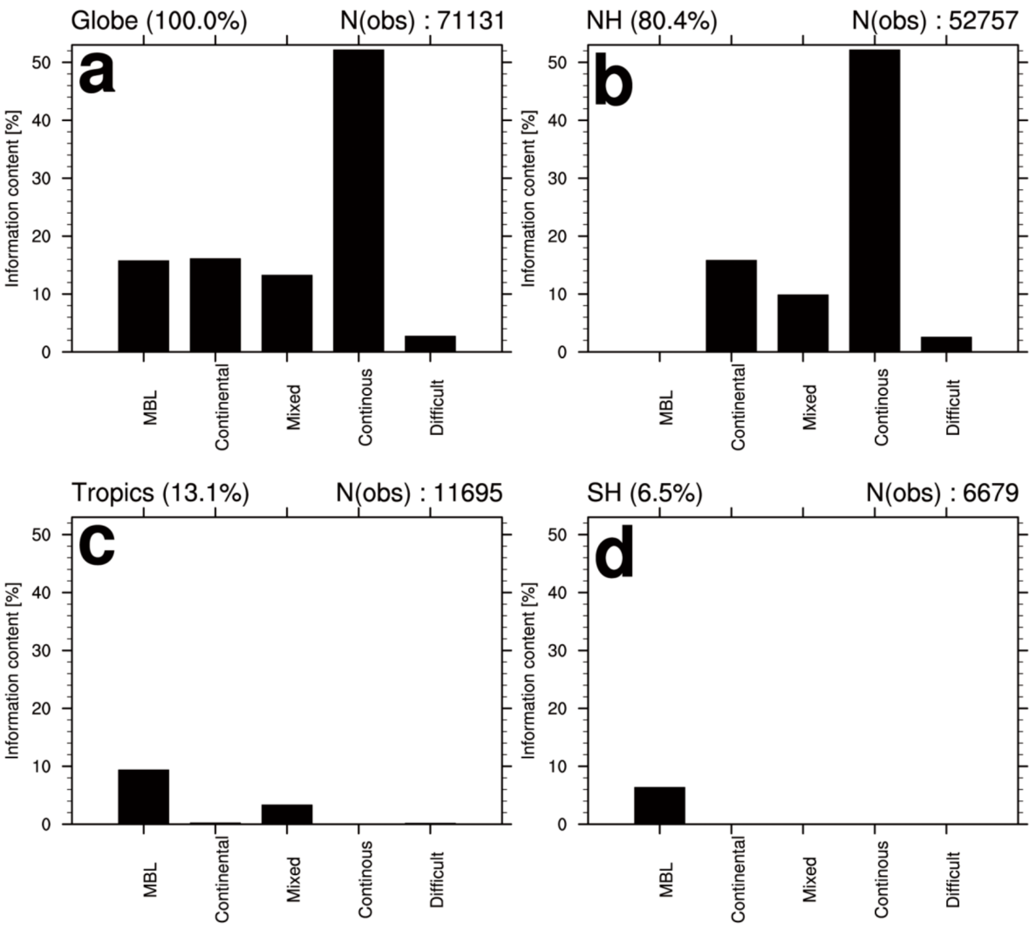
- The average self-sensitivity decreases as the observation number increases, showing the inversely proportional relationship.
- There is a seasonal variability in the average self-sensitivity, showing large values in summer and small values in winter.

