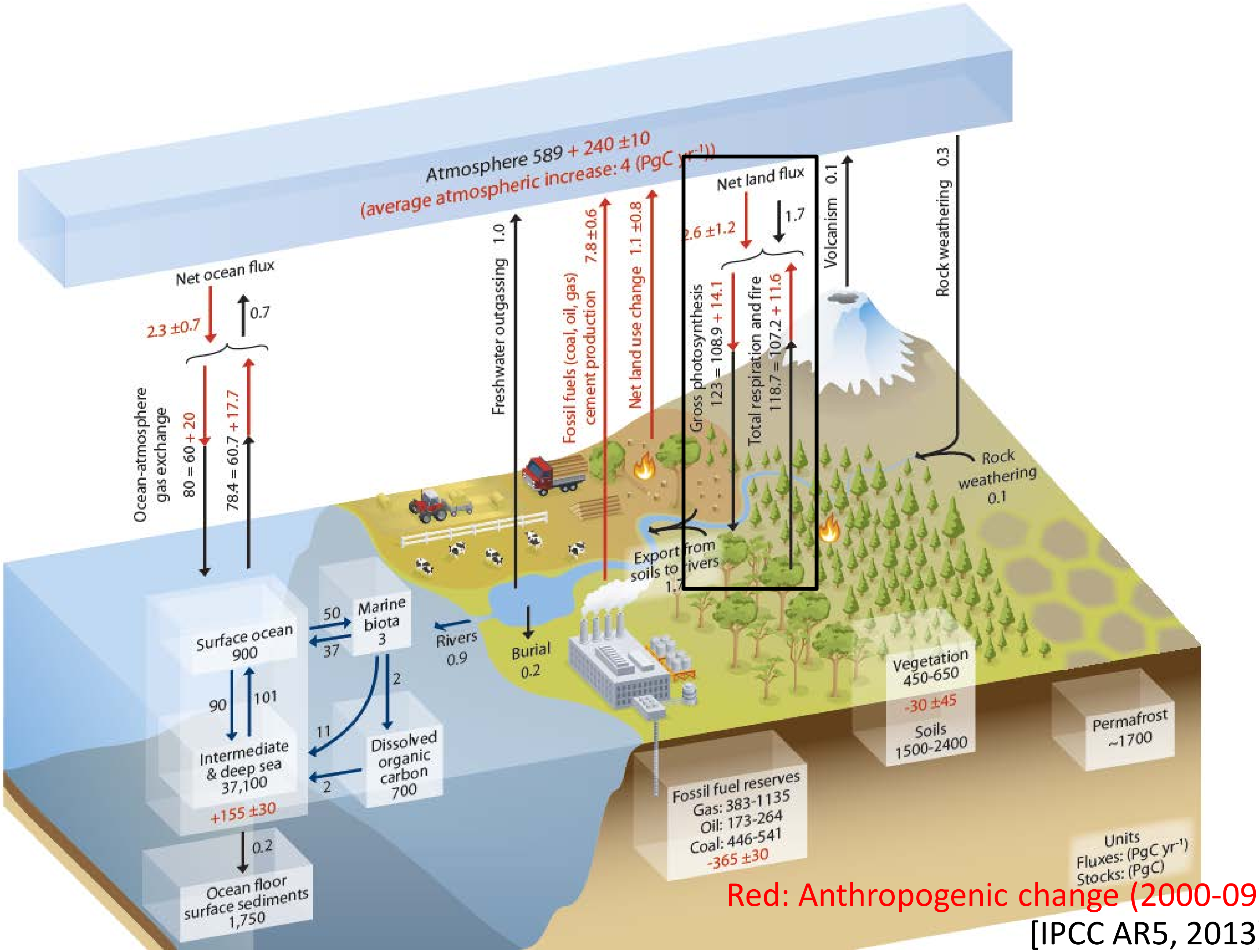
Refining terrestrial carbon flux estimation in Asia by synthesizing bottom-up and top-down estimations: Available methods and first results

Kazuhito Ichii

DEGCR Seminar 2014/09/29

Global Carbon Fluxes

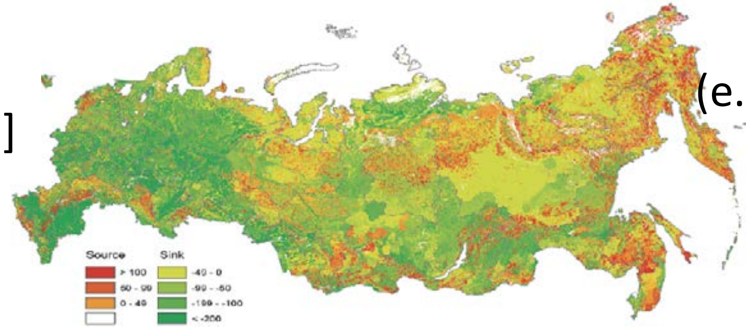


Red: Anthropogenic change (2000-09)

[IPCC AR5, 2013]

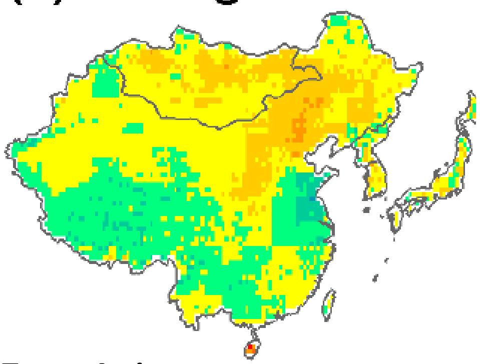
Quantify (Land) Carbon Budget in Asia using available information

Russia:
[Dolman et al. 2012]

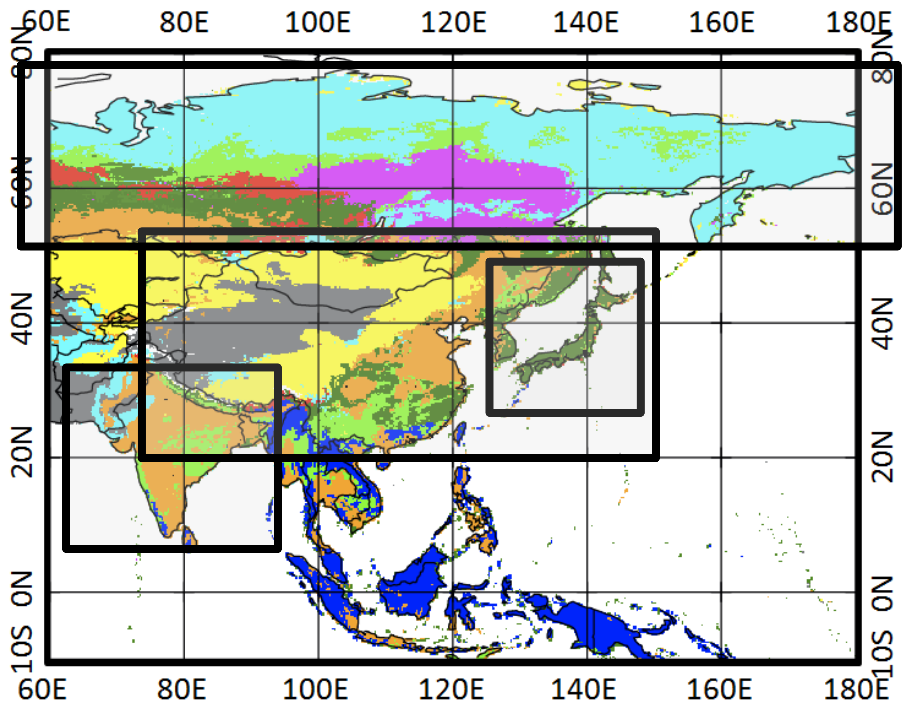


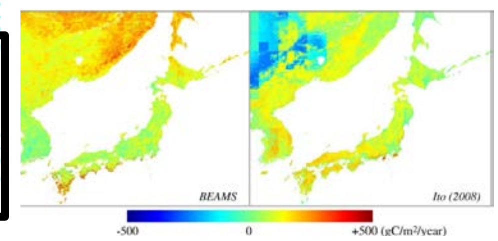
(e.g. RECCAP)

(a) Average

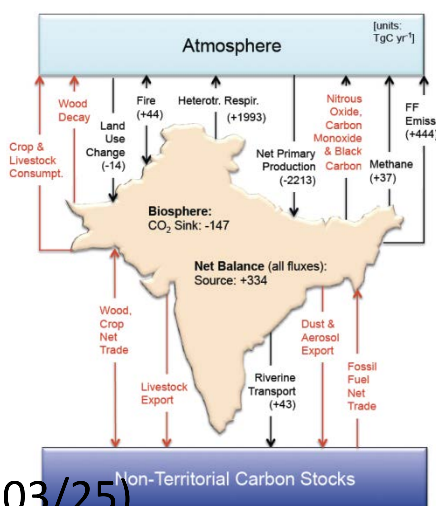


East Asia
[Piao et al., 2012]





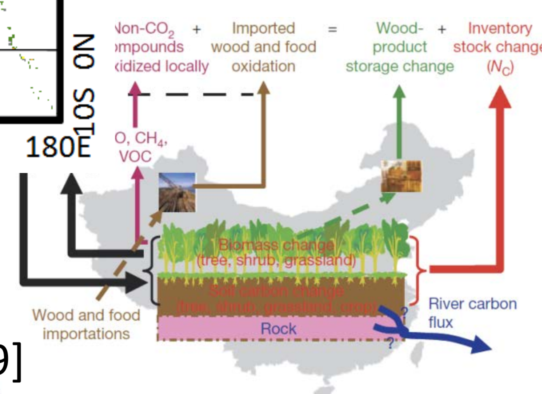
Japan:
[Ito 2008;
Ichii et al. 2010,
Sasai et al. 2011]



(03/25)

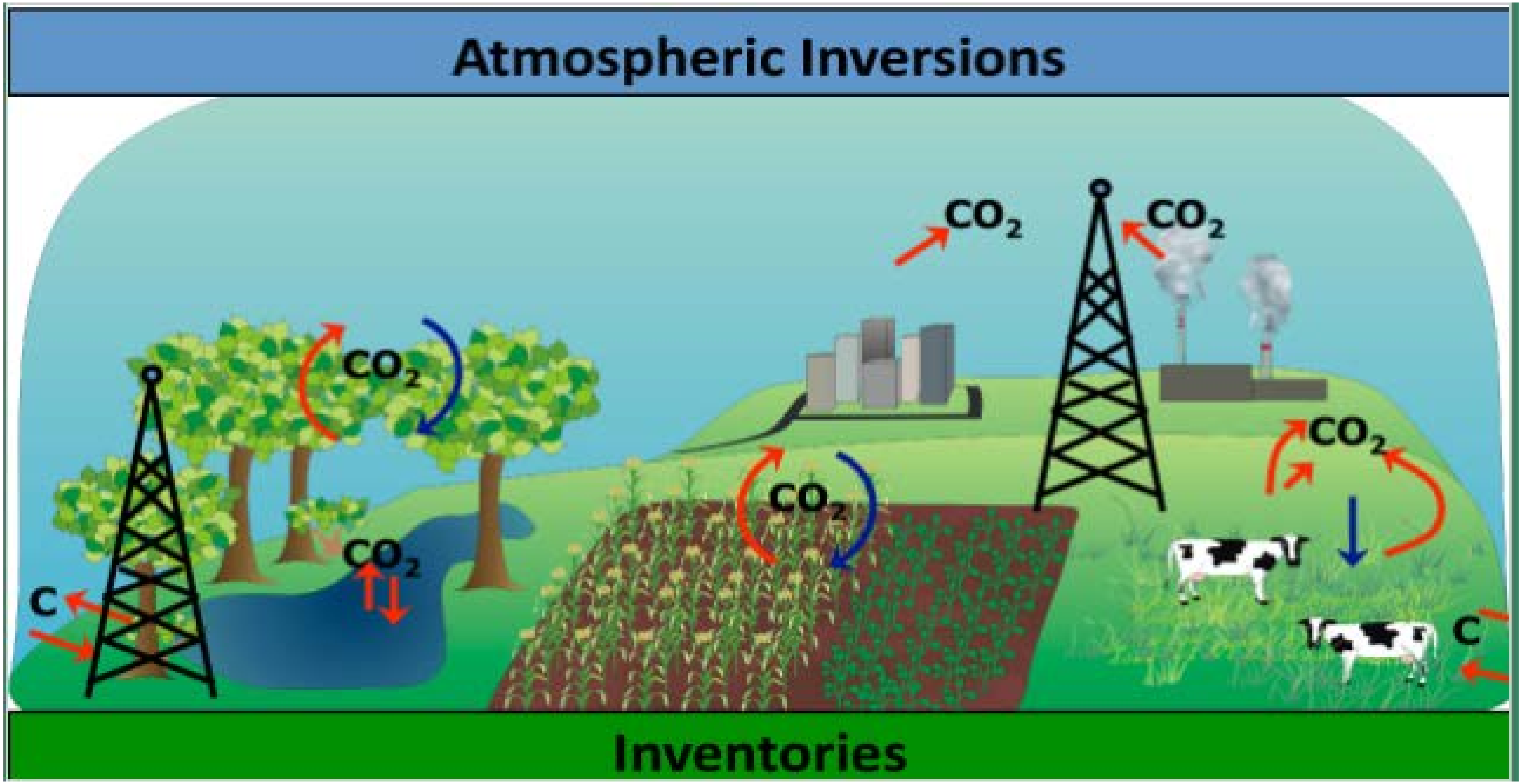
South Asia
[Patra et al., 2013]

China:
[Piao et al. 2009]



Different Approaches to Quantify Carbon Budget

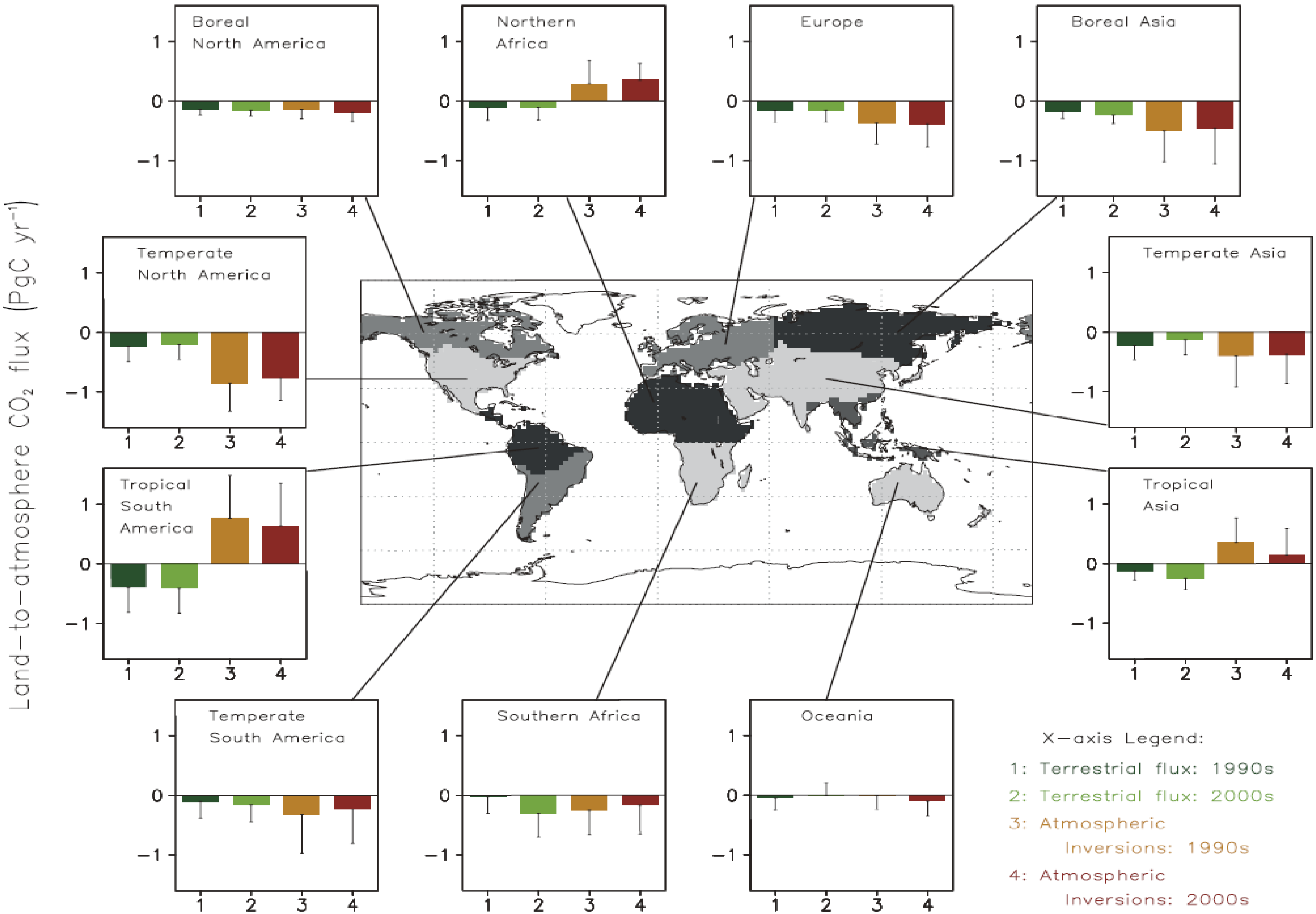
Top-down approach: Constrain "Total" --- Break-down into smaller scales



