IWGGMS-14
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GOSAT CO_2 Inversion Inter-comparison Experiment Phase-2: interim progress report

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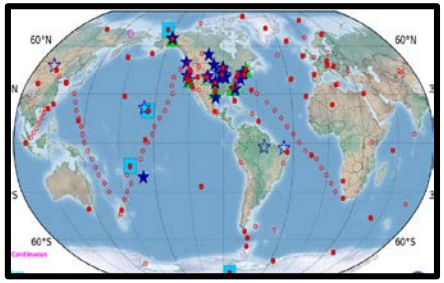
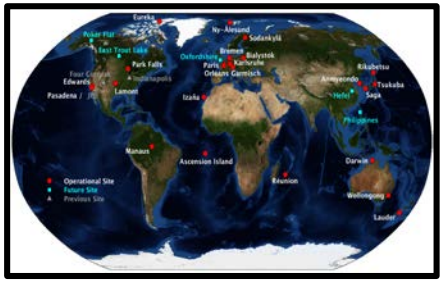
5 Department of Physics, University of Toronto, Canada
6 School of Geosciences, University of Edinburgh, UK
7 International Institute for Earth System Science, Nanjing University, China

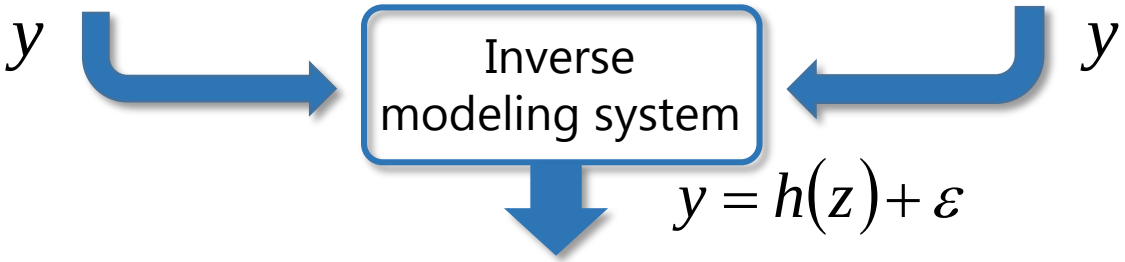
Introduction



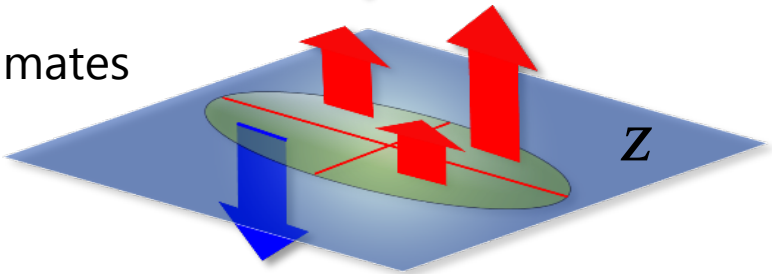


Surface-based CO_2 observations

Satellite X_{CO2} retrievals



Global carbon flux estimates



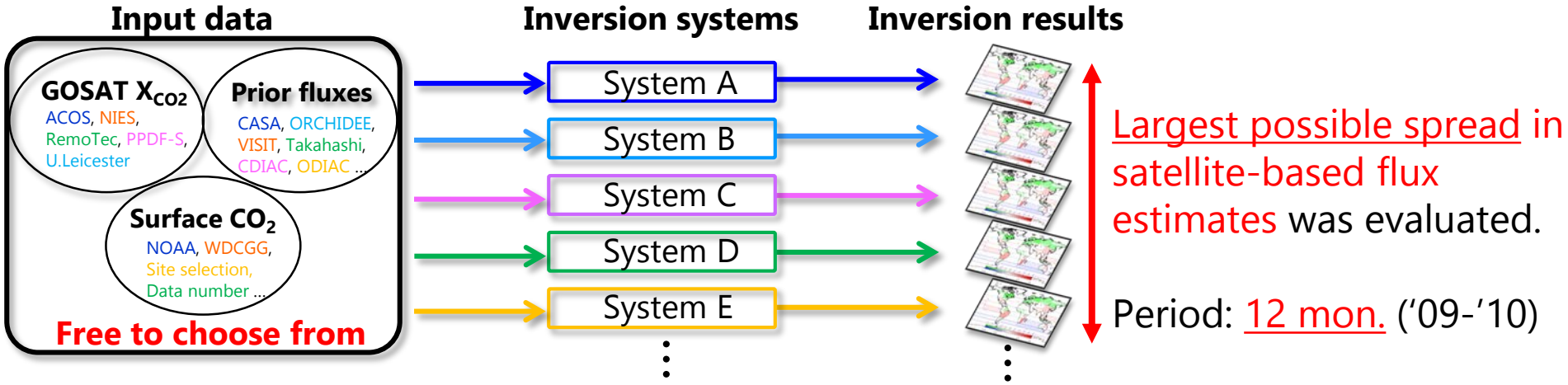
To gain further the process-level understanding of carbon fluxes being modified by human activities, it is essential to **quantify, evaluate, and reduce** uncertainties in the flux estimation process → Model inter-comparisons provide such an opportunity

GOSAT CO_2 Inversion Inter-comparison studies

GOSAT inversion intercomparison Phase-1 (finished)

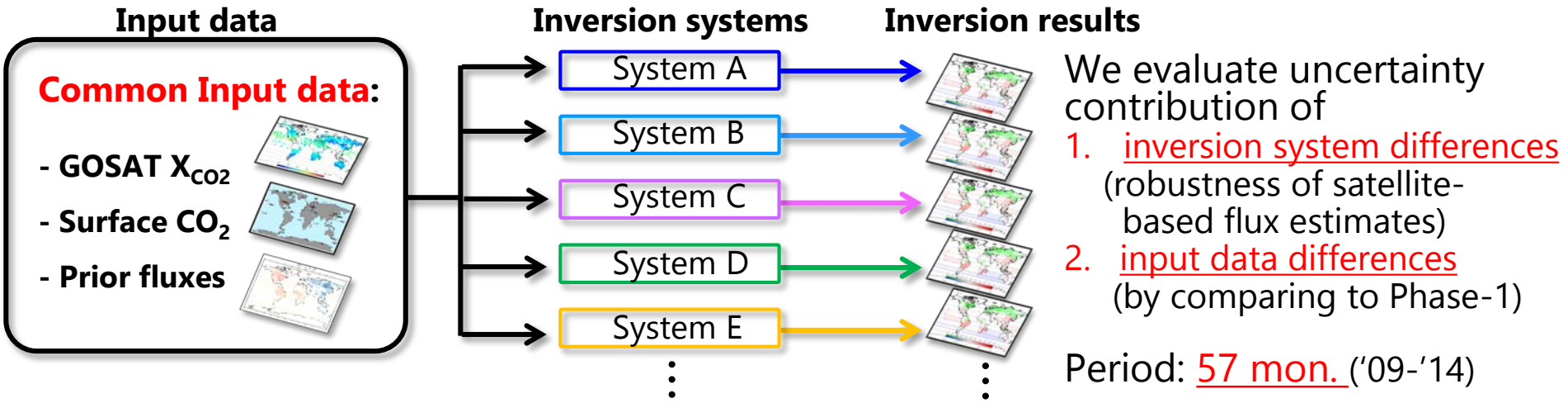
"Free-style" inversion experiment

Houweling et al. 2015 JGR



GOSAT inversion intercomparison Phase-2 (this study, ongoing)

"Common-input" inversion experiment

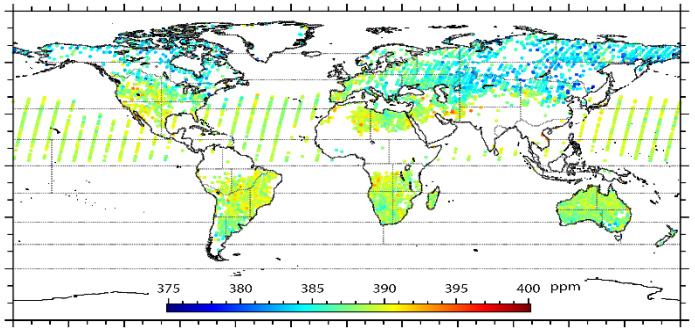


Phase-2 Experimental protocol

Common input dataset: CO_2 concentration and a priori flux

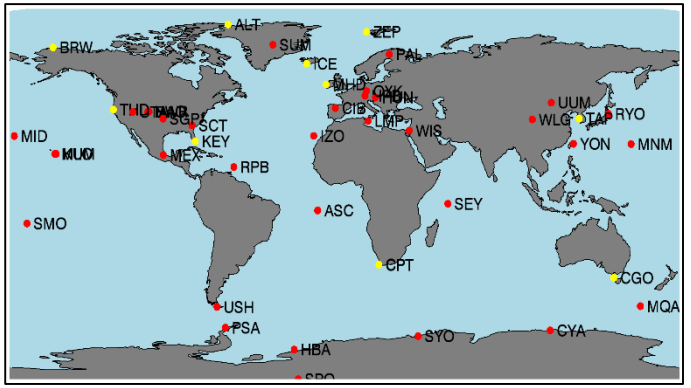
ACOS B3.5 LITE X_{CO2} retrieval dataset

- use "good" quality, bias-corrected X_{CO2}
- use both land and ocean retrievals



NOAA ObsPack GV plus surface observations

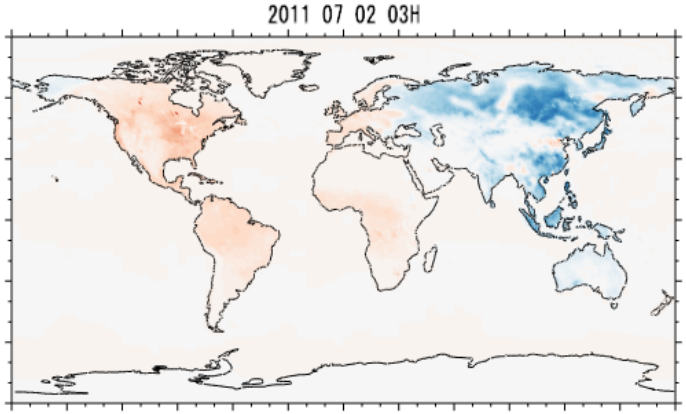
- 44 sites out of 205 were selected for their fewer data gaps over 2009-2014 period



NOAA CarbonTracker 2015 a priori flux data

- CASA-GFED 4.1s, OIF ocean, ODIAC fossil fuel, and GFED 4.1s fire (downscaled to CT specifications)
- 3-hourly fluxes on a 1° × 1° mesh used

(Courtesy of A. Jacobson, NOAA and source data providers)



Inversion systems and variance-covariance matrices

Inversion system: use best system setups by each participant

Variance-covariance matrices

- Variance-covariance matrices for observation (**R**) and prior flux uncertainties (**B**) were defined by each participant.