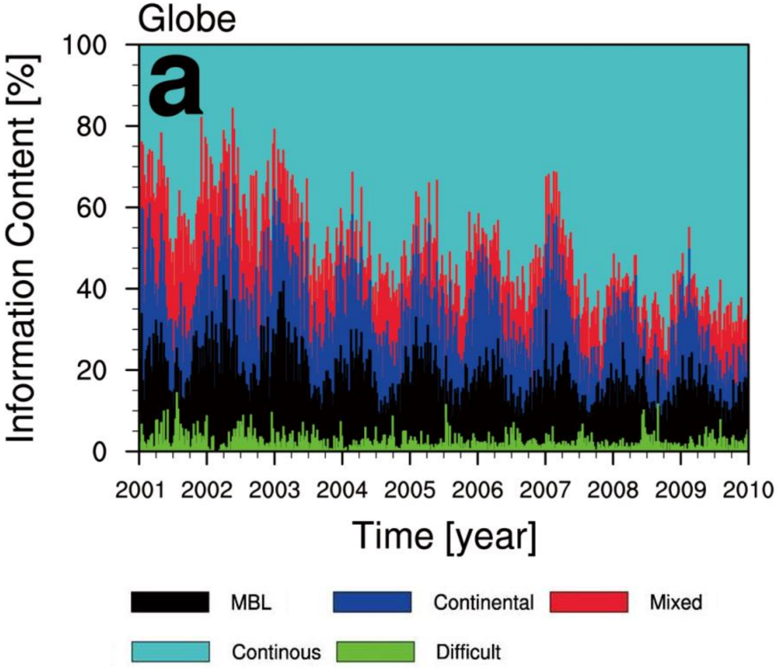
Results : Surface CO_2 flux spread



- The ensemble spread of the prior surface CO_2 fluxes reflects uncertainties, which are projected onto the ensemble spread of the background and analysis CO_2 concentrations by the transport model.

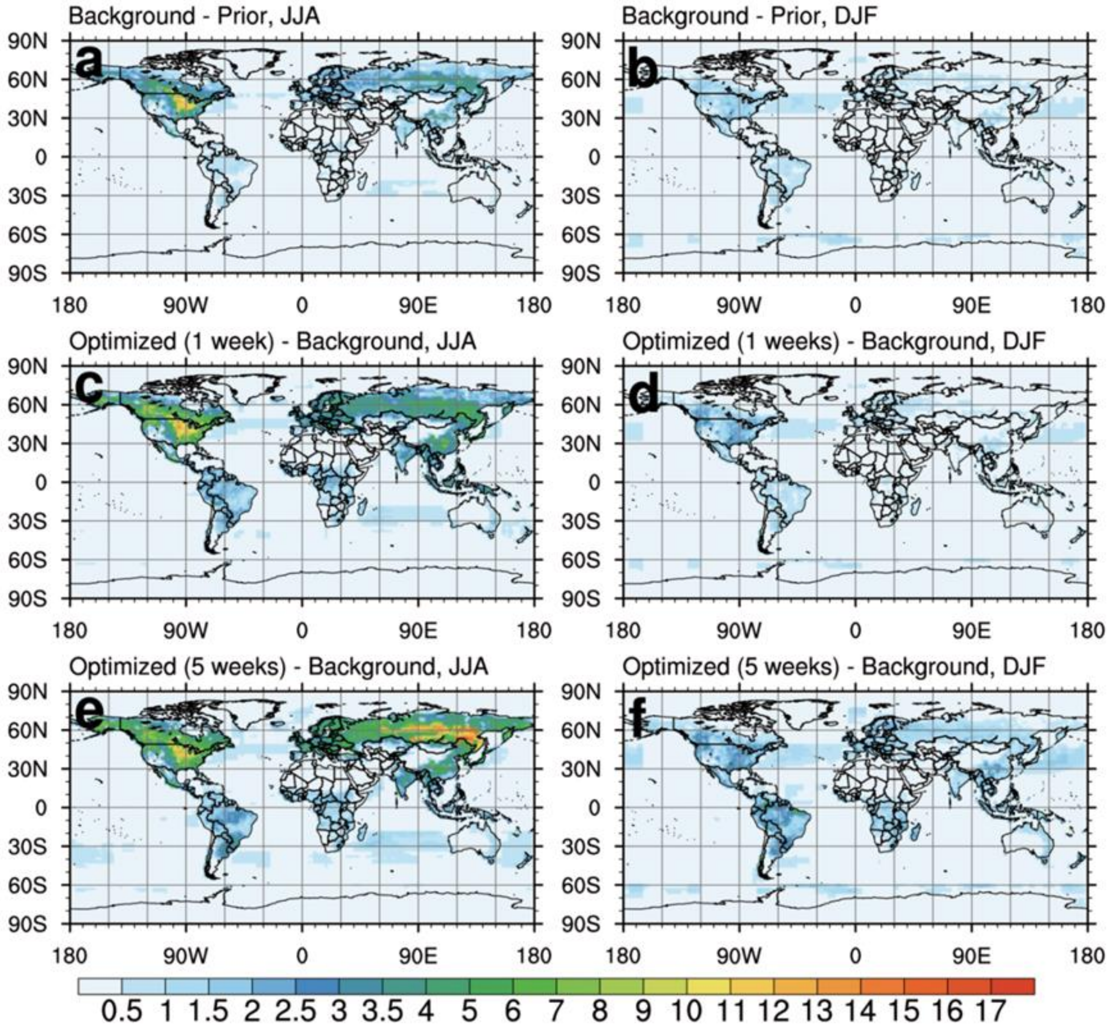
Results : Information content





- Most informative observation site category is continuous category.
- MBL, Continental, and Mixed site categories show similar magnitude of information content, but Difficult site category shows smallest information content.