Bottom-up Approach: Constrain "Point" ---- Sum-up

Image: http://biocycle.atmos.colostate.edu

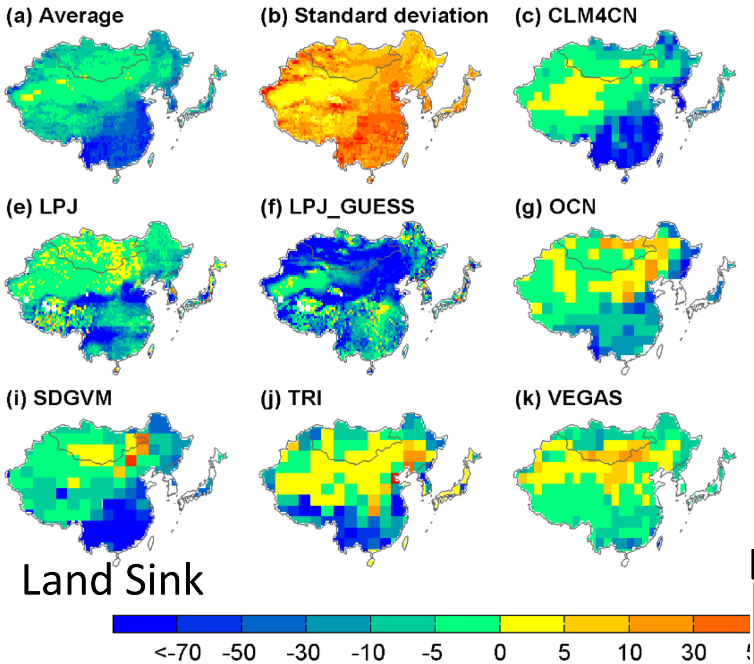
Difference of Bottom-up - Top-down Estimation



[IPCC AR5, 2013]

Large Uncertainties in bottom-up estimation

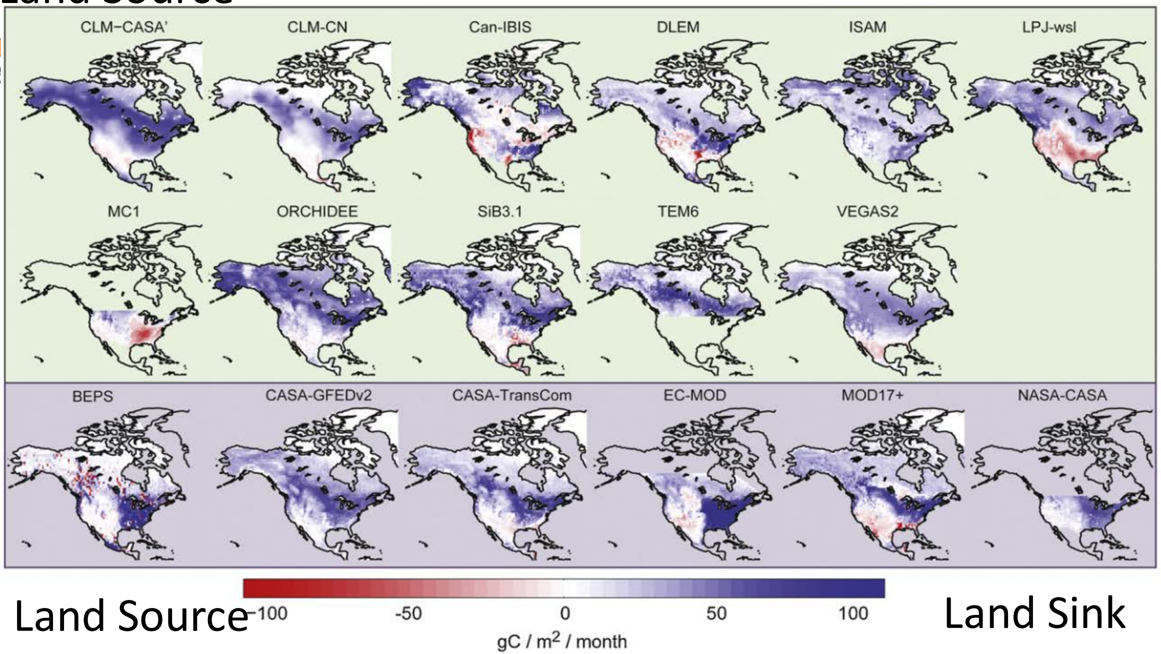
※ So far, most bottom-up estimates rely on process-based model



Net Ecosystem Carbon Balance (1990-2009) [Piao et al., 2012]

Land Sink

Land Source



Net Ecosystem Carbon Balance (**<u>JJA average</u>** from 2000-2005)

(06/25) [Huntzinger et al., 2012]

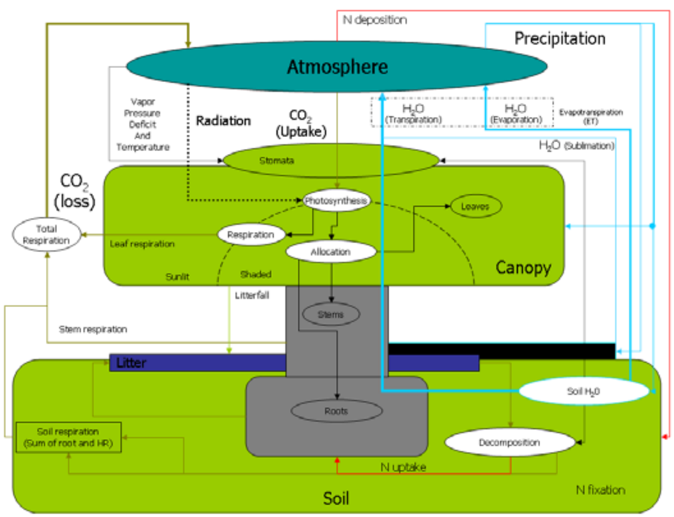
Land Source

Land Sink

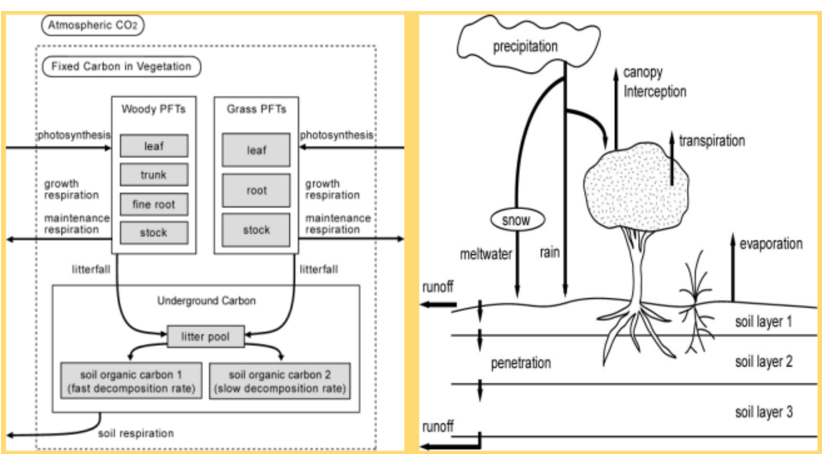
Bottom-up: New estimation

Process models

[VISIT, SEIB-DGVM, Biome-BGC etc.]



[Biome-BGC]



(07/25)

[From Sato-san's web]

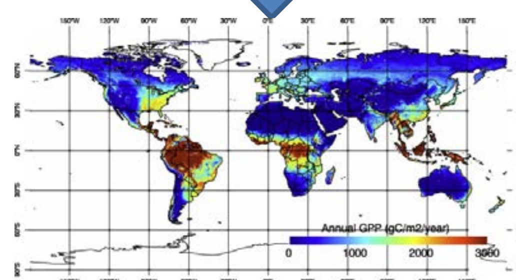
Empirical models – Newly Available

(e.g. MPI-GPP)

Input: RS Data
(e.g. VI, LST, Srad)

Obs: C-Flux
(e.g. FLUXNET)

Regression Model



Objectives

Evaluate terrestrial carbon fluxes in Asia (+global) using available data and models

Contents

- Bottom-up (Empirical upscaling)

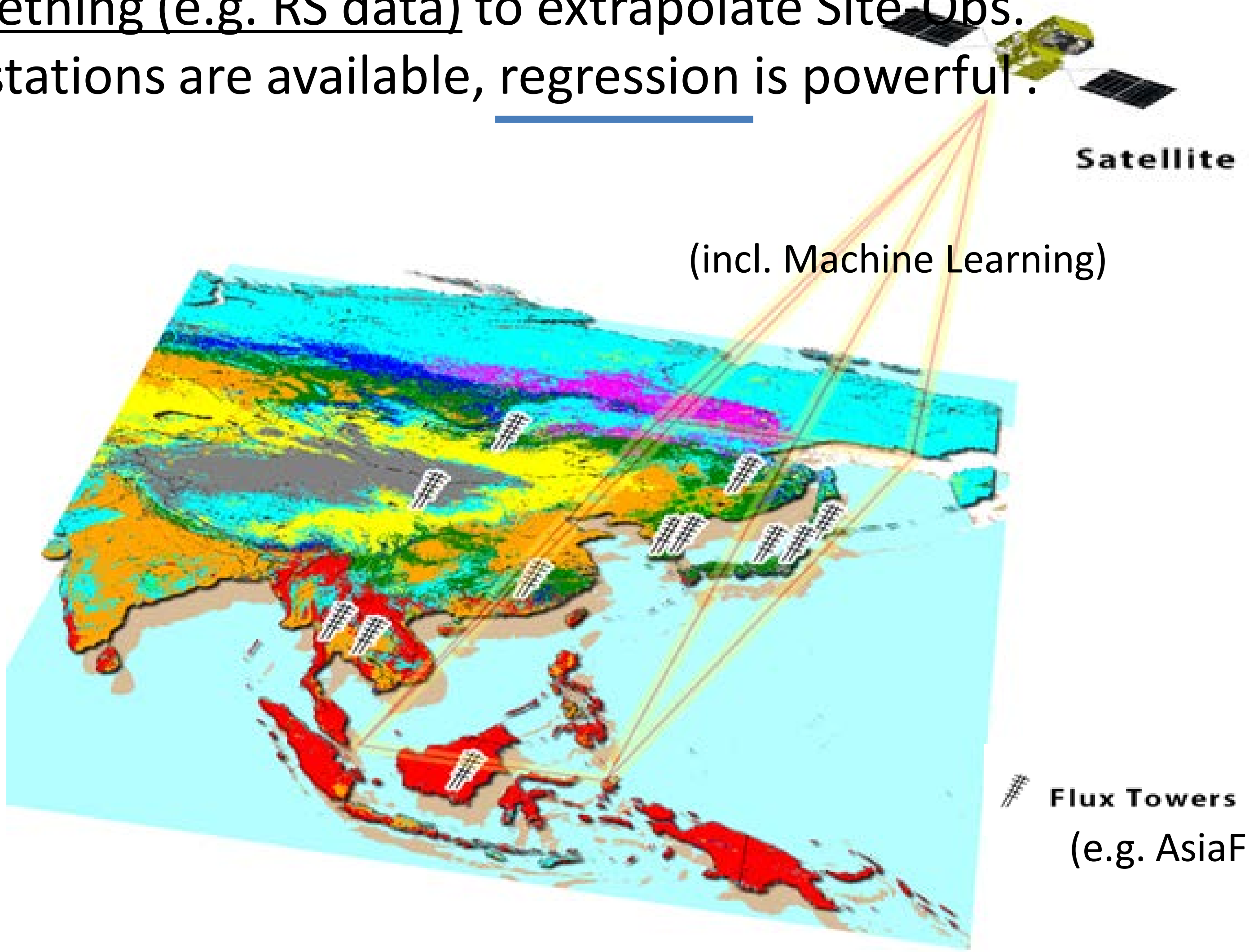
- Comparison with Top-down (GOSAT L4A)

-Bottom-up; FLUXCOM overview (international effort)

Upscaling: From SiteObs to Spatial Estimation

- Site-Obs: impossible to cover everywhere
- Use something (e.g. RS data) to extrapolate Site-Obs.
- If many stations are available, regression is powerful .