- But to maintain weight of CO_2 obs. within a comparable range among the participants, minimum values for the diagonals of matrix **R** are set to:
  - ACOS B3.5 X_{CO2} : 2.0 ppm
  - ObsPack GVplus surface CO_2 : 0.5 ppm

- To avoid over-constraining prior fluxes, participants are asked to adjust balance between **R** and **B** (prior flux unc.) such that posterior reduced X^2 has an upper bound of 1.

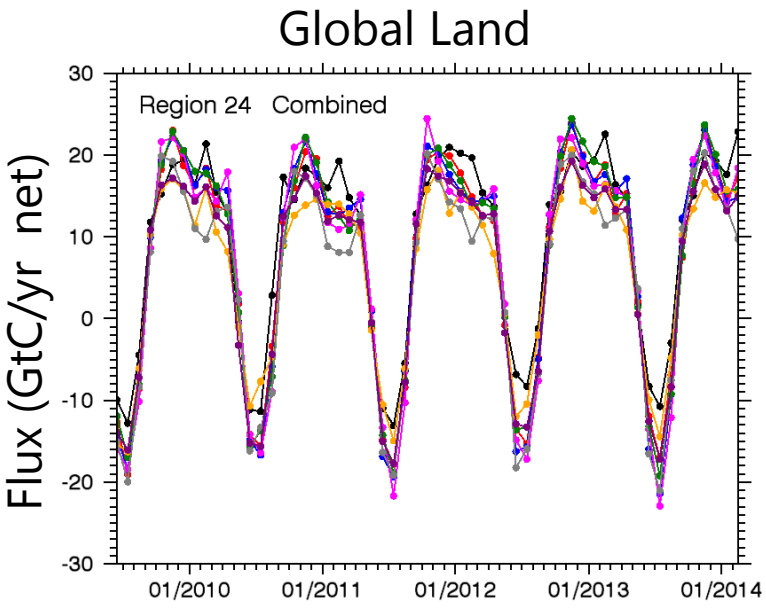
Flux data submitted:

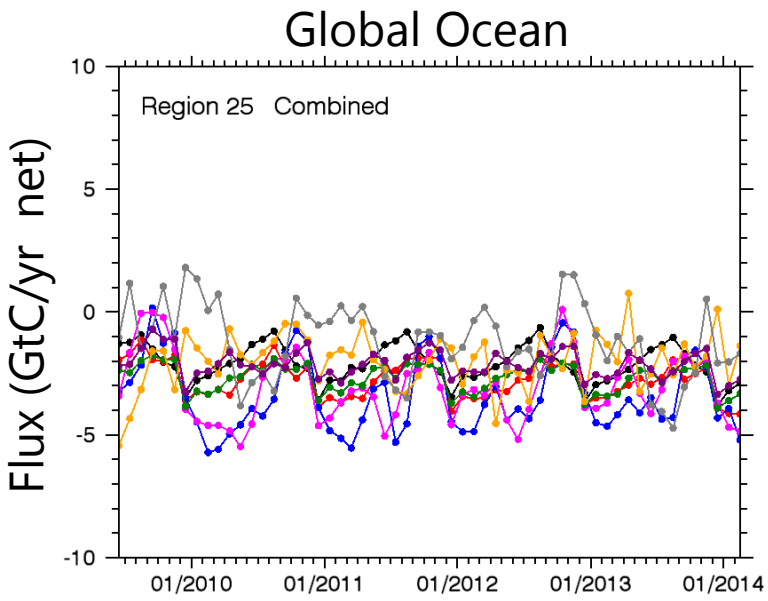
Surface-data-only, Satellite-data-only, and Sfc. & Sat. combined

Participating groups and modeling systems

Participants Phase-2 This report	Participants Phase-1 (finished)	Inversion Method	Atmospheric Transport Model	Model resolution
CSU-NOAA	CSU-NOAA	Variational	PCTM	0.7° × 0.5° × 40 lev
LSCE	LSCE	Variational	LMDZ4	3.75° × 1.9° × 39 lev
NIES	NIES	Kalman Smoother	NIES08.1	2.5° × 2.5° × 32 lev
SRON	SRON	Variational	TM5-4DVAR	6.0° × 4.0° × 60 lev
U.Edinburgh	U.Edinburgh	Ens. Kalman Filter	GEOS-Chem	5.0° × 4.0° × 47 lev
U.Toronto	U.Toronto	Variational	GEOS-Chem	5.0° × 4.0° × 47 lev
Nanjing U.	-	Ens. Kalman Filter	MOZART v4	2.8° × 2.8° × 28 lev
	MPI-BGC	Variational	TM3	5.0° × 3.8° × 19 lev
	CAO	Kalman Smoother	GELCA v1.0	2.5° × 2.5° × 32 lev

Results: Global total flux





■ : CSU
■ : LSCE
■ : NIES
■ : SRON
■ : U. Toronto
■ : Nanjing U.
■ : U. Edinburgh
■ : A priori

Surface & Satellite combined inversion result

Global Annual Total (GtC/yr net)

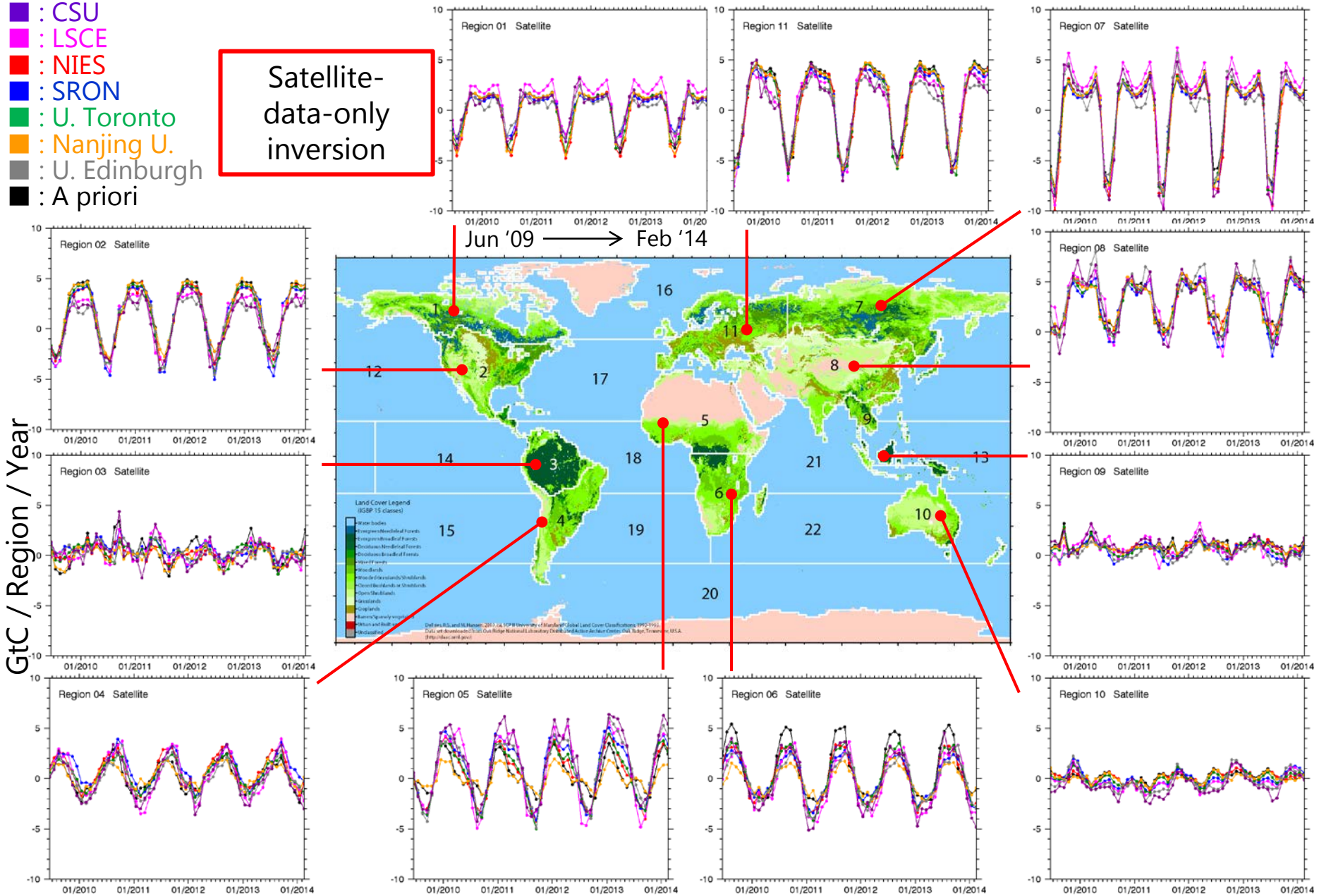
	2010	2011	2012	2013
CSU	4.2	3.8	4.8	4.3
LSCE	4.6	3.0	5.1	4.4
NIES	5.4	3.6	5.2	5.1
SRON	5.0	3.0	5.1	4.4
UOE	4.8	3.3	5.3	4.1
UTRO	5.4	3.8	5.6	5.1
NJU	4.5	4.2	4.6	5.2
NOAA growth rate*	5.1	3.5	5.0	5.1

* Source: ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_gr_gl.txt (updated on 20170405)

57-mon. flux time series for TransCom land regions
(Jun. 2009 – Feb. 2014)

- : CSU
- : LSCE
- : NIES
- : SRON
- : U. Toronto
- : Nanjing U.
- : U. Edinburgh
- : A priori