Results : Information content



- The regions of large average information content are consistent with the regions of large root mean square differences (RMSD) of the surface CO_2 fluxes.

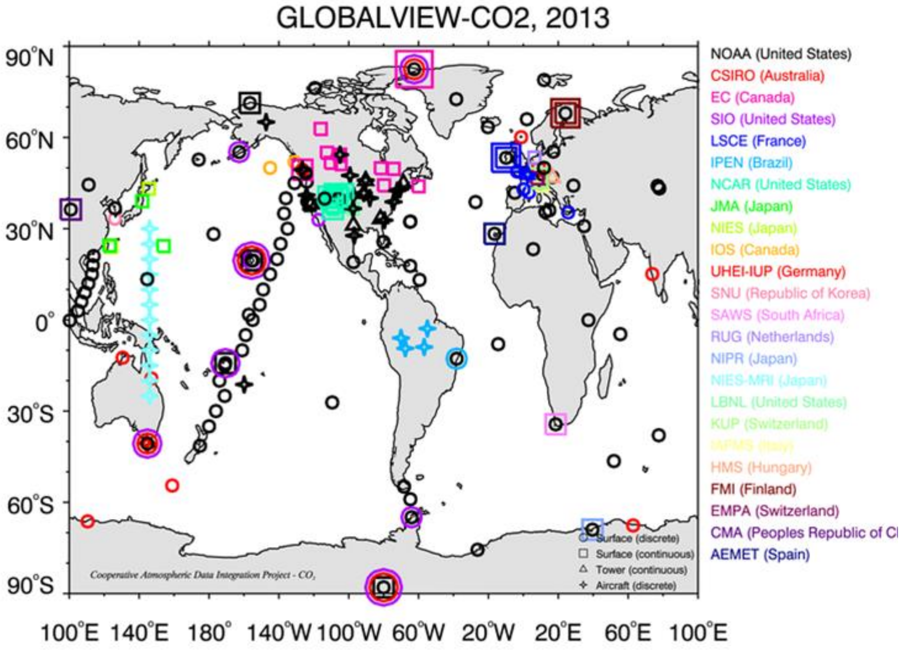
Conclusion (Part I)

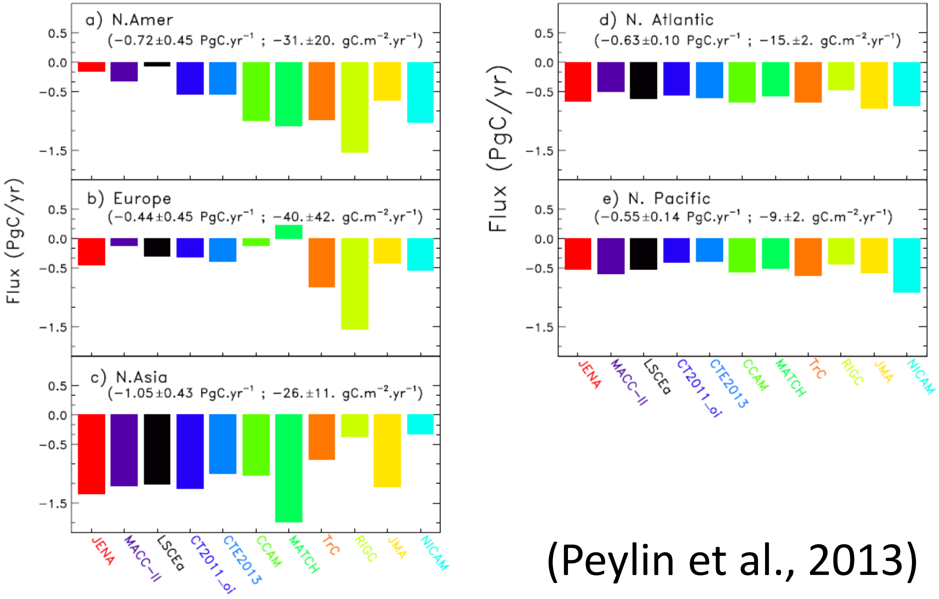
- In part I, the effect of CO_2 concentration observations on the optimized surface CO_2 fluxes in CarbonTracker was evaluated by calculating the influence matrix.
- The analysis sensitivity is inversely proportional to observation numbers used in the assimilation.
- The time series of globally averaged analysis sensitivities show seasonal variations of greater (smaller) sensitivities in summer (winter), which is attributed to the surface CO_2 flux uncertainties.
- The strong correlation between the information content and the optimized surface CO_2 fluxes exists.
- The results indicates that additional observation in other regions is necessary to estimate the surface CO_2 flux in theses areas as accurately as in North America.