(incl. Machine Learning)



(e.g. AsiaFlux)

(e.g. Papale et al. 2003; Yang et al., 2006; Jung et al., 2009; Xiao et al., 2010)

(our approach)

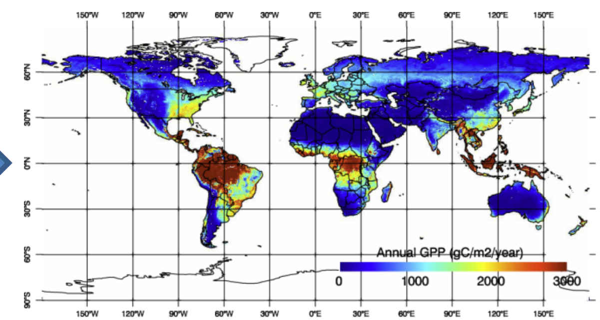
Empirical Upscaling using FLUXNET (incl. AsiaFlux)

Input: RS Data
(VI, LST, Srad)

Obs: C-Flux
(e.g. FLUXNET)

Advantage :
①Observation-based outputs
②Independent from model (if use only RS)

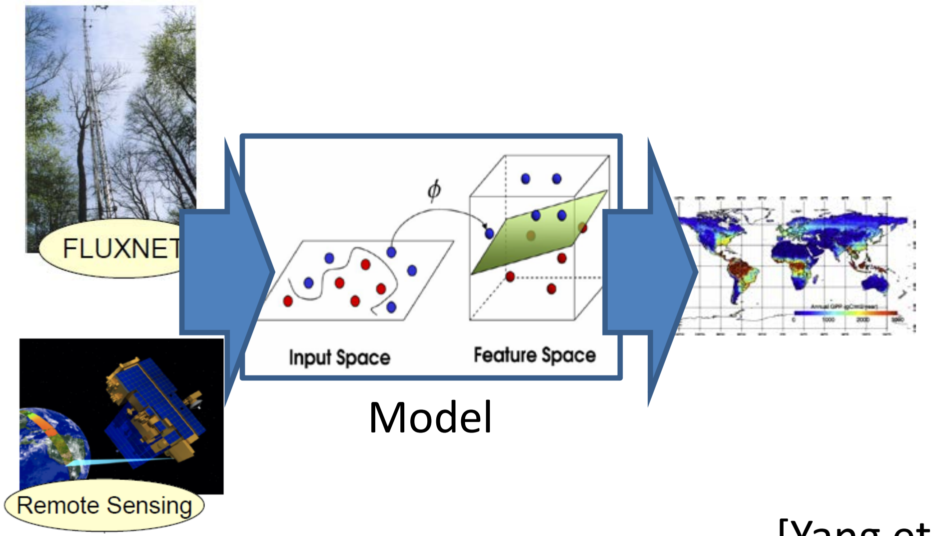
Establish
Empirical Model
(e.g. Regression, Machine Learning)



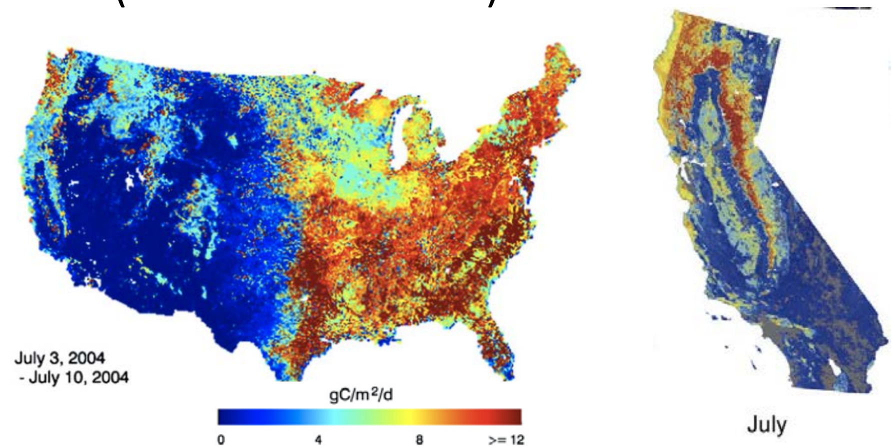
Interpolation/Extrapolation
(e.g. Spatial C flux outputs)

Methods (Different ML algorithms)	
Neural Network	[Papale et al. 2003]
Support Vector Regression (SVR)	[Yang et al., 2006; 2007]
Model Tree Ensemble	[Jung et al., 2009; 2010]
Regression Tree	[Xiao et al. 2008; 2010]

Example: Support Vector Regression

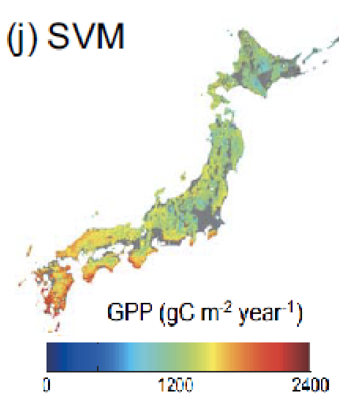


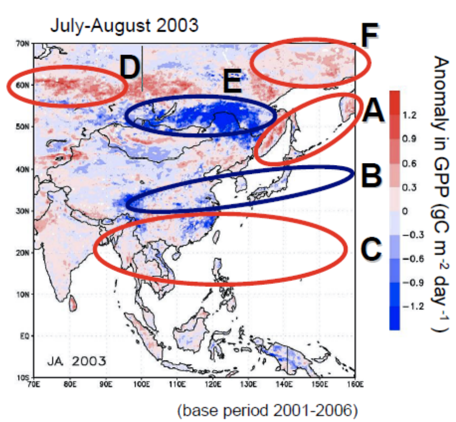
US (Seasonal Variation)



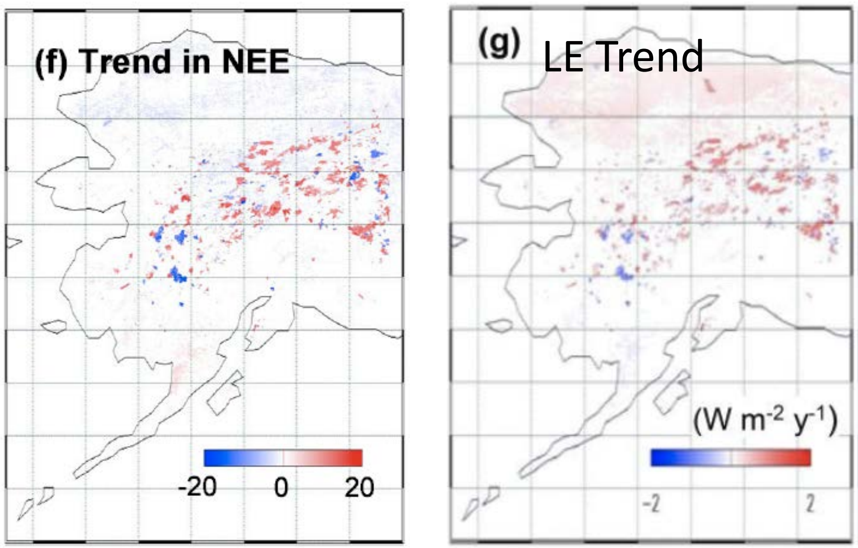
[Yang et al. 2006 TGARS, 2007 RSE; Ichii et al. 2009 AFM]

Asia (Interannual Variation; Anomaly)





Alaska (Trend – 10 Year)

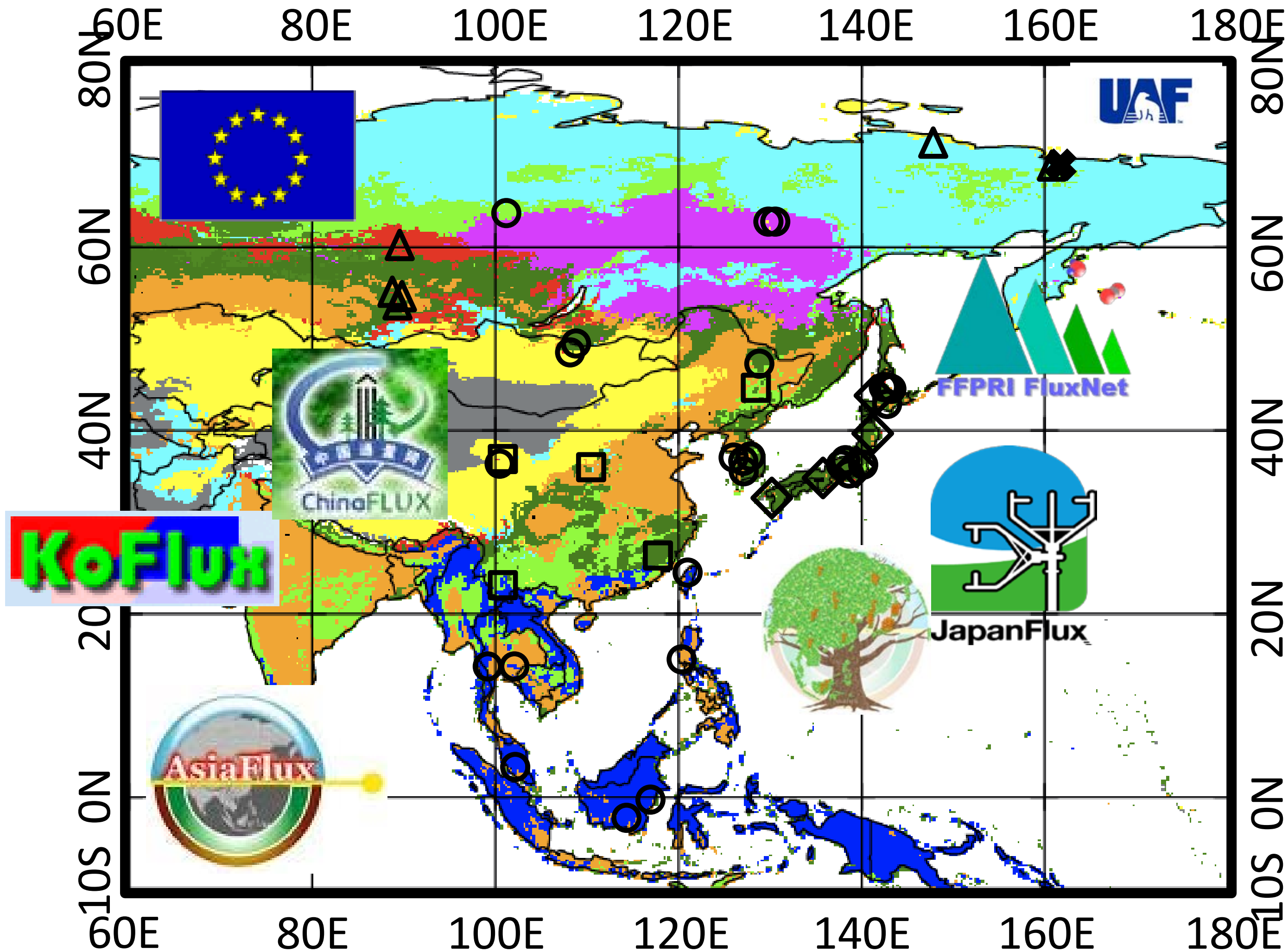


[Ichii et al. 2010 BG; Saigusa et al. 2010 BG] [2000-2011] [Ueyama et al. 2013; 2014; JGR]

Asia Upscaling: Eddy-covariance network in Asia

Dataset created for Asia-MIP project (44 sites)

Consistent Processing (QA, gapfill, flux-partitioning)



○ AsiaFlux (26)　□ CarboEastAsia (5)　✖ AON (1)

◇ FFPRI (6)　△ European DB (6)

(12/25)

Input Variable Selection

SRAD	JAXA Product	(Frouin and Murakami, 2007)
LST	(Average of daytime, nighttime LST)	(MOD11A2)
Land Cover		(MCD12Q1)
Vegetation Index	(one of NDVI, EVI,LAI, FPAR, GR)	（GR=G/(R+G+B))

Split observed data into train, test (+generalization)

Training – Establish Model

YR 2000-2004

Test – Test an Established Model

YR 2005-

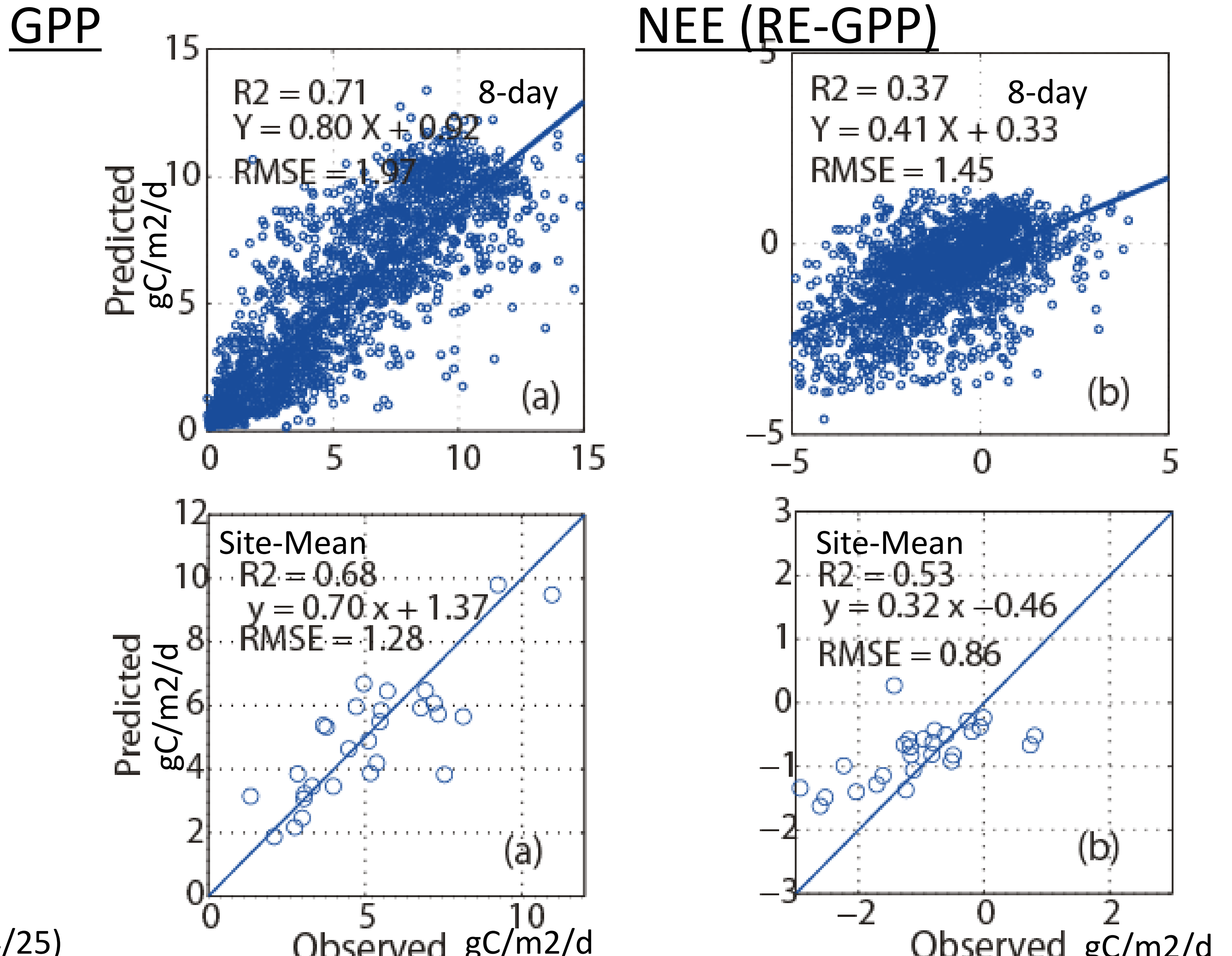
Test Spatial Extrapolation Capability (7 sites)

YR 2005-

Site Data unused as training data set

(Sites, covering only 2005- period)

Model Evaluation (ALL TEST DATA)



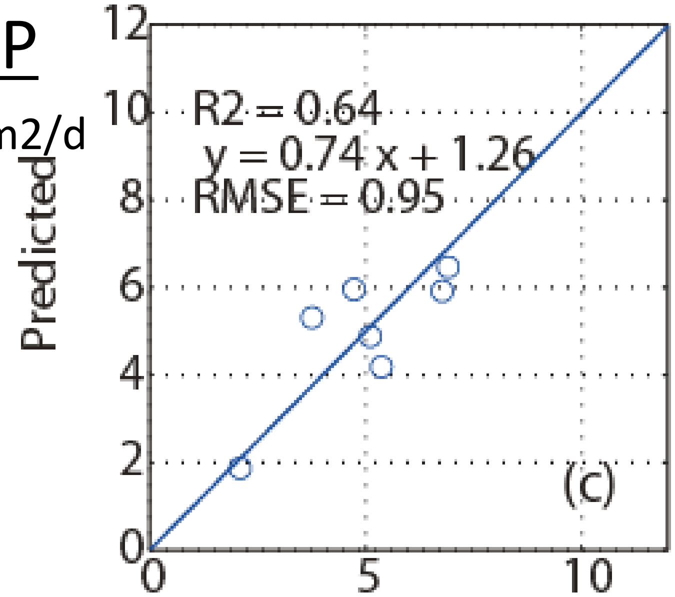
Model Evaluation (TEST-only sites)

Test Spatial Extrapolation Capability

Site-by-Site
(Mean)