Satellite-data-only inversion



57-mon. flux time series for TransCom land regions

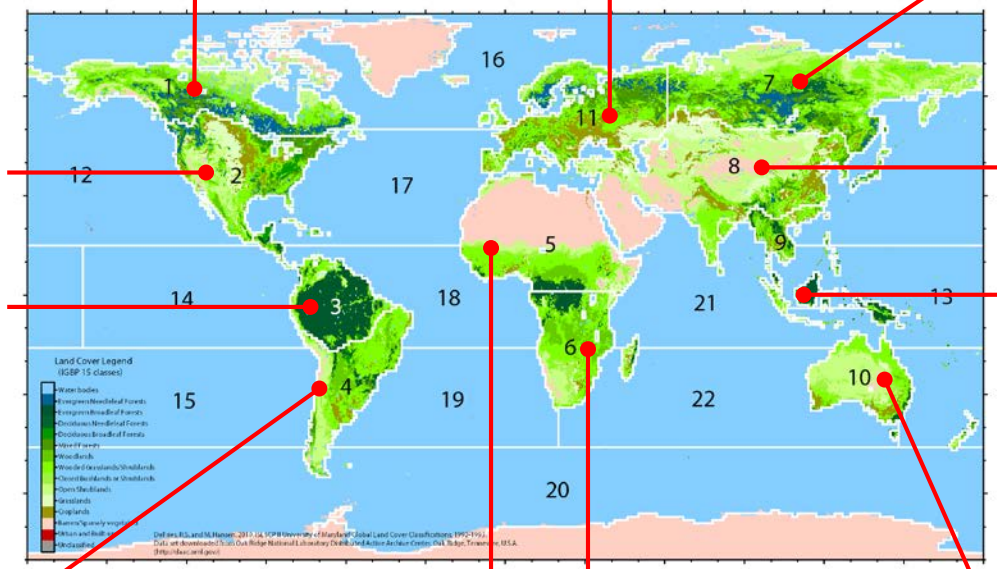
■ : Phase-1
■ : Phase-2

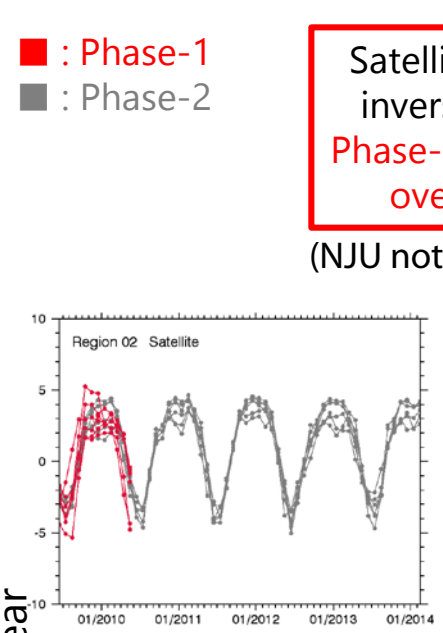
Satellite only inversion & Phase-1 results overlaid

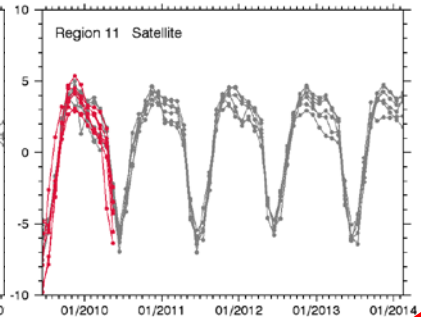
(NJU not included)

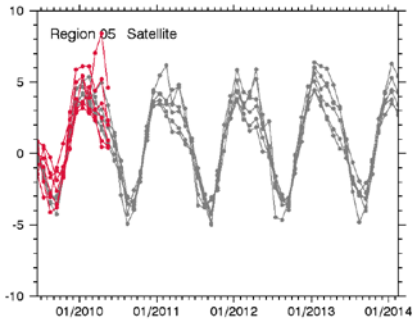
Jun '09 → Feb '14

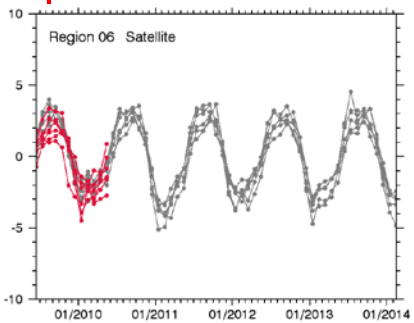
GtC / Region / Year

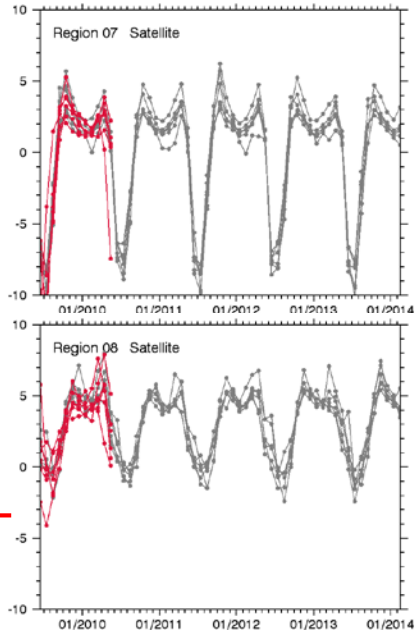










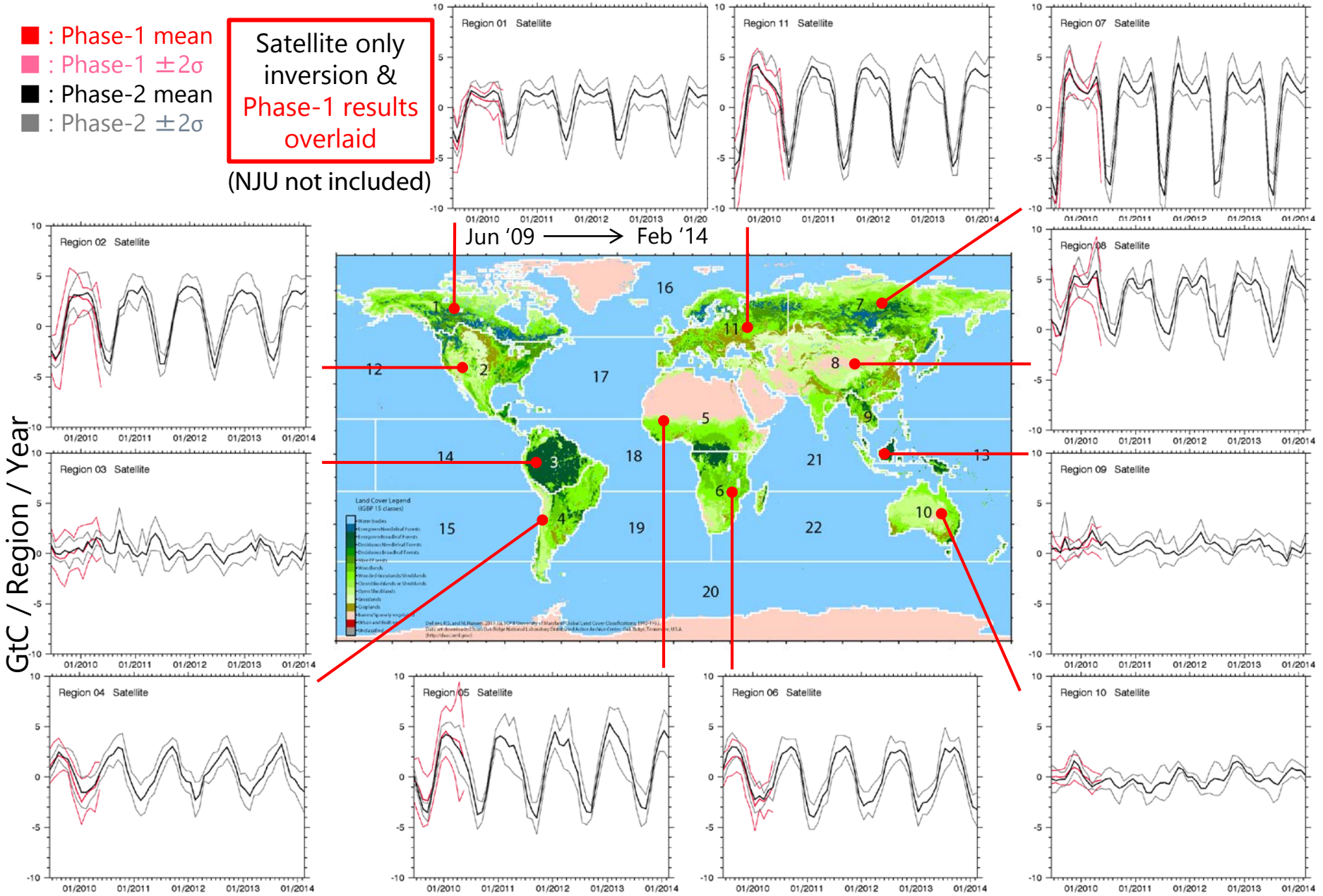


57-mon. flux time series for TransCom land regions

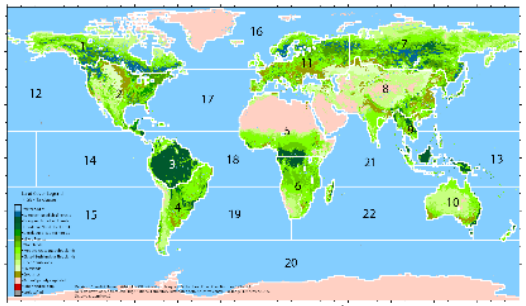
■ : Phase-1 mean
■ : Phase-1 ±2σ
■ : Phase-2 mean
■ : Phase-2 ±2σ

Satellite only inversion & Phase-1 results overlaid

(NJU not included)



Changes in spread of flux estimates (Phase 1 → 2)



TransCom Regions

Values in red :
"between-model" uncertainty
→ indicates degree to which inv. system differences contribute to range of satellite-based flux estimates for '09-'10 period.

Spread (1σ) of six flux estimates

(annual flux Jun'09-May'10)

(Nanjing U. not included)

Region Unit: GtC / yr	Satellite-only estimate	
	Phase-2	Phase-1
Boreal N America	**0.6**	**0.8**
Temp. N America	**0.7**	**1.3**
Trop. America	**0.5**	**1.0**
S. America	**0.6**	**0.9**
Trop. Africa	**0.6**	**1.4**
S. Africa	**0.5**	**0.9**
Boreal Eurasia	**0.8**	**1.4**
Temp. Asia	**0.8**	**1.3**
Trop. Asia	**0.5**	**0.5**
Australia	**0.4**	**0.5**
Europe	**0.7**	**1.2**
Average reduction (Phase 1 → 2)	35% (Range: 0 – 60%)	

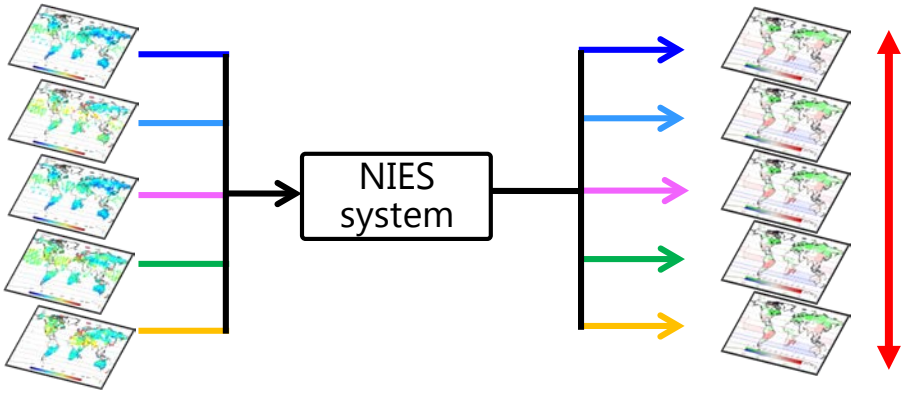
Changes in spread of flux estimates

GOSAT inversion intercomparison Phase "0" (finished)