Part II

Impact of Siberian observations on the optimization of surface CO_2 flux

Motivation

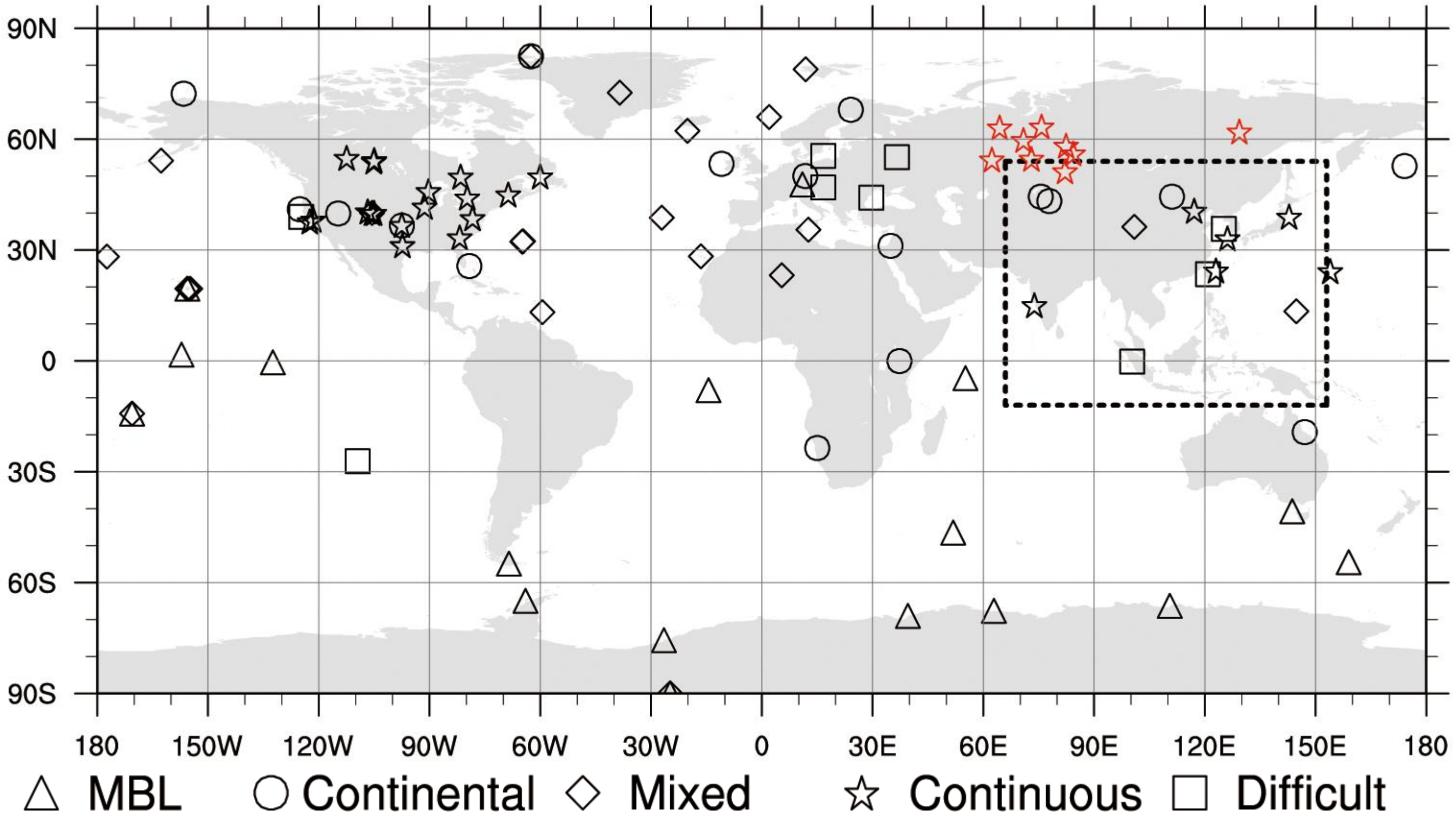




(Peylin et al., 2013)