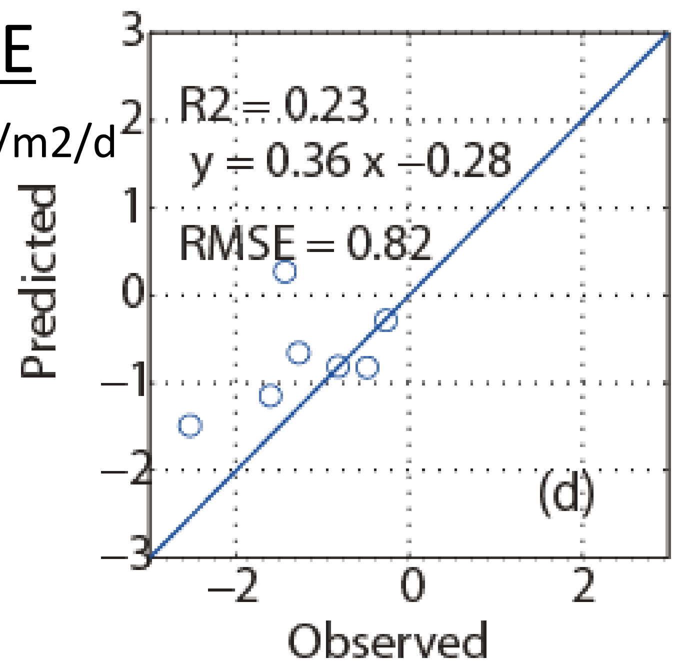
GPP

gC/m2/d

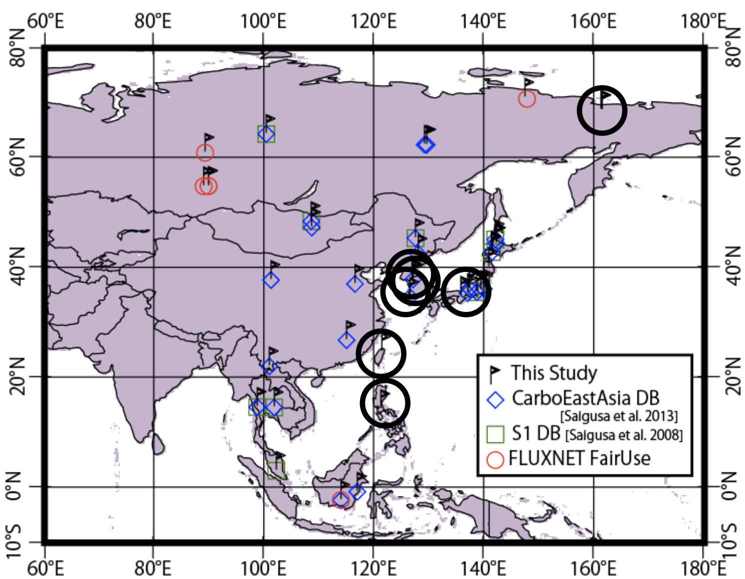


NEE

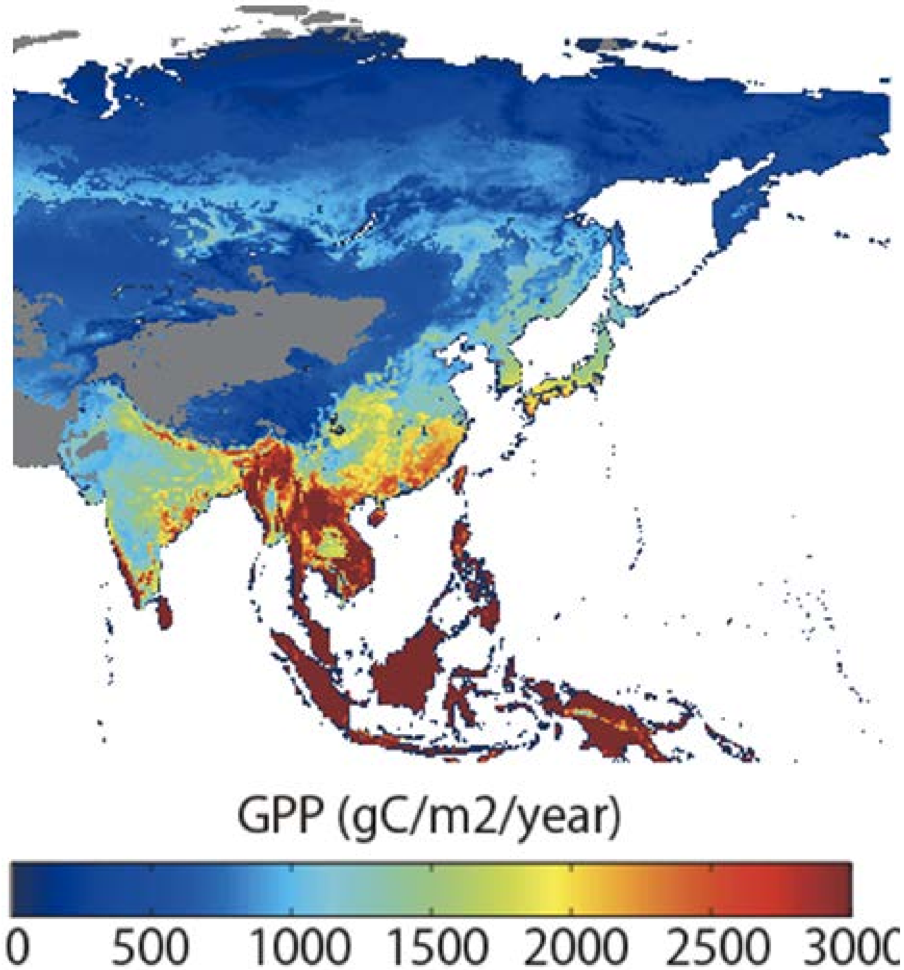
gC/m2/d

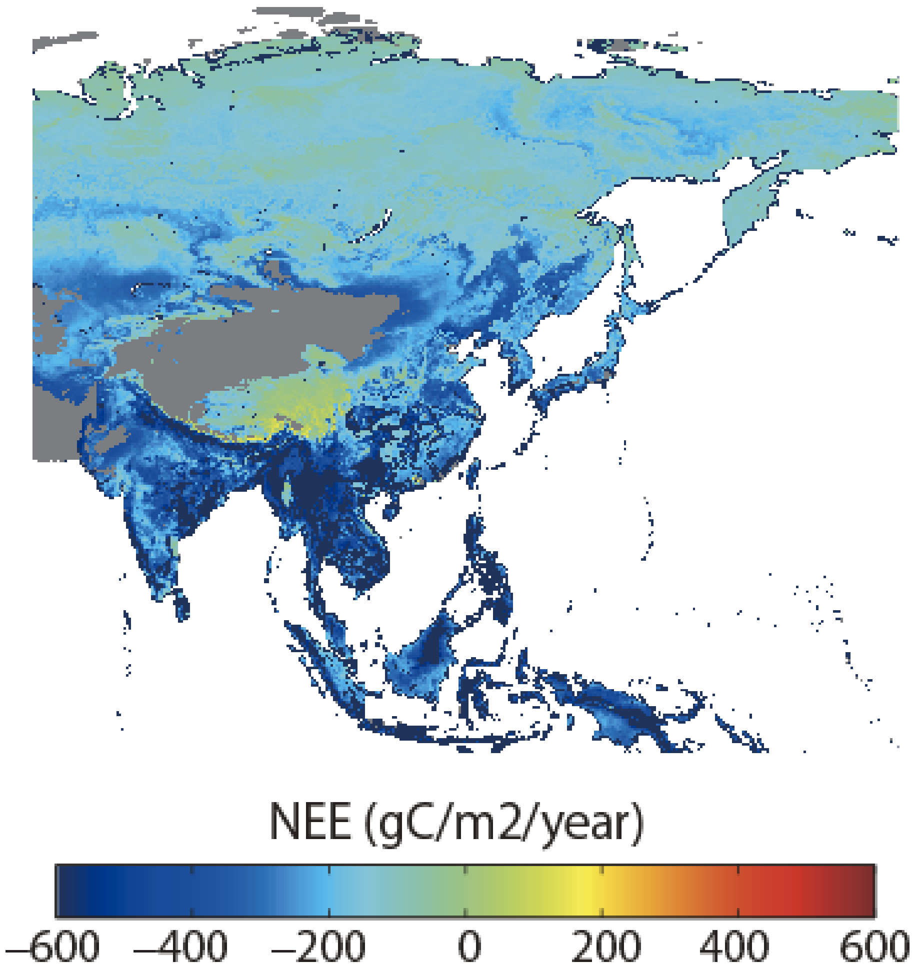


TEST-only sites (Obs: 2005- only)



Data-Driven Carbon Flux in Asia



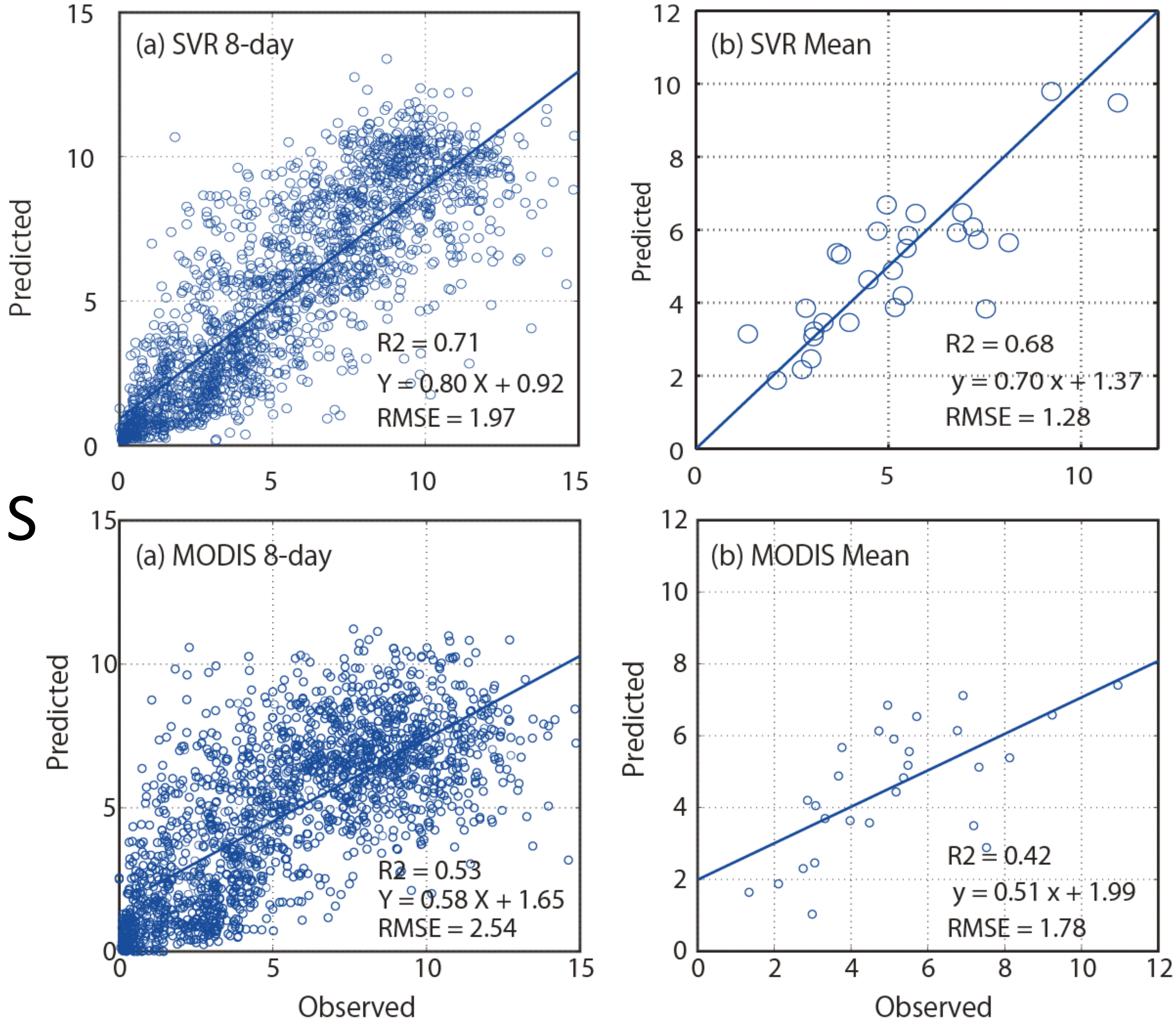


(2001-2011 Average)

SVR GPP: Better than MODIS-GPP

○SVR

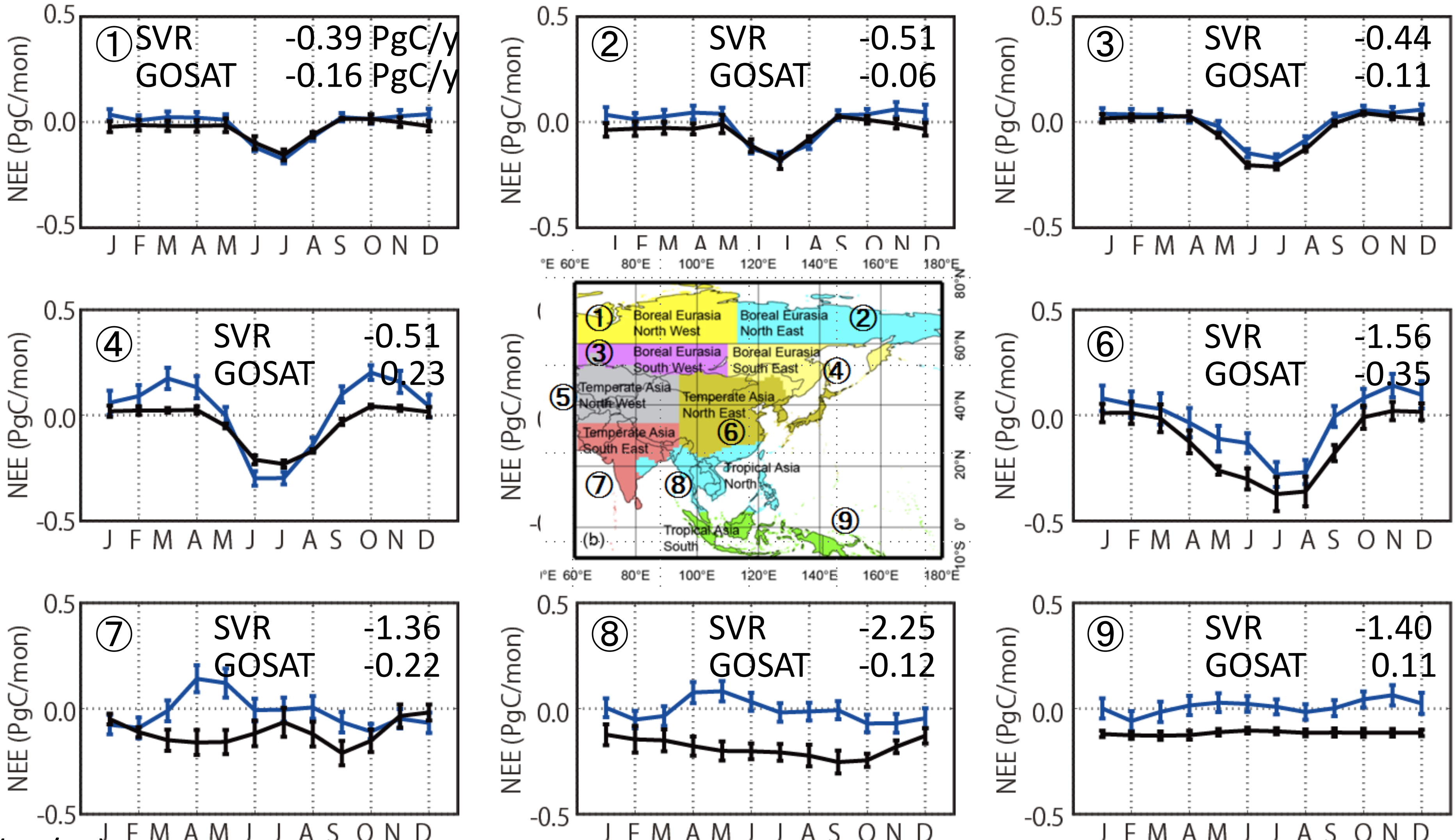
△MODIS



SVR NEE vs GOSAT L4A: Larger Sink in SVR

GOSAT L4A: Top-down estimation (V02.02 – Latest)

GOSAT CO_2, Ground CO_2 + Inverse model



AsiaSVR: Summary

1. Empirically Upscaled Estimation of Terrestrial C Fluxes in Asia

    SVR using 44 eddy-covariance sites (AsiaFlux etc.)