Takagi et al. 2014 GRL

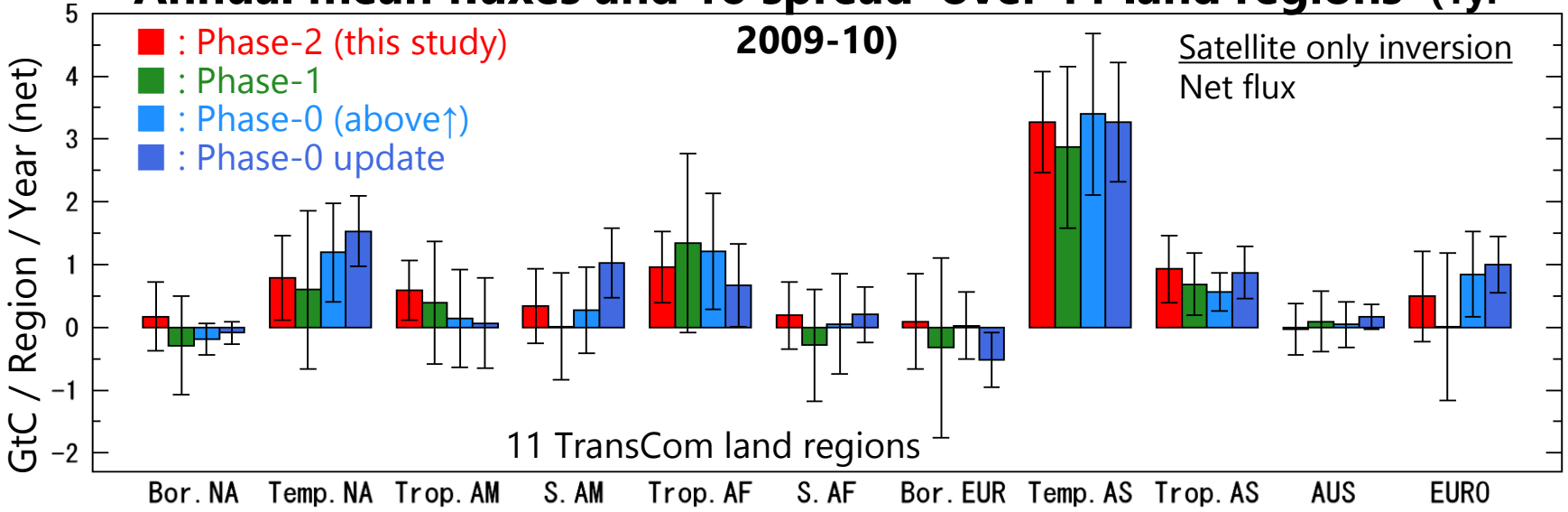
GOSAT X_{CO2} data products | **Inversion system** | **Inversion results**

- NIES L2 v02.**
- update NIES L2 v02.21
- ACOS B2.1
- update ACOS B3.5
- PPDF-S
- update PPDF-S v02.21
- RemoTeC v2.0
- update RemoTeC v2.3.8
- U. Leicester v3G
- update U. Leicester v7.0



Impact of differences in X_{CO2} products on fluxes was evaluated.
(2009-2010 1yr. period same as Phase-1)

Annual mean fluxes and 1σ spread over 11 land regions (1yr 2009-10)



→ Phase-2 spread is comparable to Phase-0 spread (X_{CO2} differences).

Changes in spread of reginal flux estimates (Phase-0)

GOSAT X_{CO2} retrievals 2012-2013

- NIES L2 v02.**
- ACOS B2.1
- PPDF-S
- RemoTeC v2.0
- U. Leicester v3G

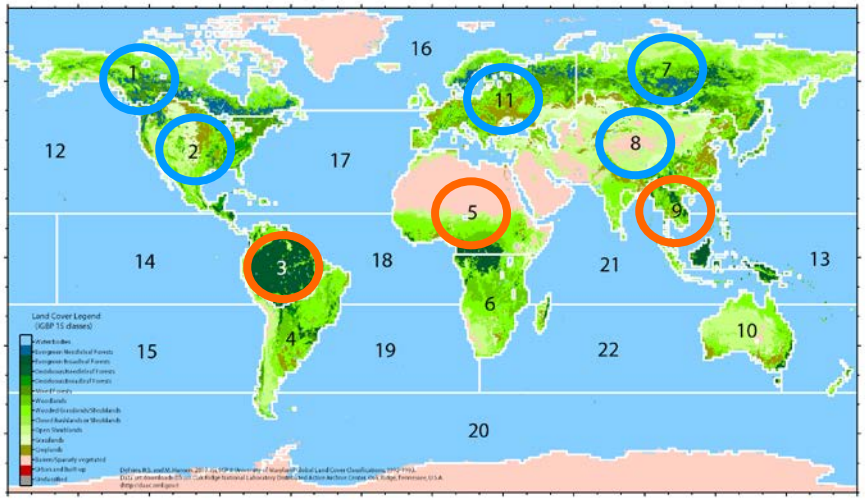
2018 update

- NIES L2 v02.21
- ACOS B3.5
- PPDF-S v02.21
- RemoTeC v2.3.8
- U. Leicester v7.0

Spread (1σ) of five flux estimates (2009-2010 1yr.)

Region	Satellite-only estimate	
	Phase-0 2018 update	Phase-0 (2012-13 data)
Boreal N America	**0.2**	**0.3**
Temp. N America	**0.6**	**0.8**
Trop. America	**0.7**	**0.8**
S. America	**0.6**	**0.7**
Trop. Africa	**0.7**	**0.9**
S. Africa	**0.4**	**0.8**
Boreal Eurasia	**0.4**	**0.5**
Temp. Asia	**1.0**	**1.3**
Trop. Asia	**0.4**	**0.3**
Australia	**0.2**	**0.4**
Europe	**0.4**	**0.7**
Average reduction (Phase 0 → 0 update)	22%	

Tropics sink minus NH Extra Tropics sink



Comparison in Houweling et al. 2015 JGR

NH Ext. Trop. Regions : 1, 2, 7, 8, & 11

Tropical regions : 3, 5, 9

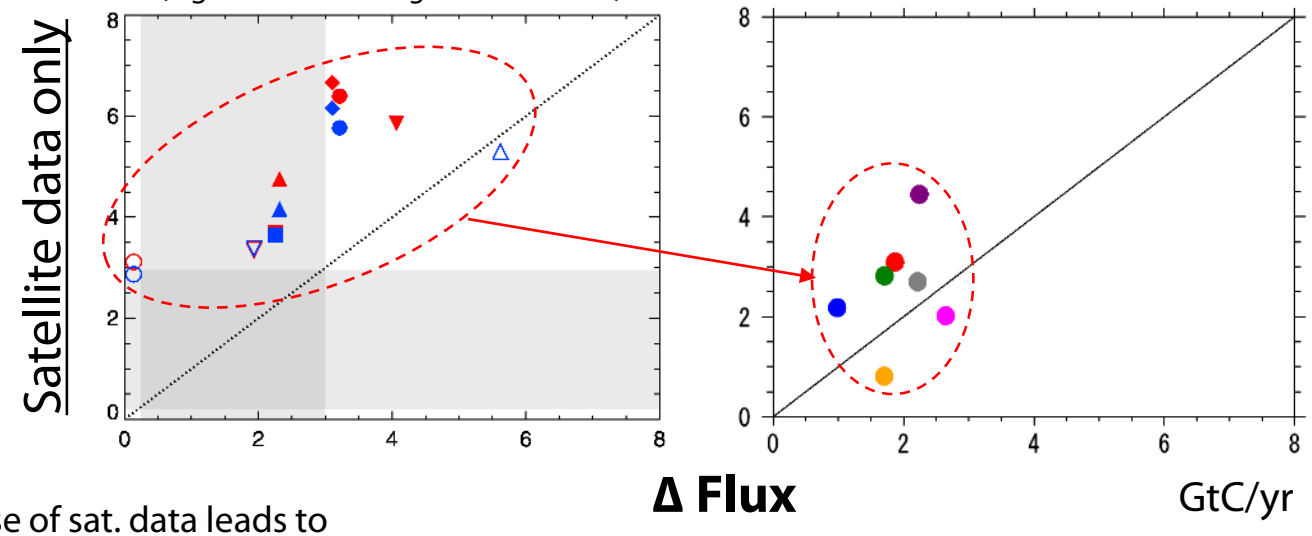
Δ Flux = (Tropics sink – NH Extra Tropics sink)

Positive Δ Flux →
NH Ext. Trop. sink is stronger than Tropics sink

Phase-1

(Figure 5 *Houweling et al. 2015 JGR*)

Phase-2



Was the Phase-1 "scatter" related to Phase-1's
- a priori data differences?
- X_{CO2} data differences?
- variance setting diff.?
- combination of all? etc. ?

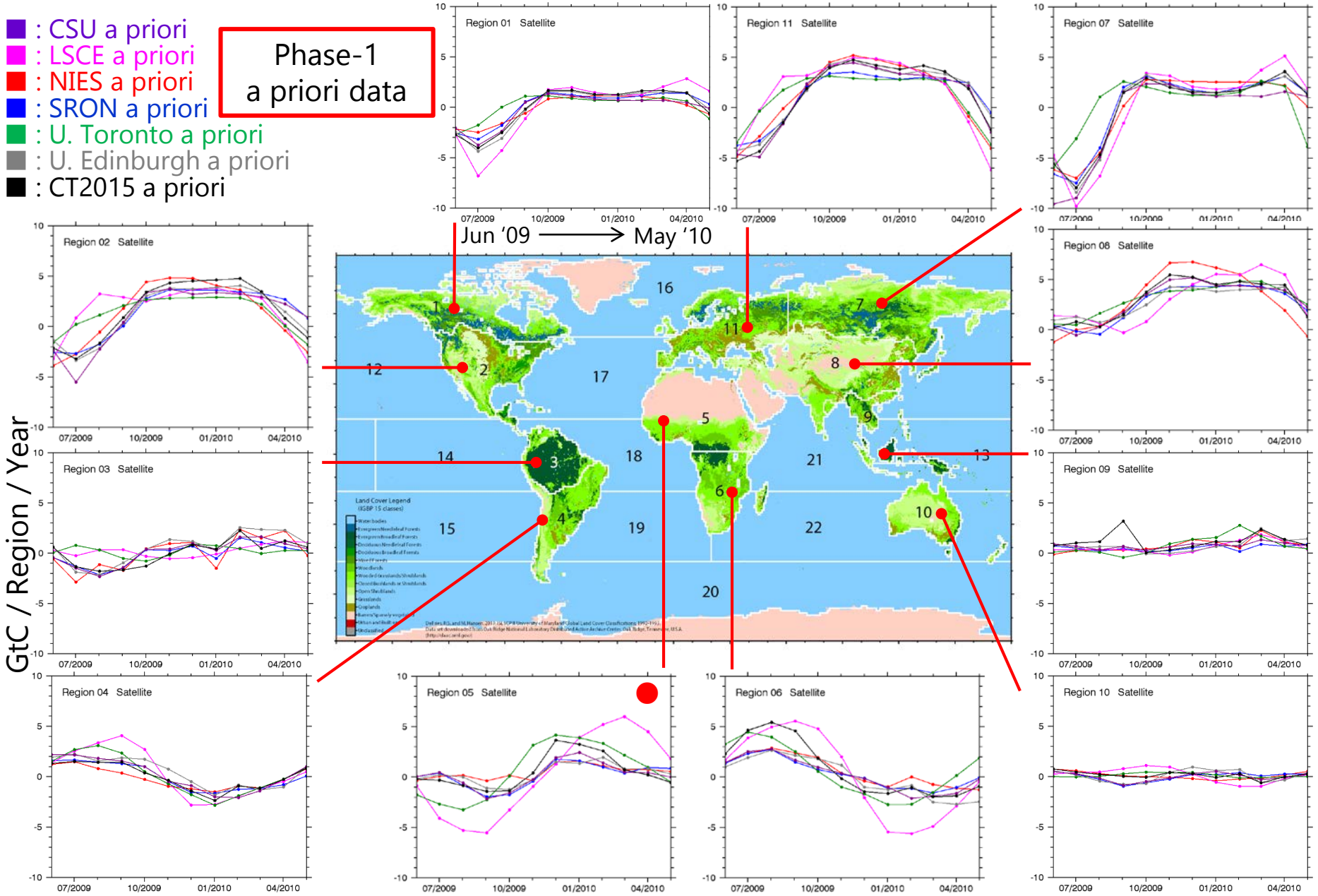
Use of sat. data leads to large sink in NH?!