- Although surface CO_2 sources and sinks in Asia affect the global carbon cycle considerably, the atmospheric CO_2 observation network is sparse in Asia.
- In part II, the impact of additional Siberian observations on the optimized surface CO_2 flux over the globe and Asian region within CarbonTracker are investigated by comparing the results of estimated surface CO_2 fluxes from two experiments with and without Siberian observations.

Method : Experiment set-up

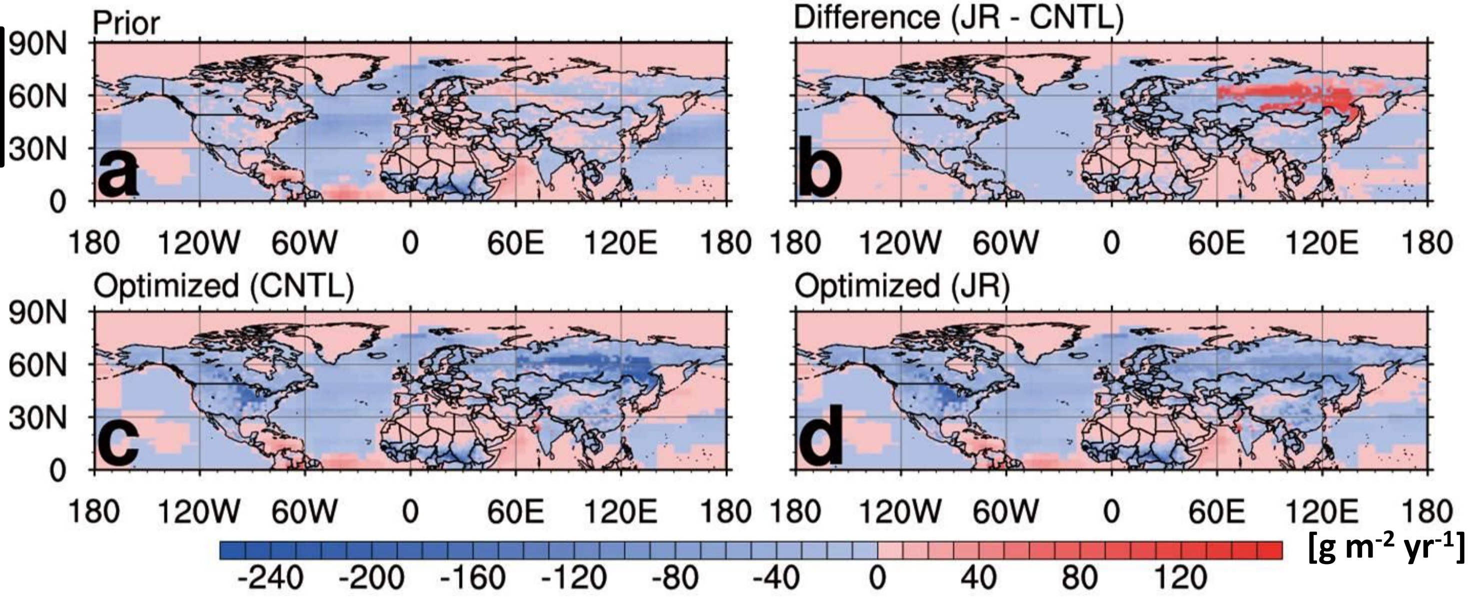


Experiment name	CNTL	JR
Period	2000. 1. 1. ~ 2009. 12. 31.	
Weeks of lag (assimilation window)	5 week	
The number of ensemble	150	

- Siberian tower network, Japan-Russia Siberian Tall Tower Inland Observation Network (JR-STATION) (Sasakawa et al., 2010; 2013), observations are used in the JR experiment.