    GPP OK

    NEE Less accurate than GPP

    13 Years, 0.25 Deg, 8-day Product

2. Initial comparison (evaluation) with other products

    - GPP (photosynthesis) flux

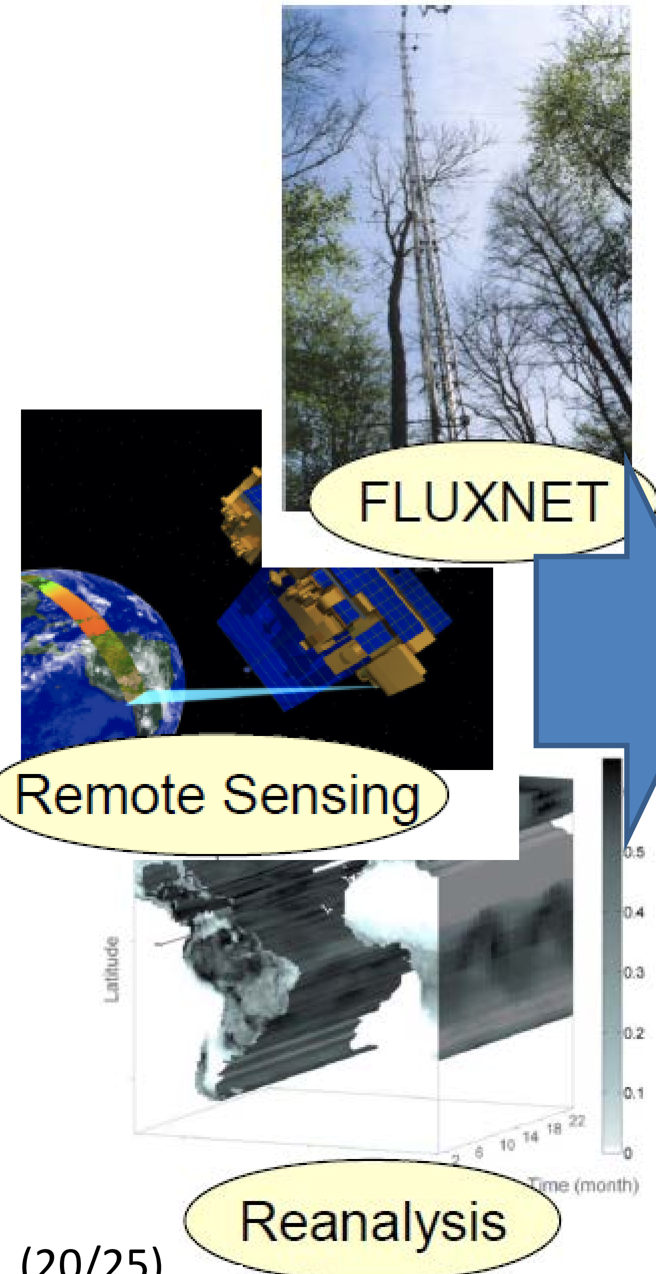
        Better than MODIS GPP product

    - NEE (net; GPP-RE) flux

        Similar seasonal variation with GOSAT L4A over mid and high latitudes

        Large Differences in tropical region.

FLUXCOM: Comparison among empirical upscaling



FluxCom

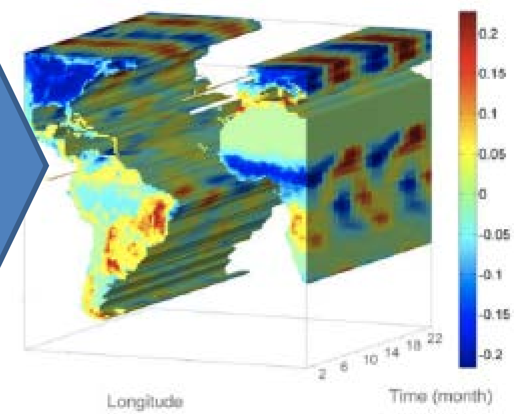
Empirical Models
(Machine Learning)

- ANN
- MTE
- SVR (K. Ichii)
- Regression

etc…

About 10 models

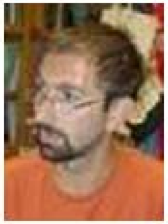
OUTPUT



Energy, Water, Carbon
Fluxes from 2001-2012
Global, 10KM, 8-day

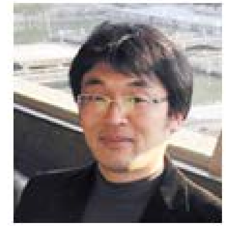
Main Purpose: Provide ensemble Estimation by data-driven approach

FLUXCOM: Empirical Ensemble Estimates of Energy, Water, Carbn Fluxes

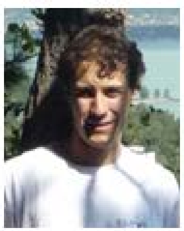

D. Papale


M. Reichstein

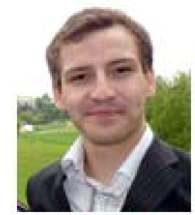

M. Jung

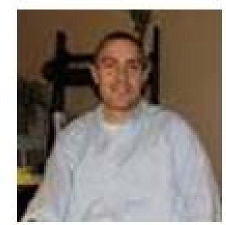

K. Ichii

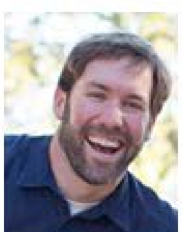

G. Camps-Valls

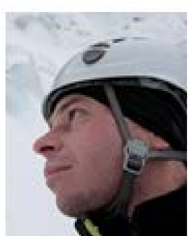

G. Tramontana

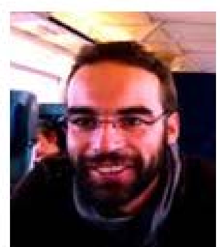
FluxCom


S. Sickert


C. Schwalm


T. Hilton

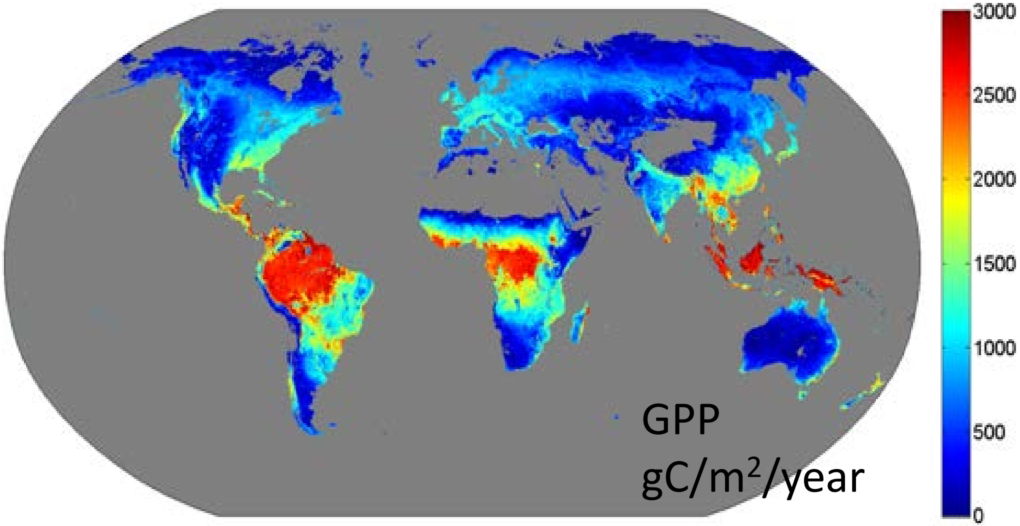

E. Tomelleri


N. Carvalhais

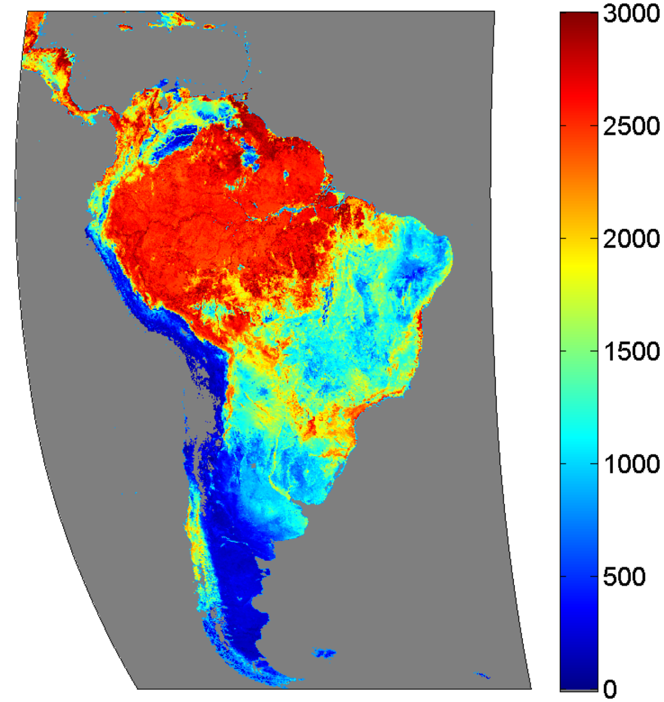

A. Bloom

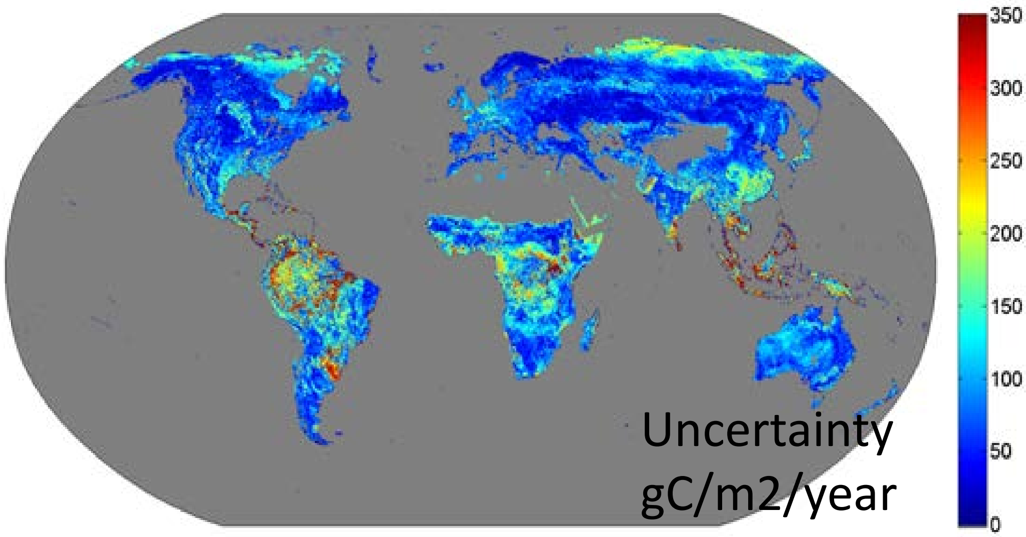

T. Keenan

Ensemble products are almost ready



Year 2001-2012 (8-Day)
～10km resolution

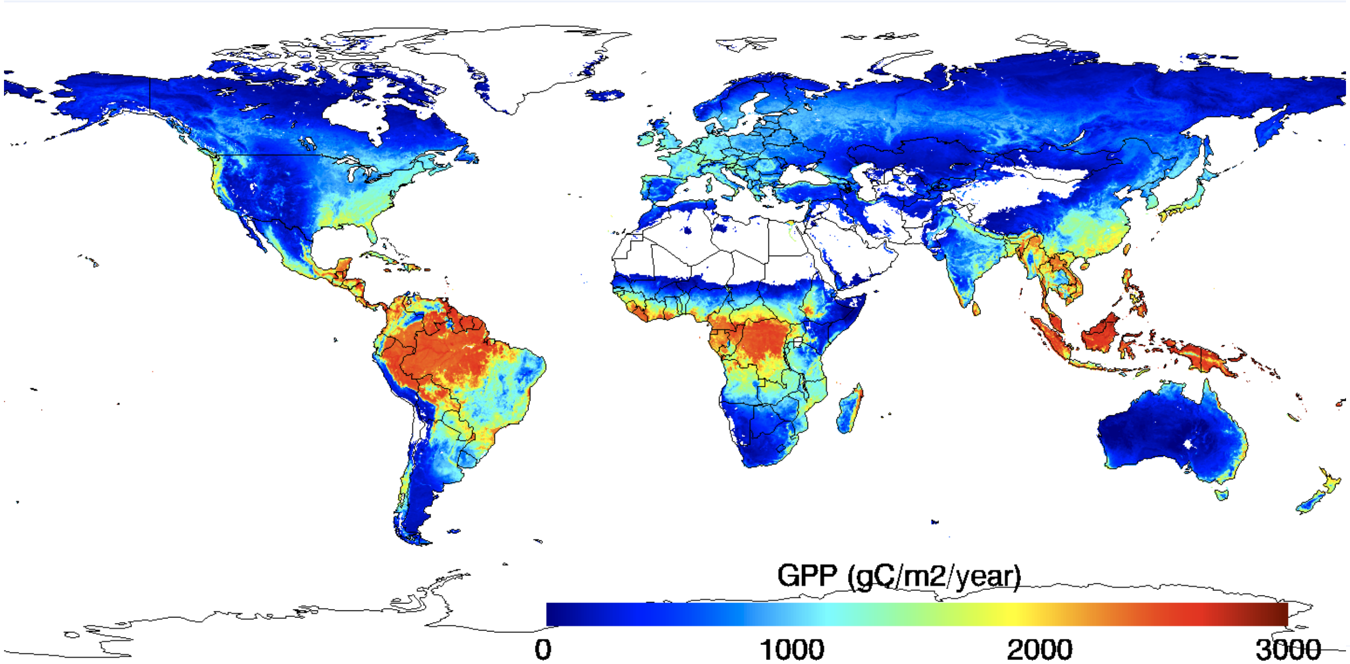




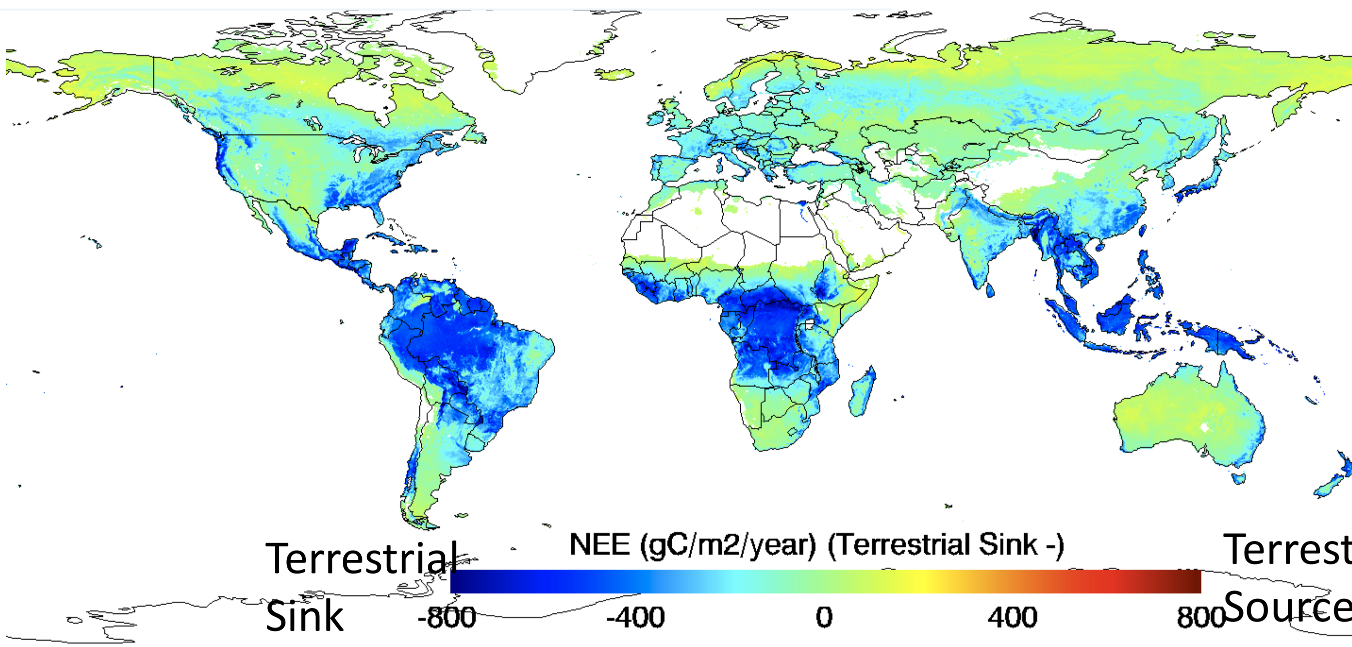
Call for Research Proposal

— Closed (now)
— Open (near future)