Surface data only inversion

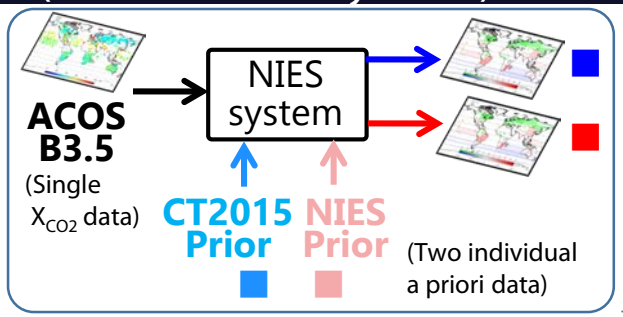
Influence of different a priori flux data used in inversion
(Jun. 2009 – May 2010)

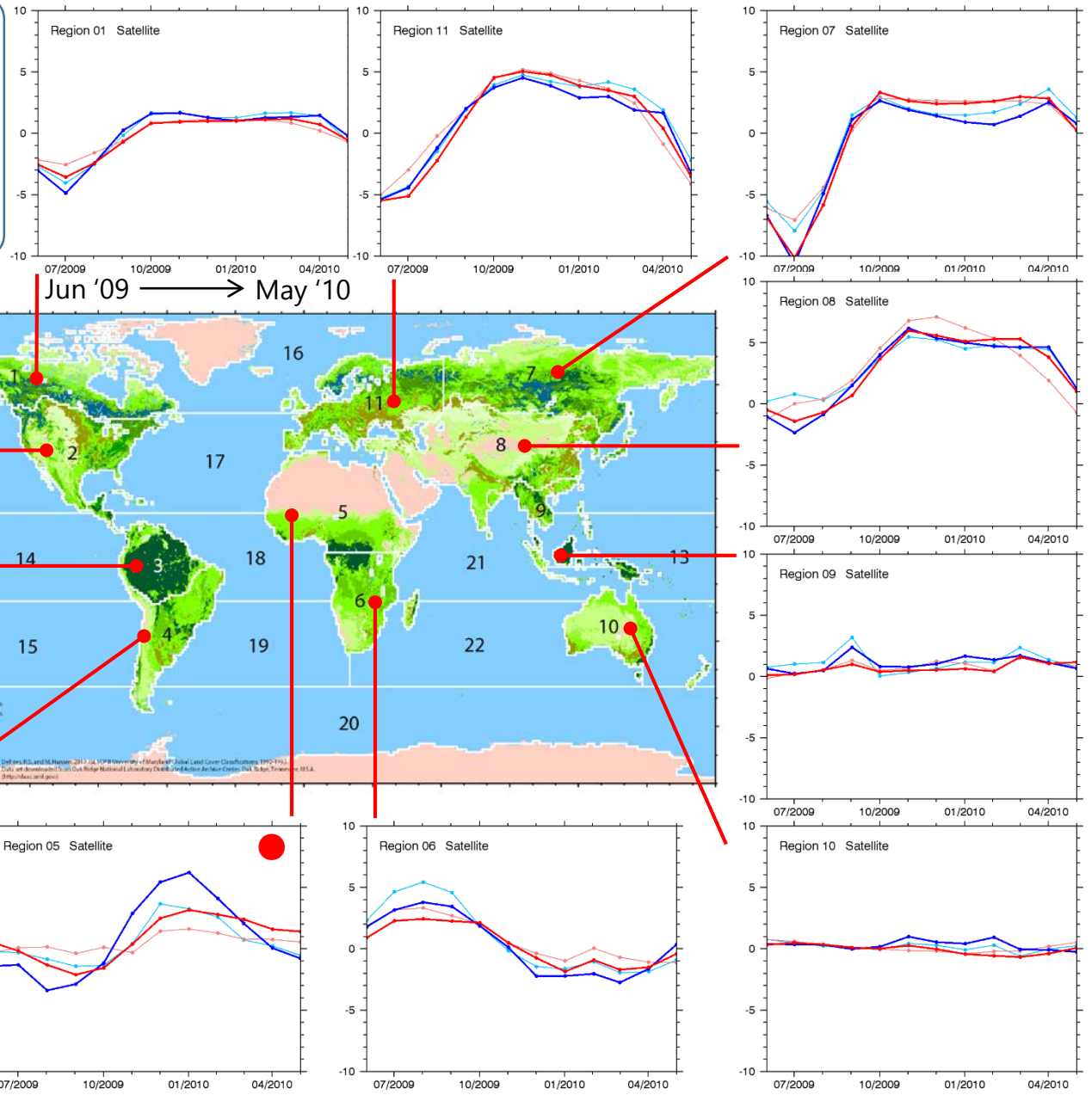
- : CSU a priori
- : LSCE a priori
- : NIES a priori
- : SRON a priori
- : U. Toronto a priori
- : U. Edinburgh a priori
- : CT2015 a priori

Phase-1
a priori data



Influence of different a priori flux data used in inversion (Jun. 2009 – May 2010)