Result : Prior and optimized surface CO_2 flux

2002-09 Average

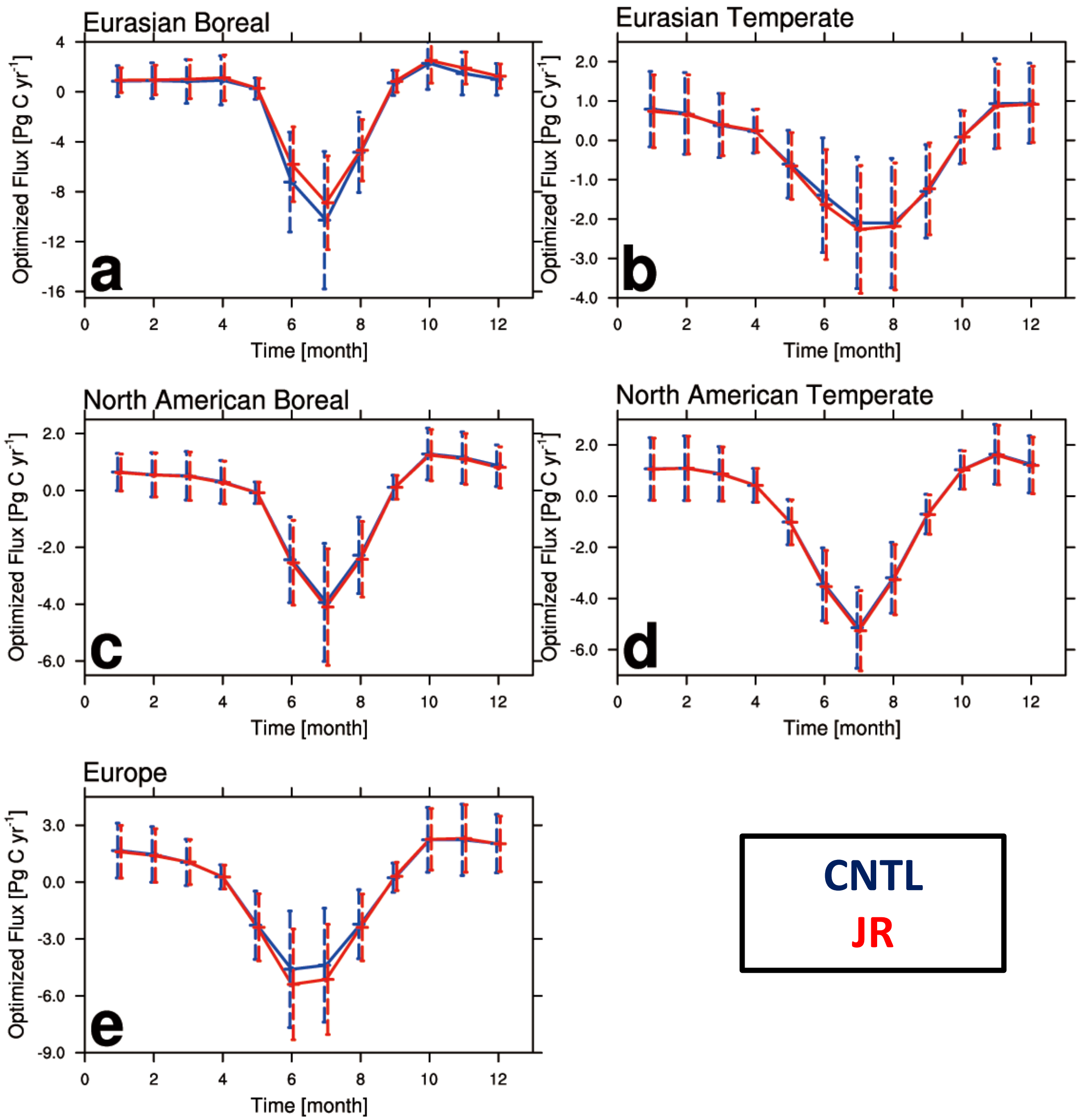


A prior and optimized surface CO_2 fluxes and their uncertainties

Region	A priori	CNTL	JR
Global total	-3.94±2.23	-5.69±1.84	-5.60±1.72
Global land	-1.36±1.90	-3.62±1.57	-3.57±1.43
Global ocean	-2.58±1.18	-1.95±0.97	-2.03±0.96

- The global total optimized CO_2 fluxes are similar for each experiment.
- The differences in fluxes between the CNTL and JR experiments are distinctive in EB (Siberia) where the new additional observations are assimilated.