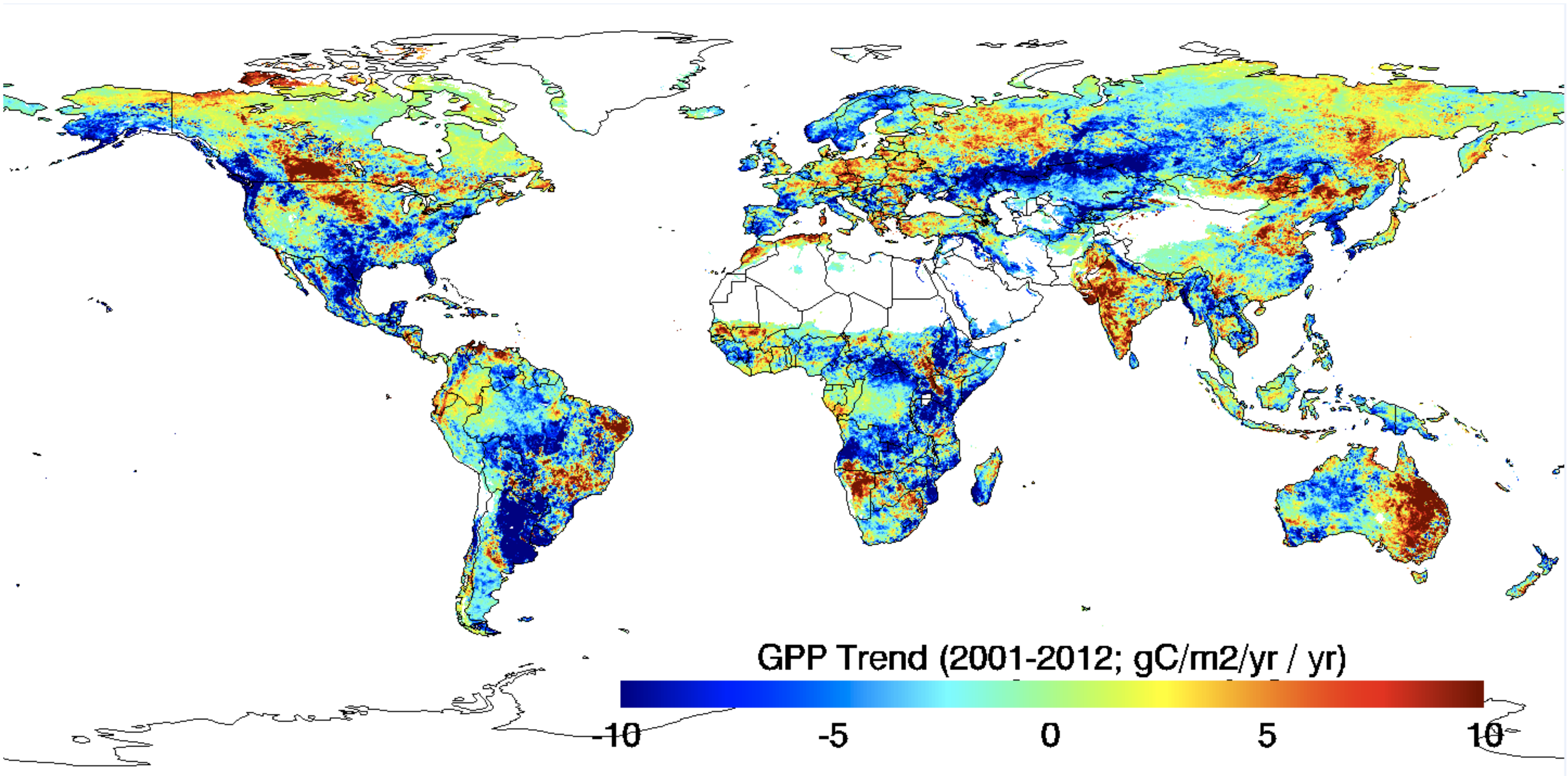
GPP, NEE (RE-GPP) Distribution



[Global ～110PgC/yr]



Preliminary Analysis: GPP Trend from 2001-2012



- Decreasing in many semi-arid regions?
- Need cross-check with other estimation (RS-data, models)

Summary

1. Empirically Upscaled Estimation of Terrestrial C Fluxes in Asia
   - SVR using 44 eddy-covariance sites (AsiaFlux etc.)
   - 13 Years, 0.25 Deg, 8-day Product
   - (Other region; e.g. Alaska 2000-2011)

2. FLUXCOM – Intercomparison of empirical estimation of carbon
   - Initial product ready
   - Ensemble of about 10 models
   - Currently, Initial analysis is on going.

3. Future Plan
   - Application: Constrain Model
   - Analyze interannual variation, decadal trend
   - Benchmark data for model intercomparison (Asia-MIP)
   - Synthesis Top-down and Bottom-up to re-evaluate carbon fluxes

Supplement Slide

Empirically upscaled estimation of NEE is reasonable

NEE (= GPP – RE) = ∼13-20 PgC/year?

Table 2. Synthesis of Global Carbon Balance Component Fluxes and Inferred Flux of Mean Annual Global Terrestrial Ecosystem Respiration

Carbon Balance Component Flux	Values (Pg C yr^{-1})	Method	Reference
Gross Primary Production (GPP)	123 ± 8	Data-oriented models using FLUXNET	*Beer et al.* [2010]
Net Biome Production (NBP)	2.6 ± 1	Atmospheric inversions	*Denman et al.* [2007]
Fire emissions (F)	1.7–2.5	Diagnostic and process models	*Thonicke et al.* [2010]
Land use change emissions (LUC)	1.5	Inventories	*Houghton* [2008]
Crop Harvest (CH)	6–9	Process model	*Bondeau et al.* [2007]
Dissolved organic and inorganic carbon (DC)	2.9	Inventories	*Tranvik et al.* [2009]
Volatile organic compounds (VOC)	1.2	Empirical model	*Guenther et al.* [1995]
Terrestrial ecosystem respiration (TER)	~100–110	residual	

[Jung et al. 2011]

Asia-MIP Objectives

Make effective use of various observation (site-obs, RS-obs),

1. Test models with observation data to characterize models.
   - Covering tropical – arctic regions in Asia

2. Find common problems in current ecosystem models
   - Causes of uncertainties in modeled CO_2/H_2O budget
   - Do model improvement

3. Estimate Carbon/Water budget in Asia by ensemble experiment
   - Provide budget with uncertainties
   - Updated analysis with region-specific data

4. Identify key processes to drive CO_2/H_2O cycle in Asia
   - Interannual and decadal variations

Experiment: Asia-MIP

Site-Level Experiment

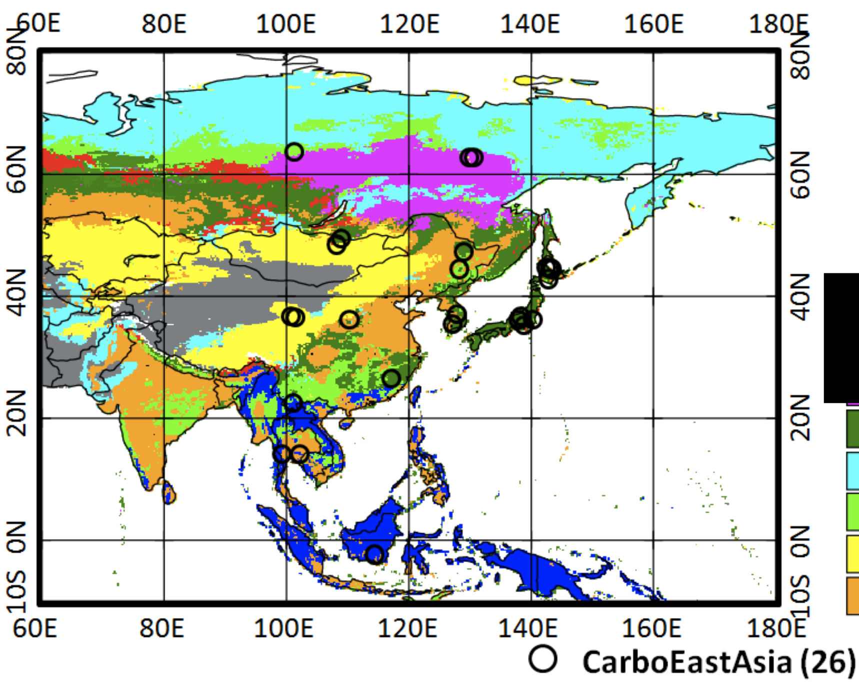
Updated 44 Sites (AsiaFlux + others)

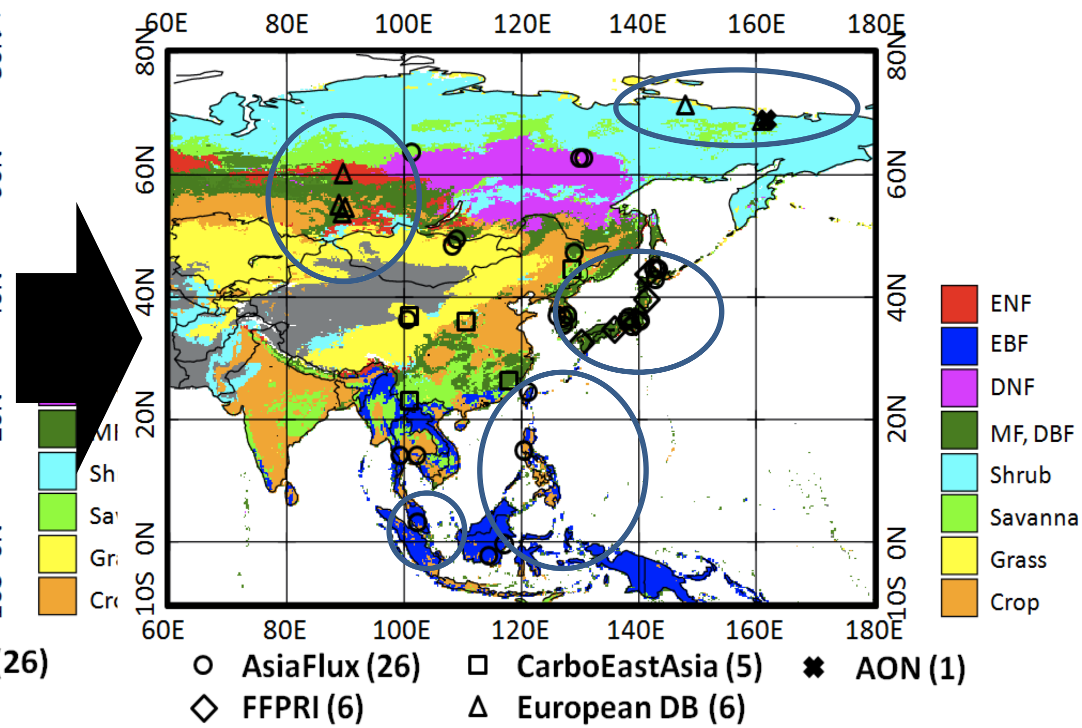
Driver (Climate, RS)　　1901-2011(2012)

Spatial Experiment

Driver (Climate, RS)　　1901-2011

RS data　　NOAA/AVHRR, Terra,Aqua/MODIS



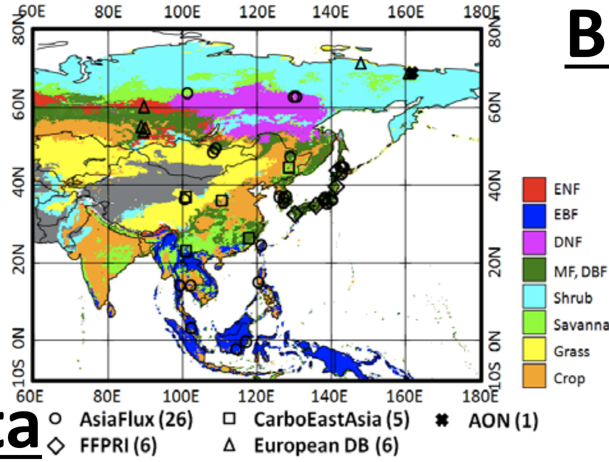


[Saigusa et al. 2013]

Materials

Site-Obs

44 Sites:
AsiaFlux + Other network sites



Climate-data

Model, Method
Temperature, CRUNCEP-type
Precipitation, CRUNCEP-type
Radiation, MTCLIM + JAXA-RAD (RS-based)
VPD, MTCLIM

[Ichii et al., 2013; RS]

RS data

Model, Method
NOAA/AVHRR LAI/FPAR3g [Zhu et al. 2013]
Terra/MODIS products
Phenology [Kobayashi]
Biomass etc.