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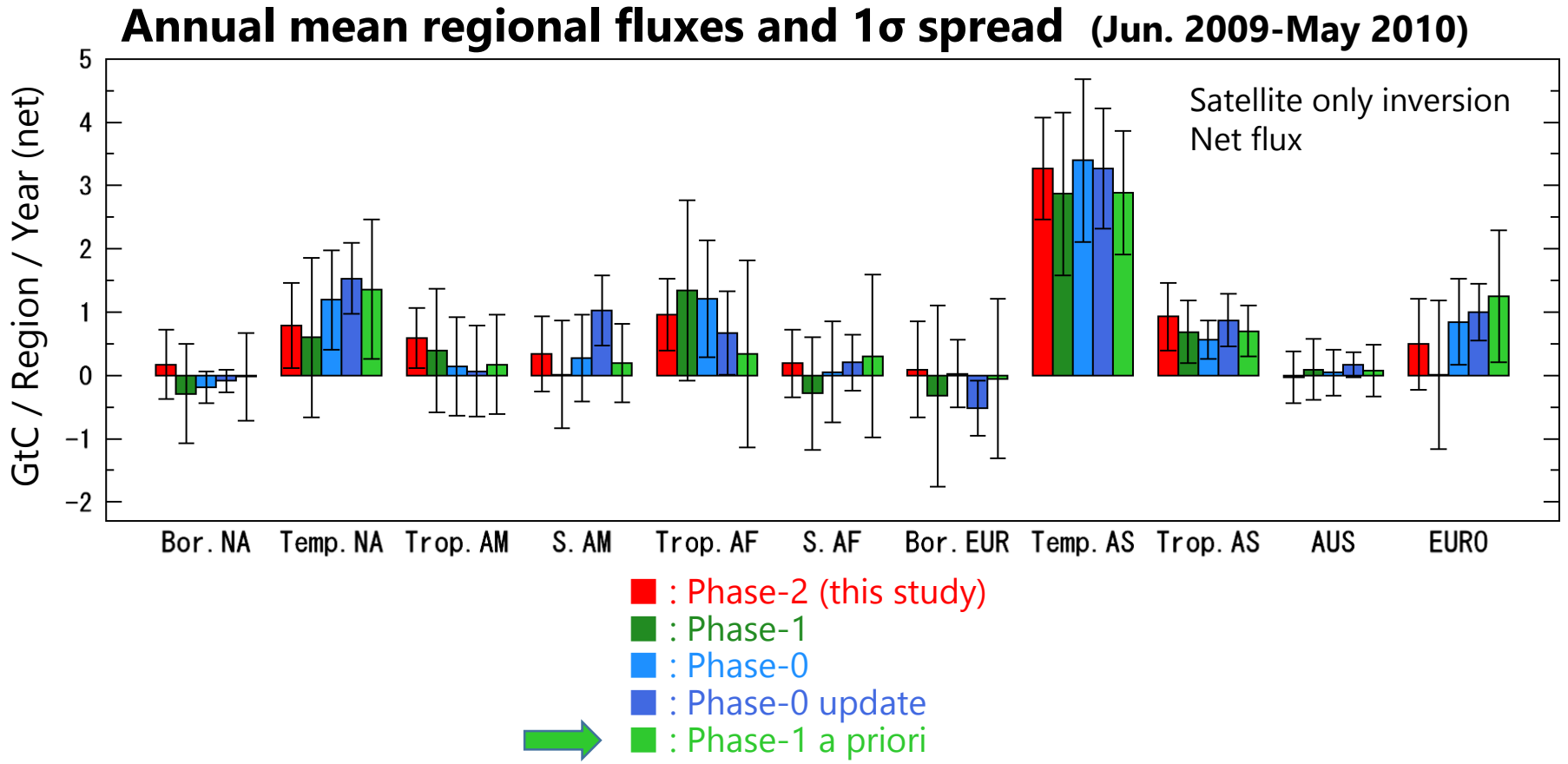
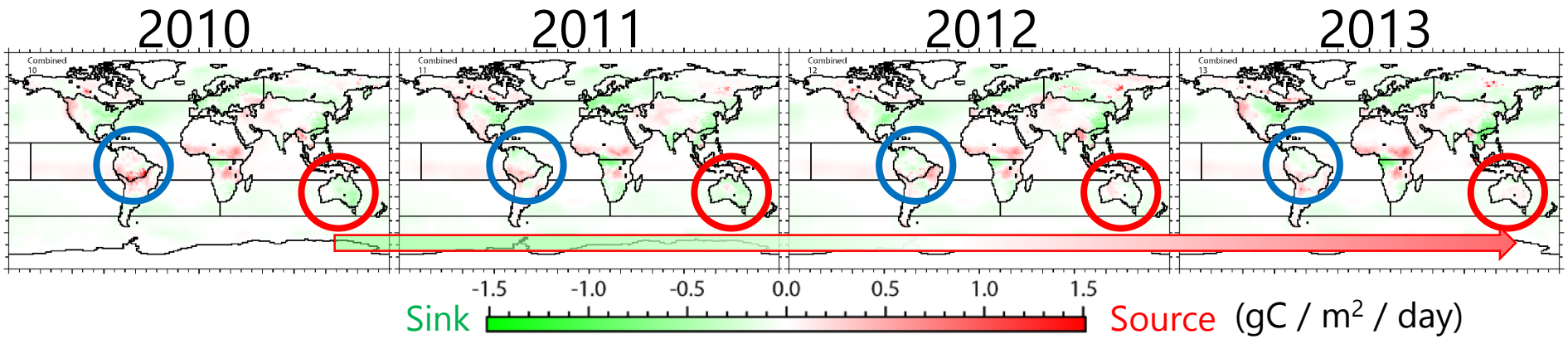
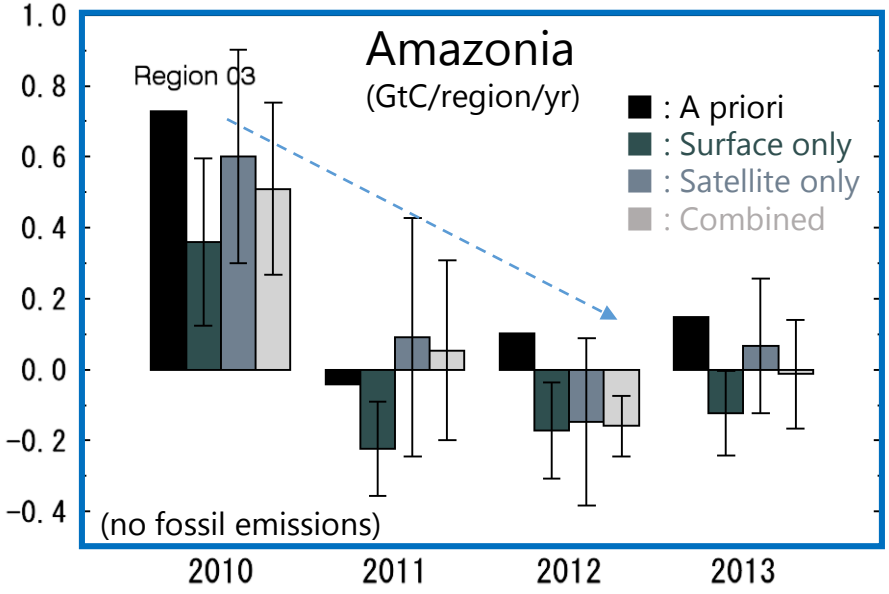
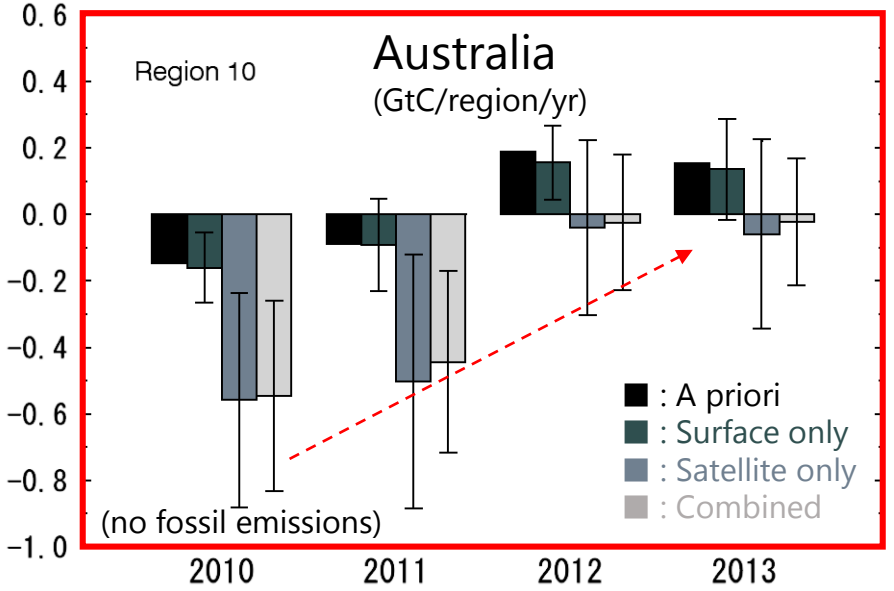


Mean of seven Phase-2 fluxes on a 1x1 grid (annual)

Surface & satellite combined inversion (fossil emissions not included)





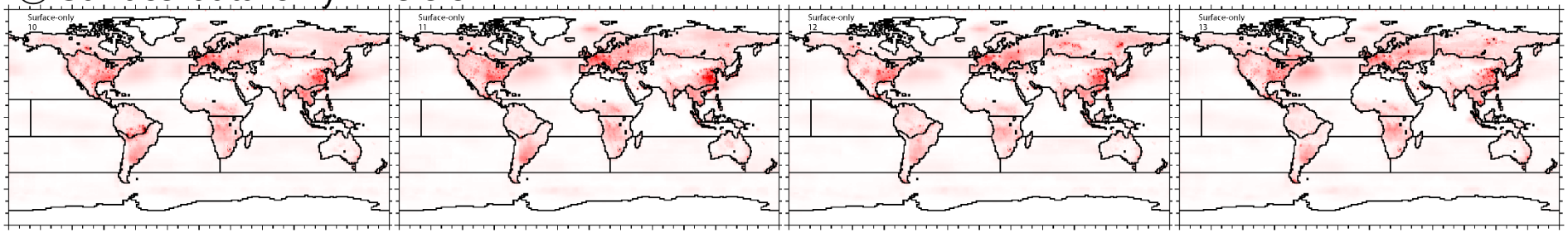


The seven models agree on - Australia went thorough a sink-to-neutral transition (*Detmers et al. 2015*)
- and Amazonia in the opposite (a see-saw oscillation)

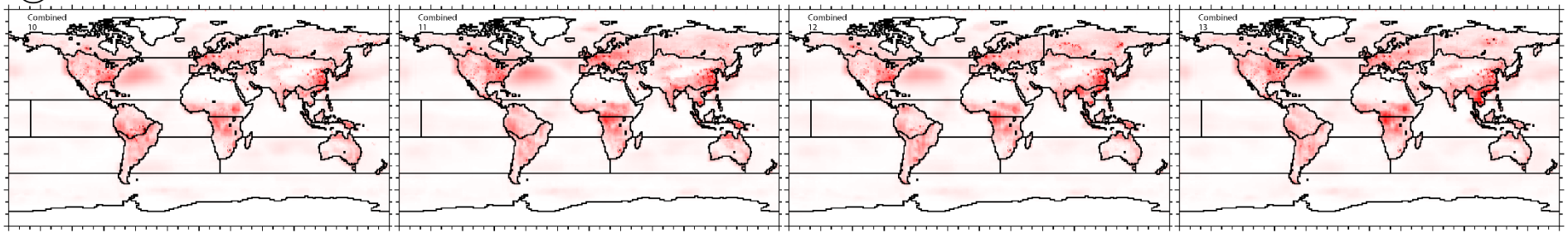
SD of seven Phase-2 fluxes on a 1x1 grid (annual)

2010 2011 2012 2013

① Surface-data-only inversion

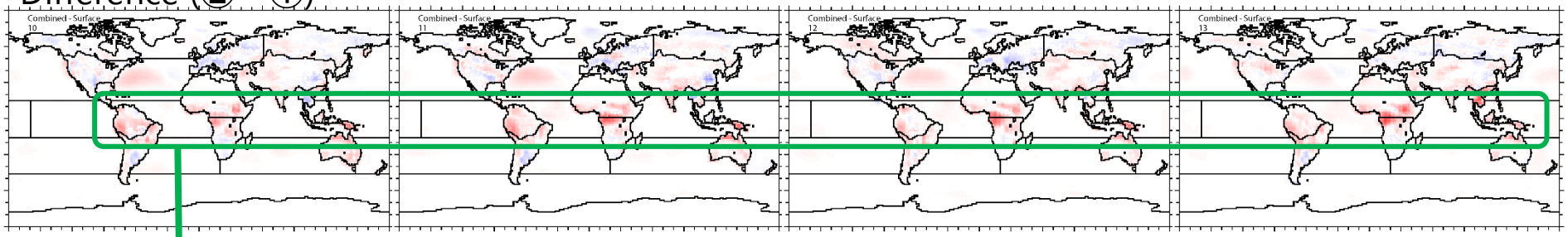


② Surface & satellite combined inversion



Standard deviation 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 (gC / m^2 / day)

Difference (② - ①)



-1.0 -0.5 0.0 0.5 1.0

Less spread than ① More spread than ① (gC / m^2 / day)

Larger spreads are found in tropical regions (Central Africa, Amazonia, and SE Asia).
Use of satellite data causes larger spread among the seven → spread may be related to transport differences for column CO_2 data.

Concluding remarks and future work

Interim report on GOSAT CO_2 inversion inter-comparison Phase-2:

- Results by 7 inversion systems are compared, and uncertainty contribution of model system differences is evaluated.
- Phase-2 spread is less than that of Phase-1 by 35% on average
  (→ input data contribution may not be negligible)
- Phase-2 spread is comparable to that of Phase-0.
  σ(inv. system differences) ≈ σ(X_{CO2} retrieval differences)
- Phase-0 update shows a reduction in the influence by X_{CO2} product differences (by ~30%).
- Signs of agreement were seen in responses to ENSO-related weather anomalies (Australian record drought/flooding).