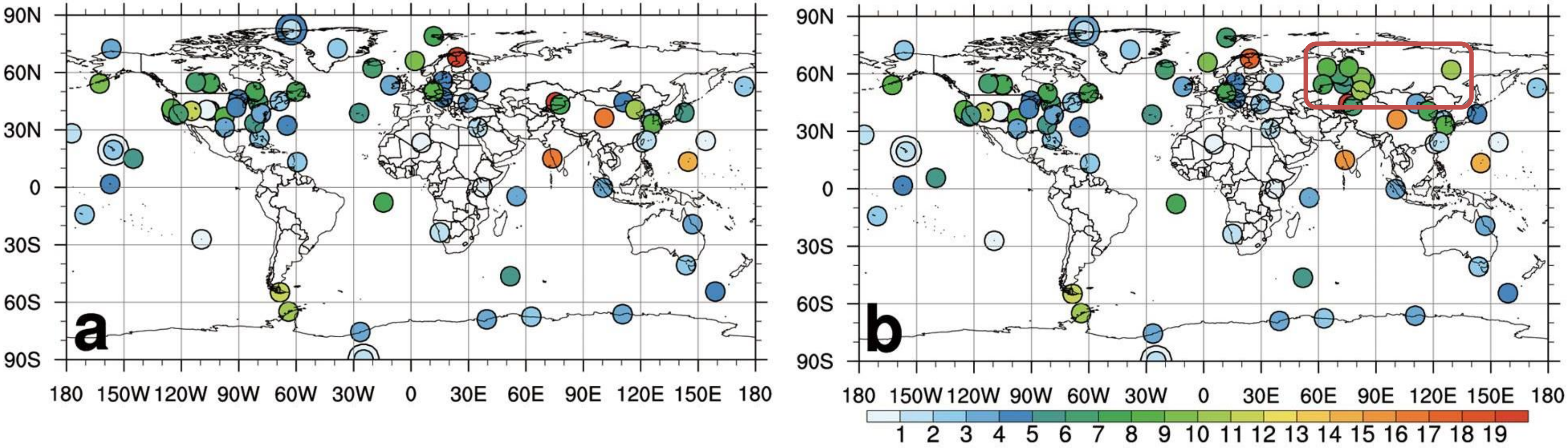
Result : Optimized surface CO_2 flux



CNTL
JR

- Additional Siberian data provides information on the surface CO_2 uptake by vegetation activity in the NH summer.
- The largest difference in surface CO_2 flux between the two experiments occurs in June and July, which represent the active season of the terrestrial ecosystem with a large surface CO_2 flux uncertainty.

Result : Observation impact



- The average self-sensitivities at the JR-STATION sites are as large as those at the tower measurements in North America.
- The average self-sensitivities of additional observations are higher than those of other sites, providing much information for estimating surface CO_2 fluxes.

Conclusion (Part II)

- In part II, to investigate the effect of the Siberian observations, which are not used in the previous studies using CarbonTracker, on the optimization of surface CO_2 fluxes, two experiments, named CNTL and JR, with different sets of observations from 2000 to 2009 were conducted and optimized surface CO_2 fluxes from 2002 to 2009 are analyzed.

- The global balances of the sources and sinks of surface CO_2 fluxes was maintained for both experiments, while the distribution of the optimized surface CO_2 fluxes changed.

- The results show that the JR-STATION data affect the longitudinal distribution of the total NH sinks, especially in the EB and Europe, when it is used by atmospheric CO_2 inversion modeling.

Concluding remarks

- CarbonTracker is an atmospheric CO_2 inverse modeling system that estimates the surface CO_2 fluxes using EnKF with atmospheric CO_2 measurements as a constraint.
- In part I, a diagnostic is developed to calculate the effect of individual CO_2 observations on estimating the surface CO_2 flux in the CarbonTrakcer framework.
- In part II, the effect of additional CO_2 observations in Siberia, where no surface CO_2 measurement site existed in the previous CarbonTracker framework, on the surface CO_2 flux analyses for the globe and Asia was investigated.
- The results show that the relative importance of each observation site and each observation site category can be evaluated by analyzing the self-sensitivity and information content and additional Siberian observations provide useful information on analyzing the distribution of surface CO_2 uptake in Northern Hemisphere.

Thank you