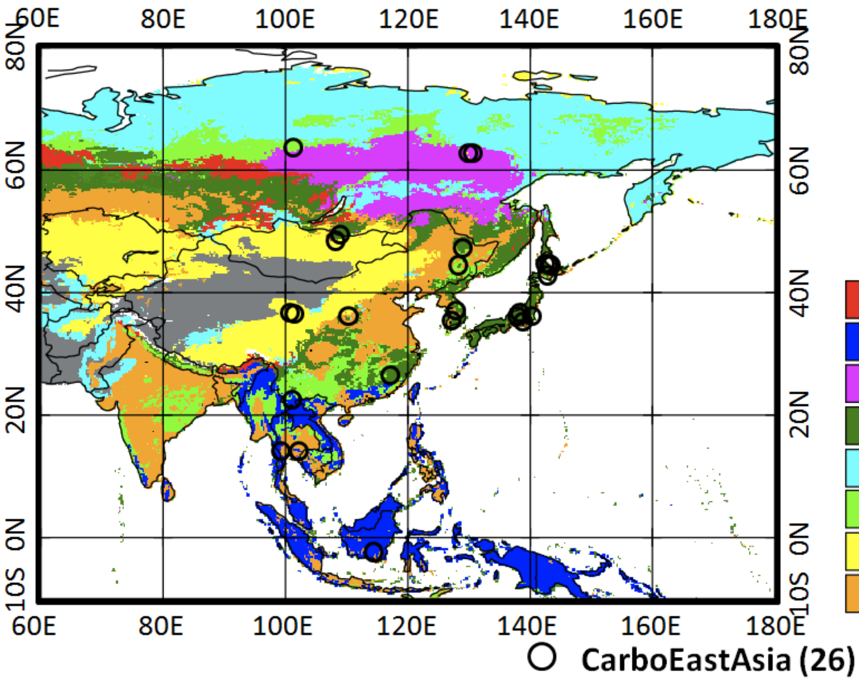
Bottom-up models

Category	Model
Empirical model	SVR
Diagnostic model	BEAMS
	BESS
	CASA
Prognostic model	Biome-BGC
	CLM-CN
	VISIT
DGVM	LPJ
	SEIB-DGVM
	TRIFFID

Top-down models

Model, Method
CarbonTracker
CarbonTracker Asia
Jena-Inversion
Other TRANSCOM models

Preliminary Analysis: CarboEastAsia-MIP



[Flux-data; Saigusa et al., 2013]

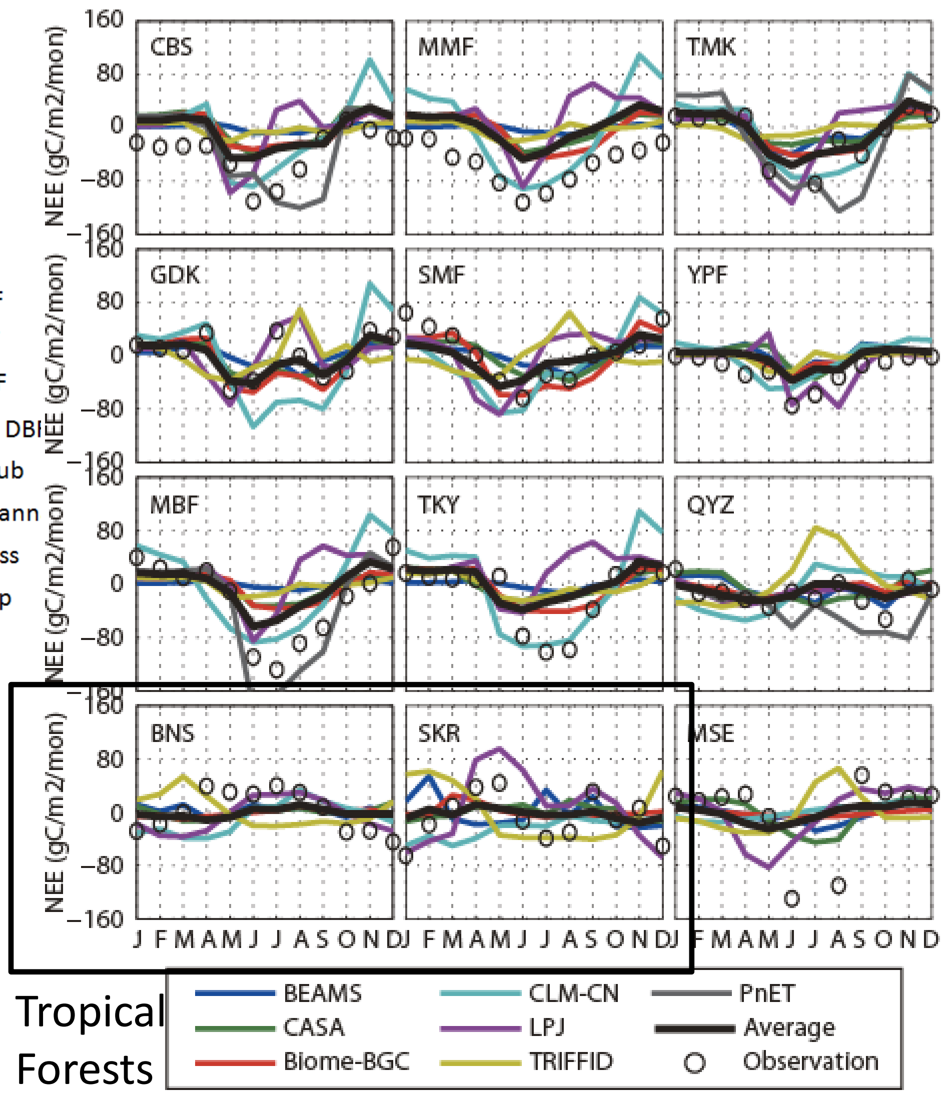
Terrestrial Carbon Cycle Models (8)

BEAMS, Carnegie-CASA, PnET

Biome-BGC, CLM-CN3.5, VISIT

LPJ, TRIFFID

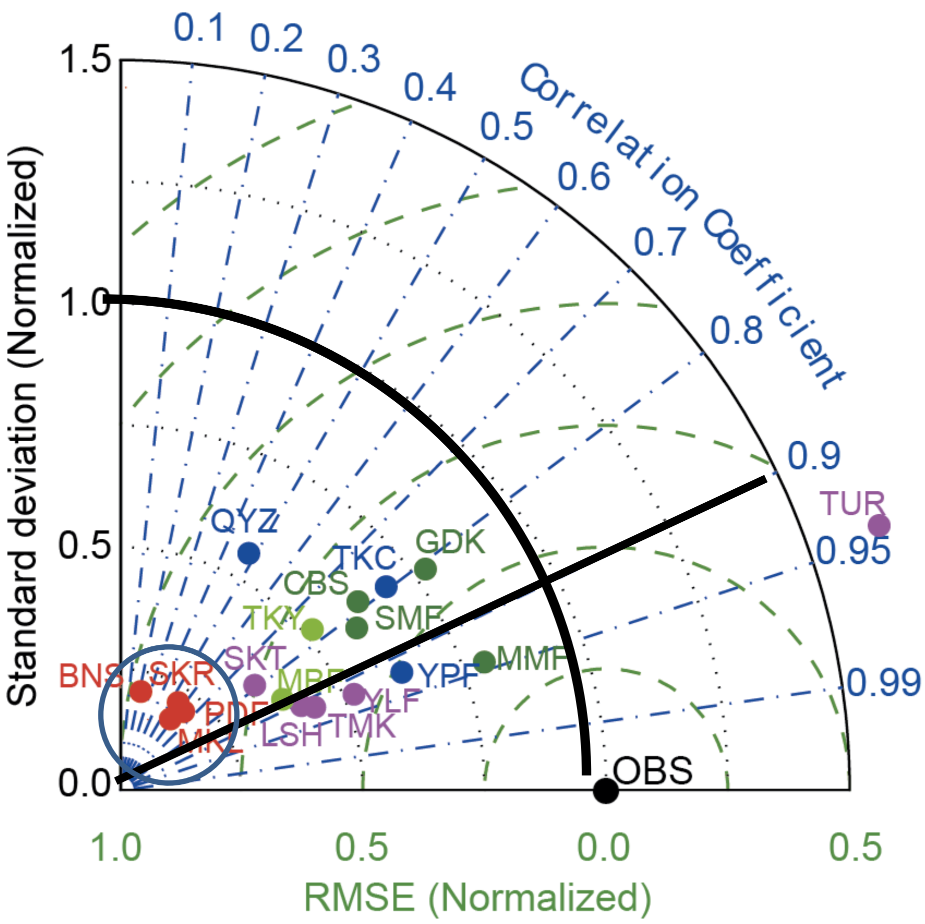
Consistent Driver for 1901-2010



[CarboEastAsia-MIP; Ichii et al., 2013]

Preliminary Analysis: CarboEastAsia-MIP

CarboEastAsia : Monthly NEE (Mean Seasonal Cycle)

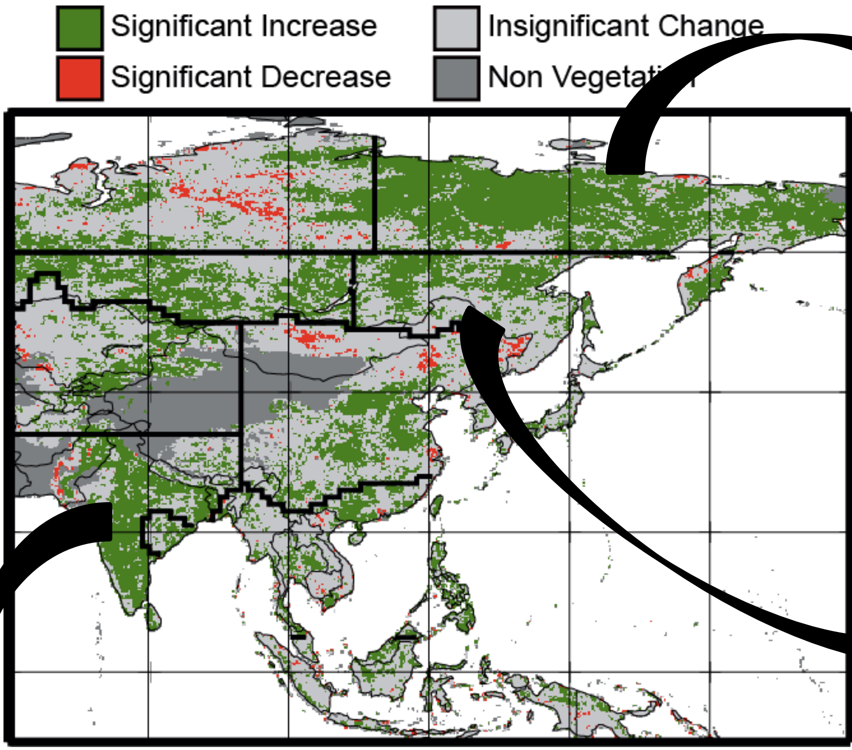


-Underestimate standard deviations
(magnitude monthly variations)

-Difficulty in tropical forests

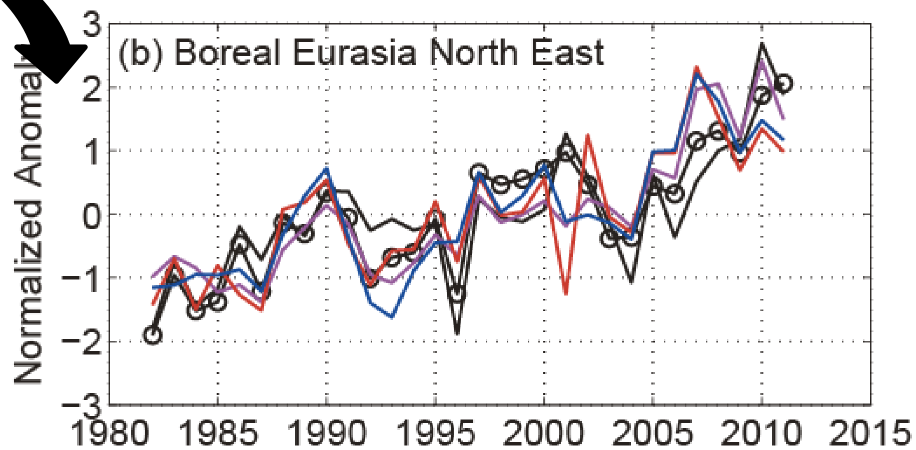
[Ichii et al., 2013]

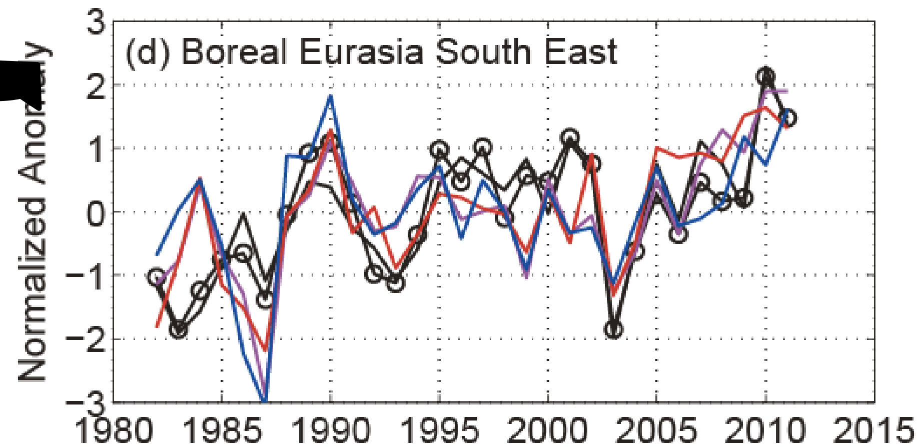
Asia-MIP, Preliminary Analysis GPP

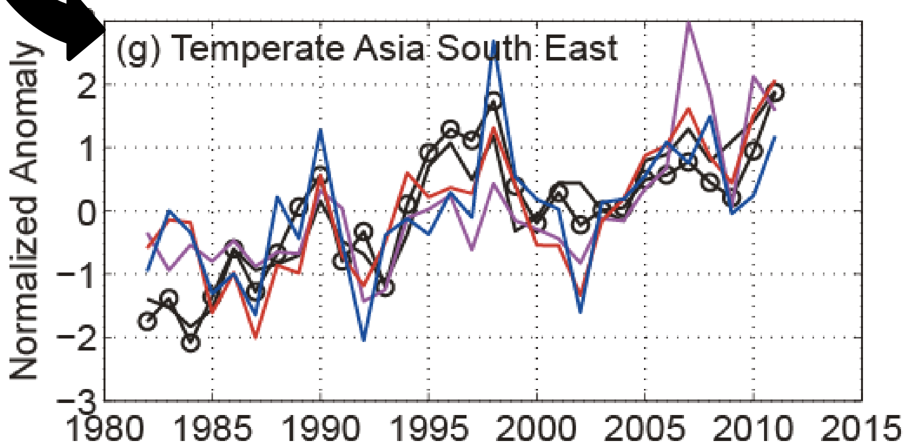


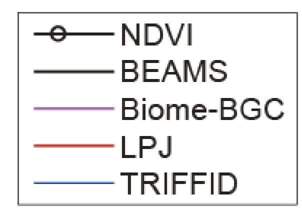
AVHRR NDVI changes (1982-2011)

Four Model GPPs vs AVHRR-NDVI







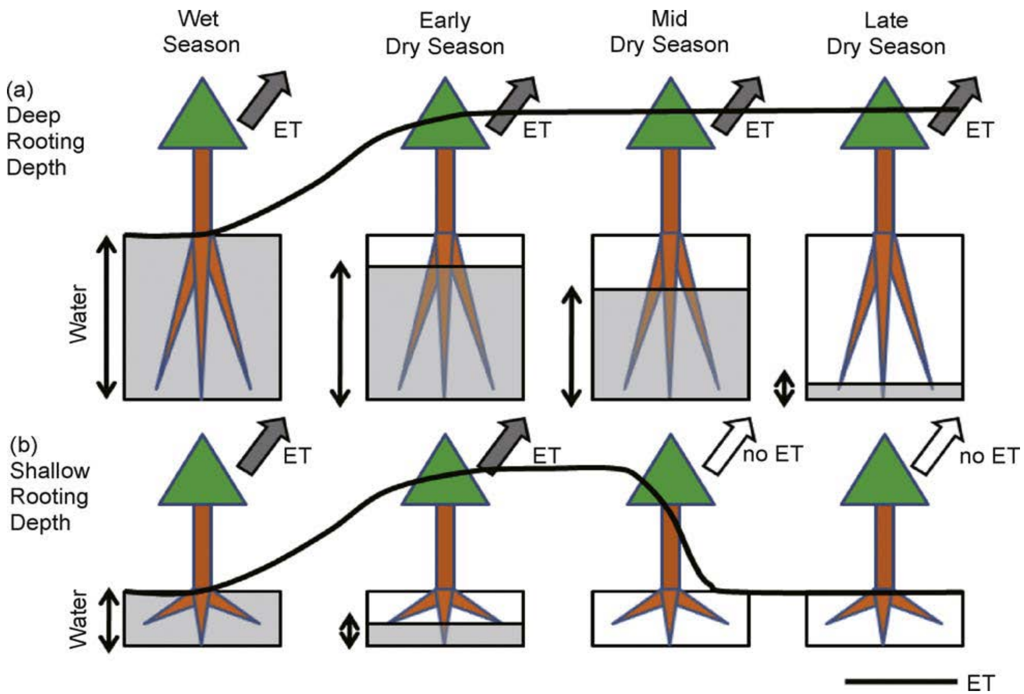


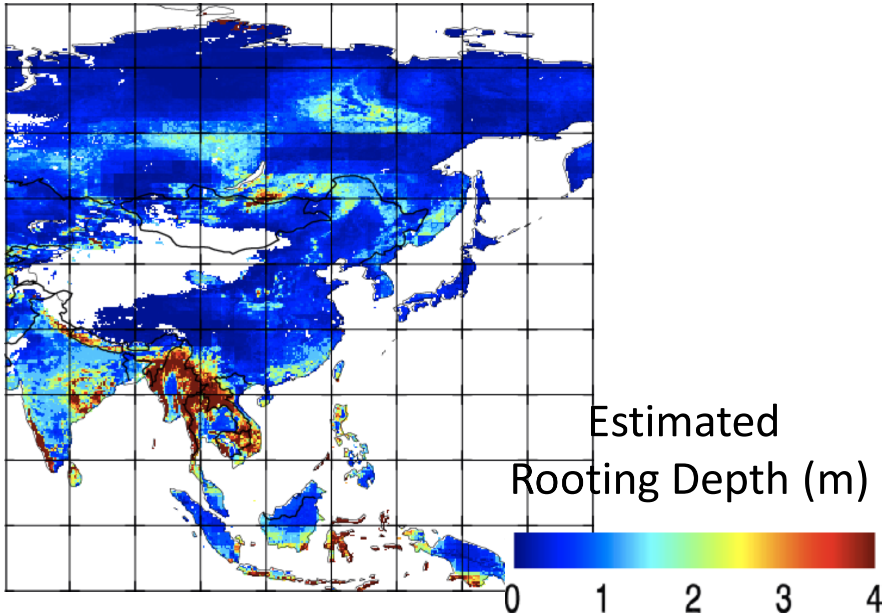
[Ichii et al. 2013]