Upcoming:

- Inversion evaluation with CO_2 observation data
- Analysis of concentration data
- More flux/uncertainty IAV analysis & comparison to prev. studies

Supplemental slides follow

57-mon. flux time series for TransCom land regions
(Jun. 2009 – Feb. 2014)

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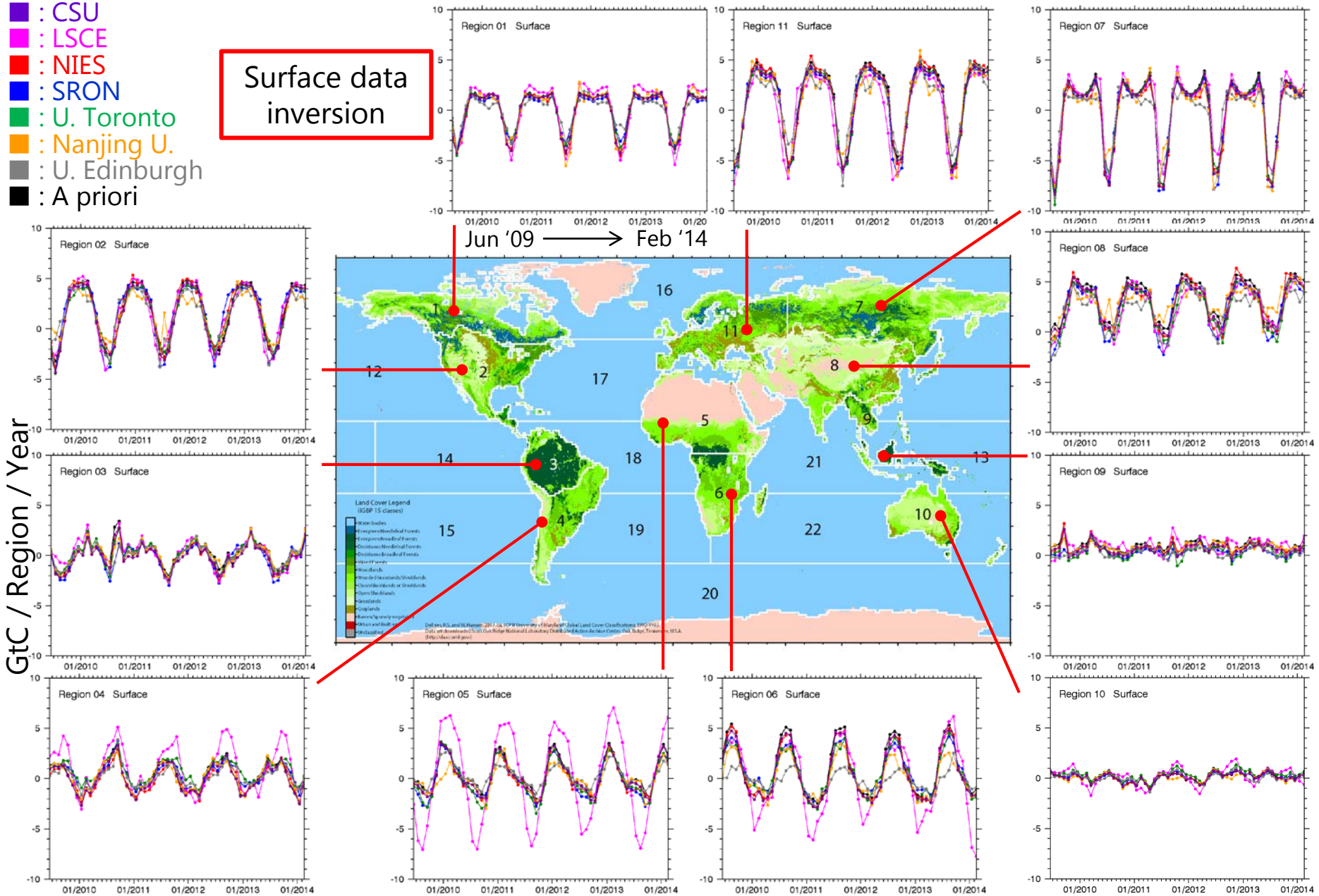
- : U. Toronto
- : Nanjing U.
- : U. Edinburgh
- : A priori

Surface data inversion



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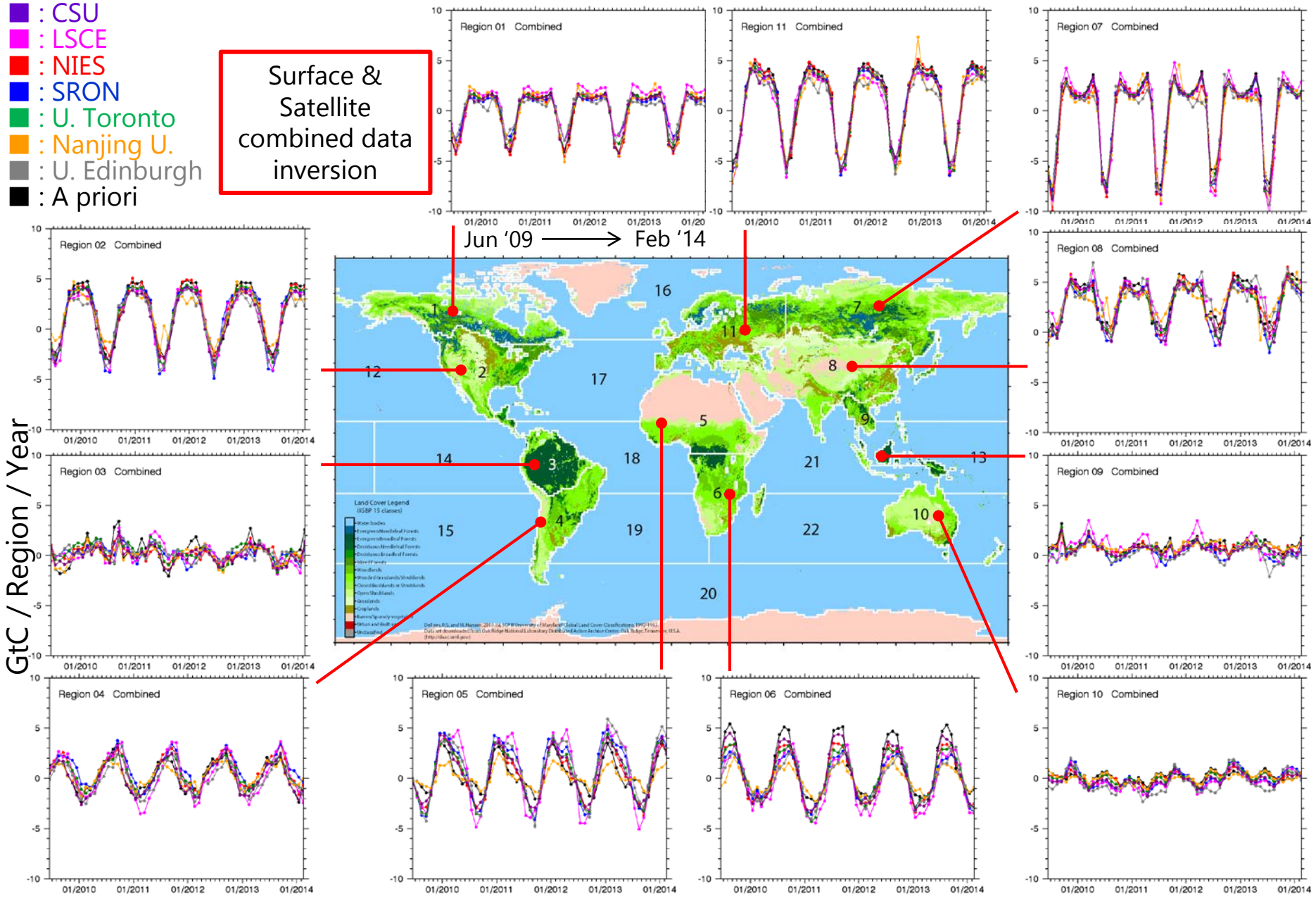
Surface & Satellite combined data inversion

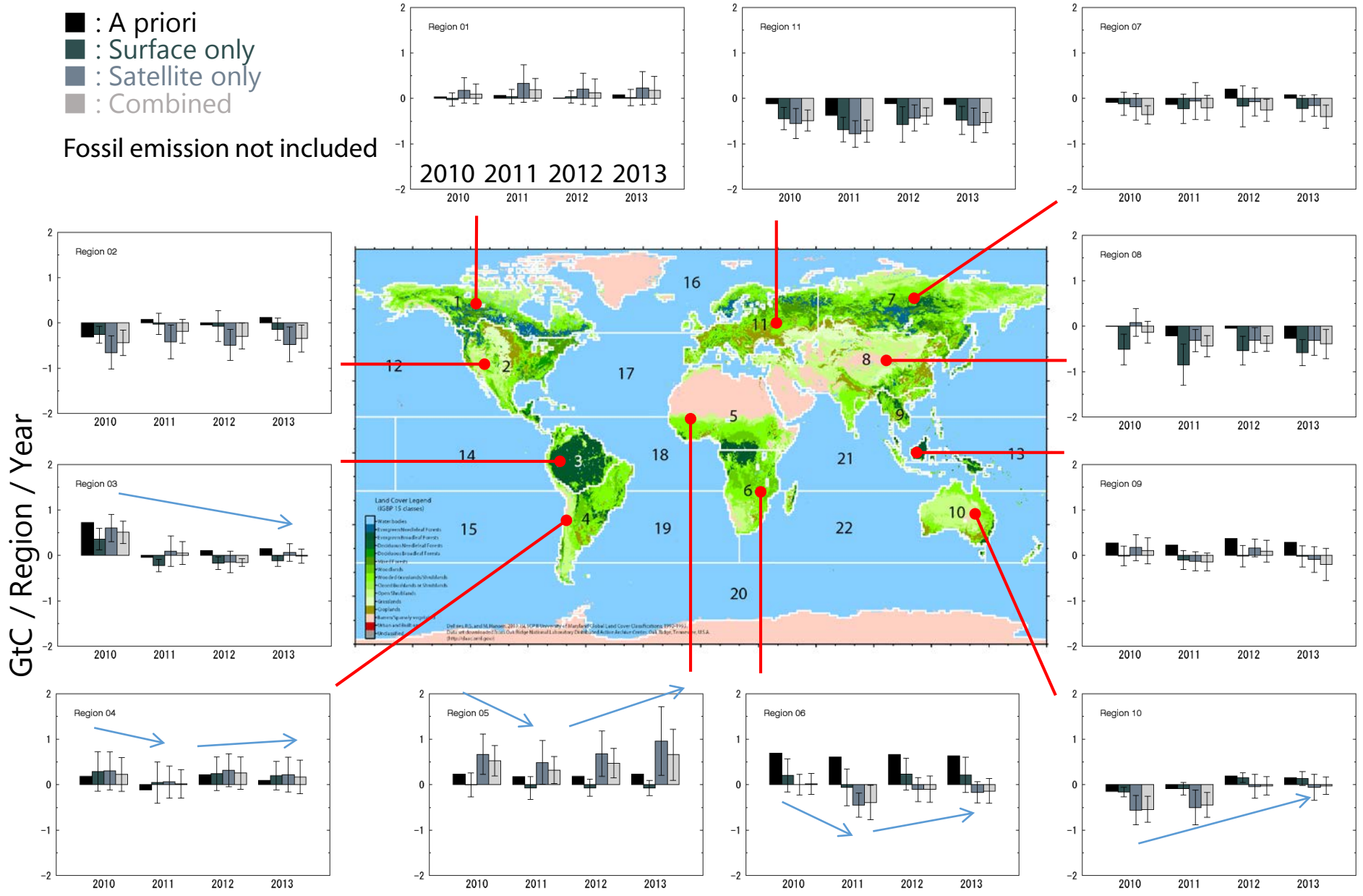


Mean of seven Phase-2 fluxes over 2010-2013

■ : A priori
■ : Surface only
■ : Satellite only
■ : Combined

Fossil emission not included

GtC / Region / Year

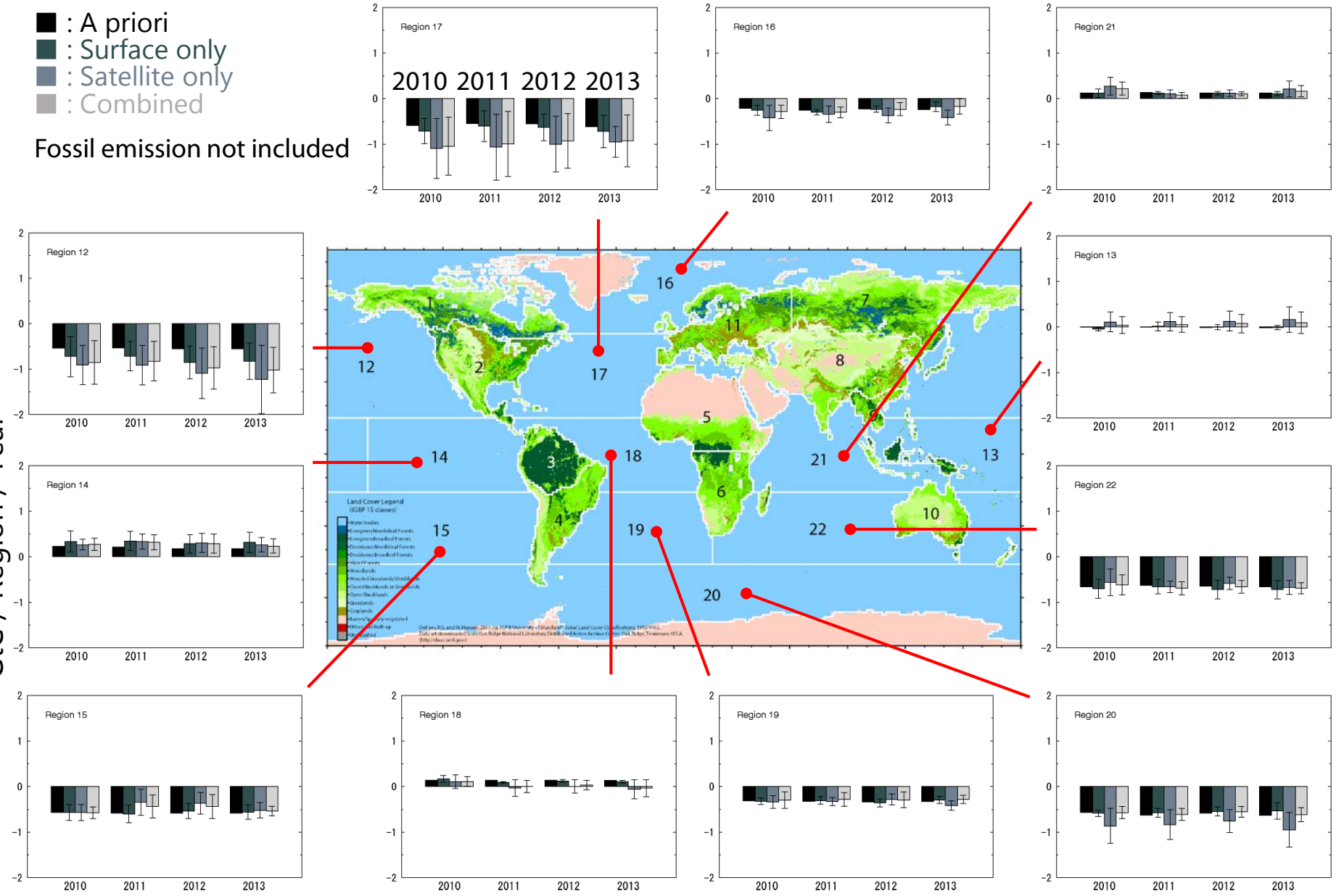


Mean of seven Phase-2 fluxes over 2010-2013 (ocean)

■ : A priori
■ : Surface only
■ : Satellite only
■ : Combined

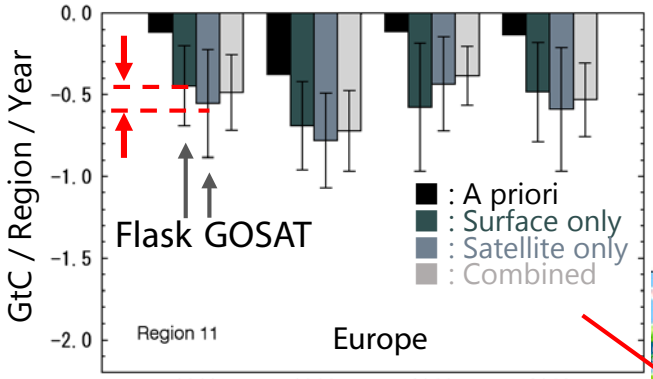
Fossil emission not included

GtC / Region / Year

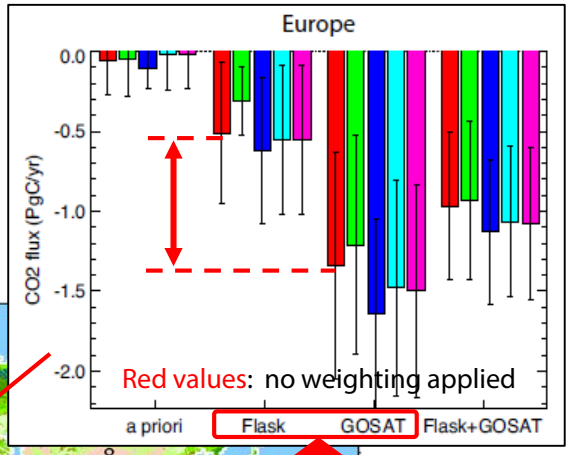


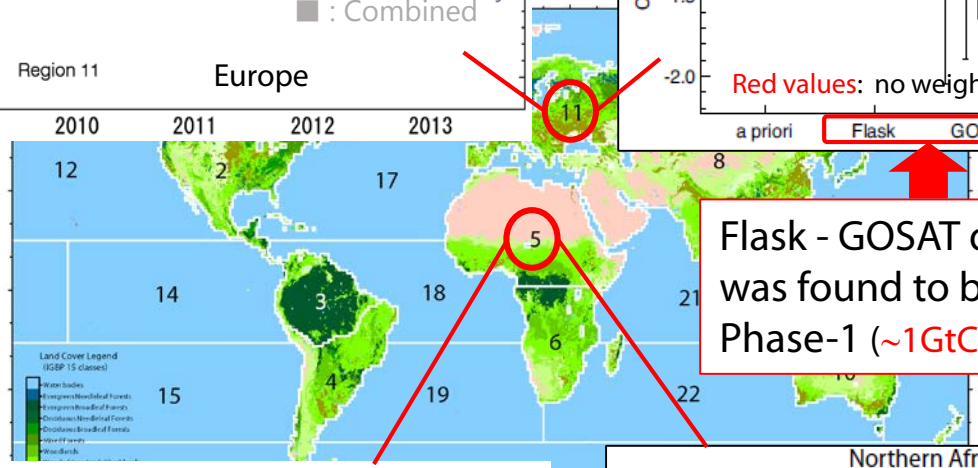
Mean of seven Phase-2 fluxes: Europe and N. Africa

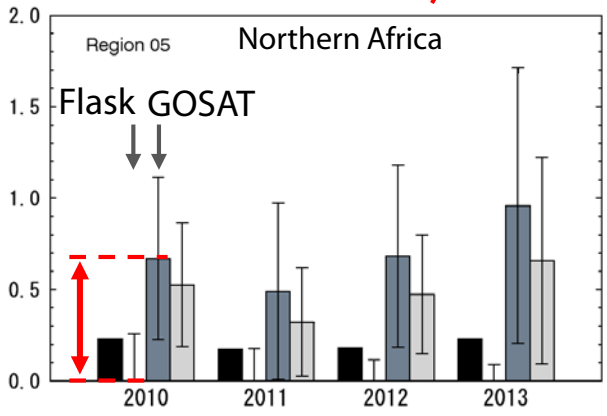
Phase-2
Multi-year

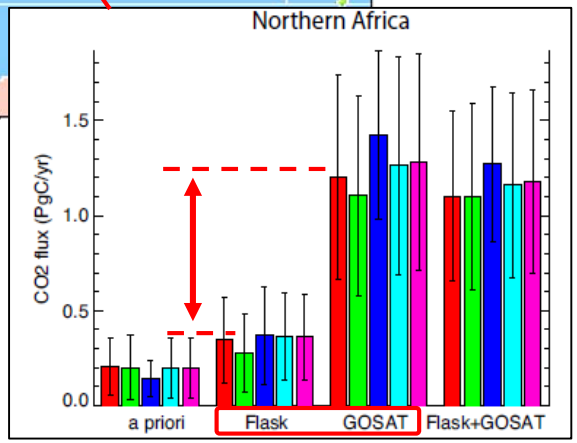


Phase-1 (1yr: Jun '09 - May '10)
(Houwelling et al., 2015 JGR)



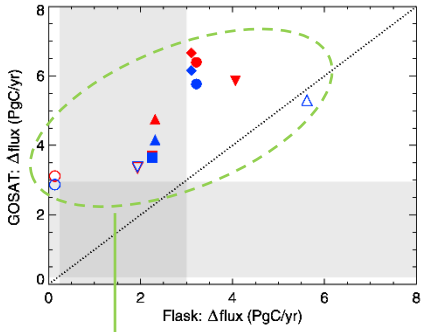




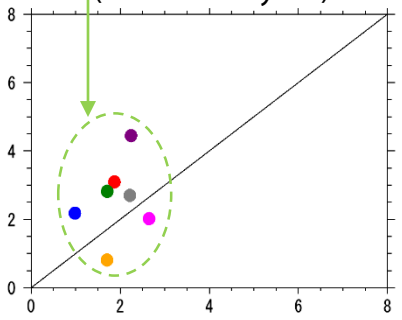


Flask - GOSAT difference was found to be large in Phase-1 (~1GtC/yr)

Phase-1
(Figure 5 *H2015 JGR*)



Phase-2
(Jun '09 - May '10)



Δ Satellite-only Flux
(Tropics – NH Extra Tropics)

Δ Surface-only Flux
(Tropics – NH Extra Tropics)

Was the Phase-1 "shift" related to Phase-1
- a priori data differences?
- X_{CO2} data differences?
- variance setting diff.?
- combination of all? etc. ?