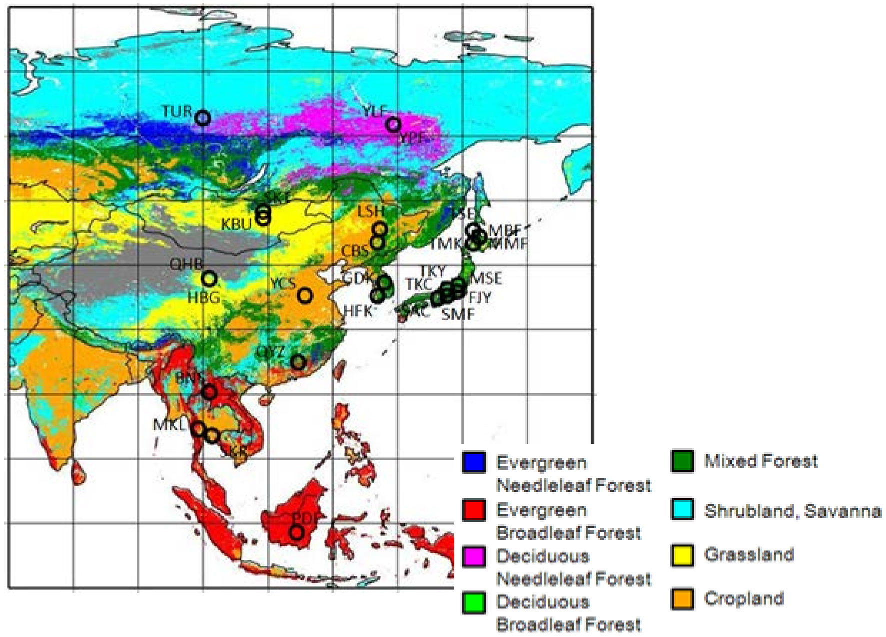
Application: Constrain Terrestrial Ecosystem Model

SVR-ET (Empirical Estimation)

[Flux obs + RS]







[e.g. Ichii et al., 2009; 2007]

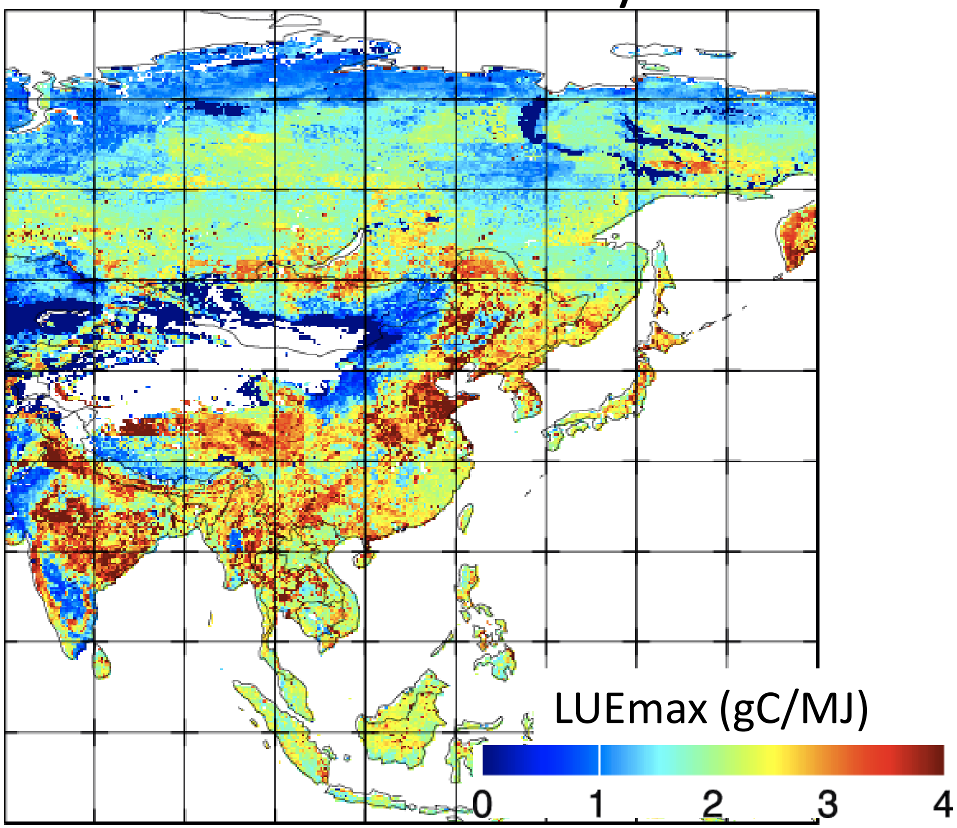
[Use old version ET]

Application: Constrain Terrestrial Ecosystem Model

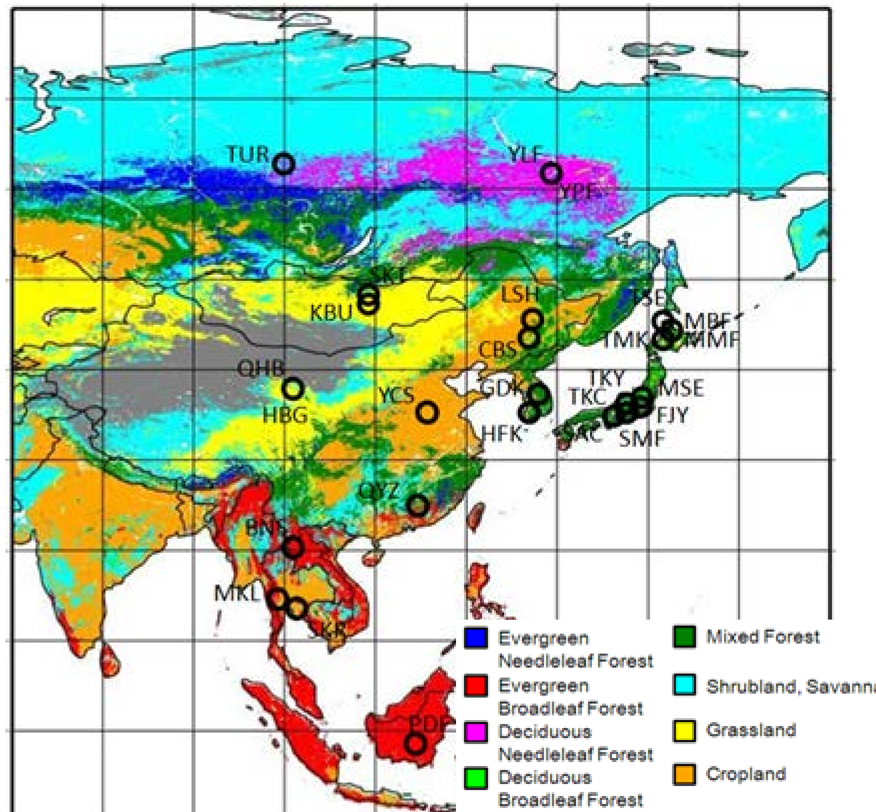
Initial Analysis: Diagnostic mode

$$GPP = e_{max} \{m(Tmin), m(vpd), m(SoilW)\}\ \mathrm{PAR} \times \mathrm{FPAR}$$

RS-GPP | Maximum Light Use Efficiency | Environmental Stress Factor | Met data | MODIS



[Use old version GPP]

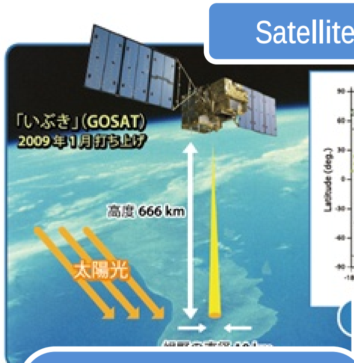


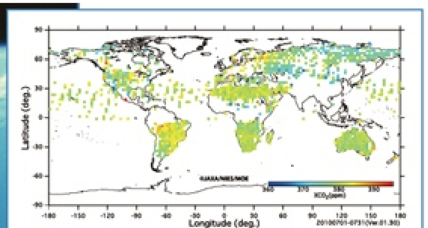
[Basic Concept: Yang et al., 2007]

Integrated carbon observation and analysis system for early detection of carbon cycle change in global and Asia-Pacific region
Suishinhi 2-1401 (H26-H28) PI: Dr. Saigusa

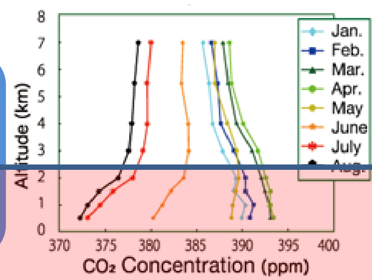
Integrated GHGs observing system

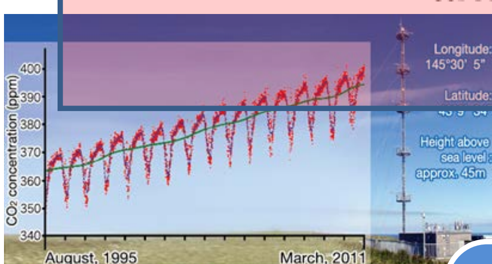
Satellite-based GHGs monitoring

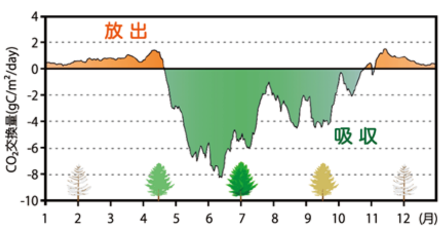




Airplane- and Ship-based monitoring of GHGs



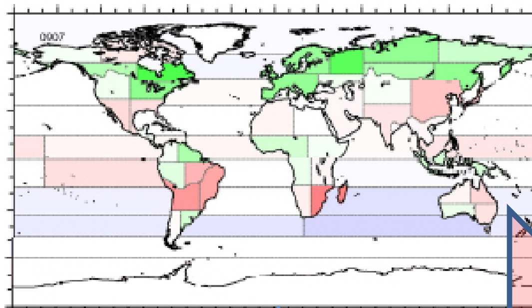




Ground-based monitoring of GHGs concentration and their fluxes

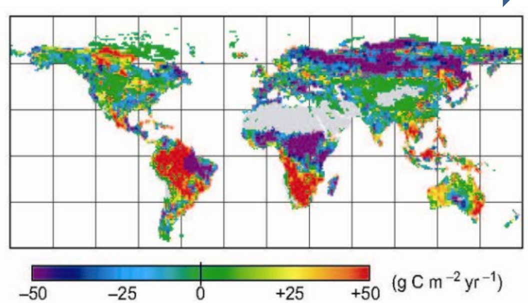
Improved estimates of terrestrial carbon fluxes

Top-down estimation (atmospheric inverse models)



Comparison, Refinement

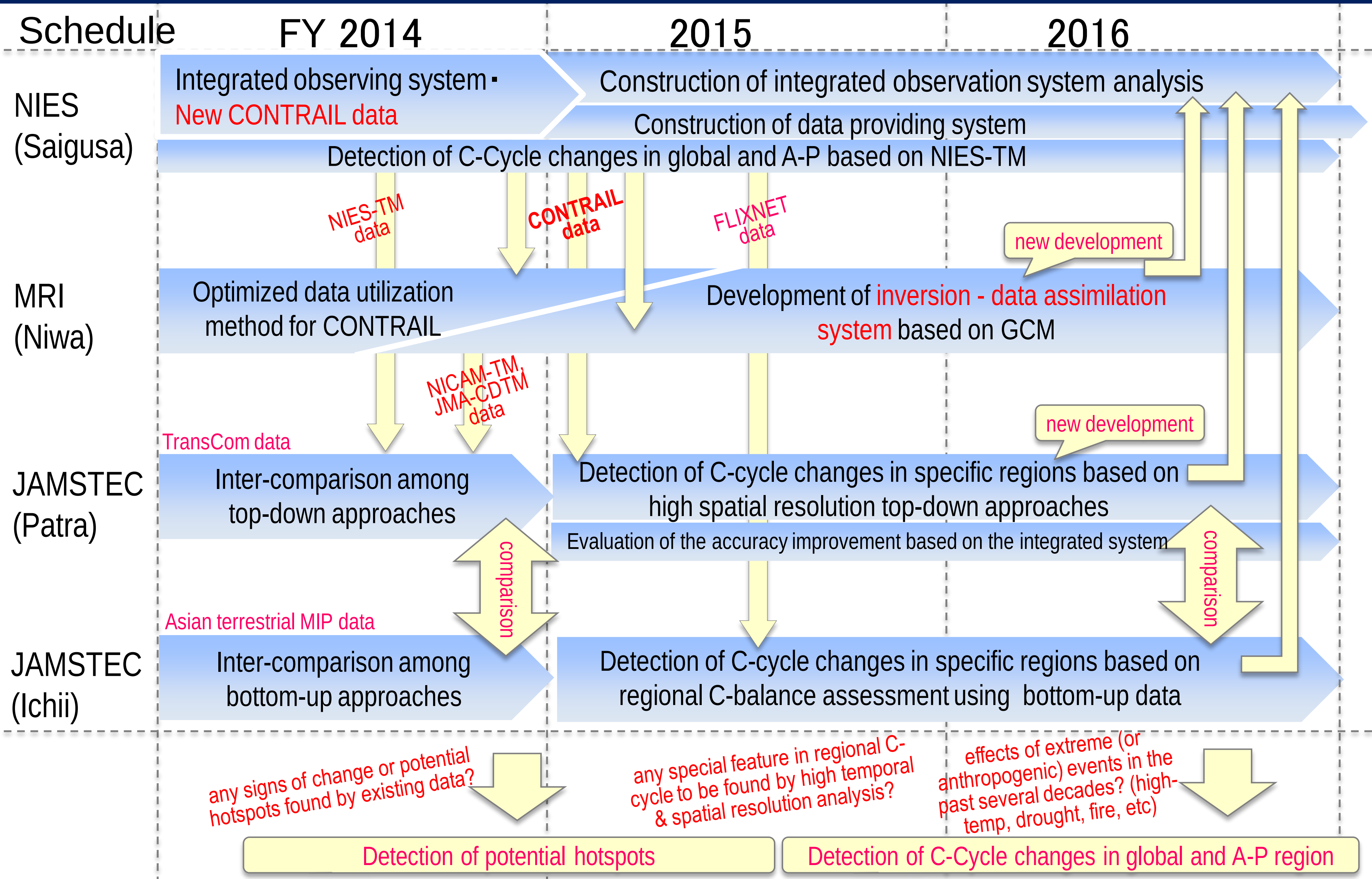
Bottom-up estimation (model, upscaling)



Goal

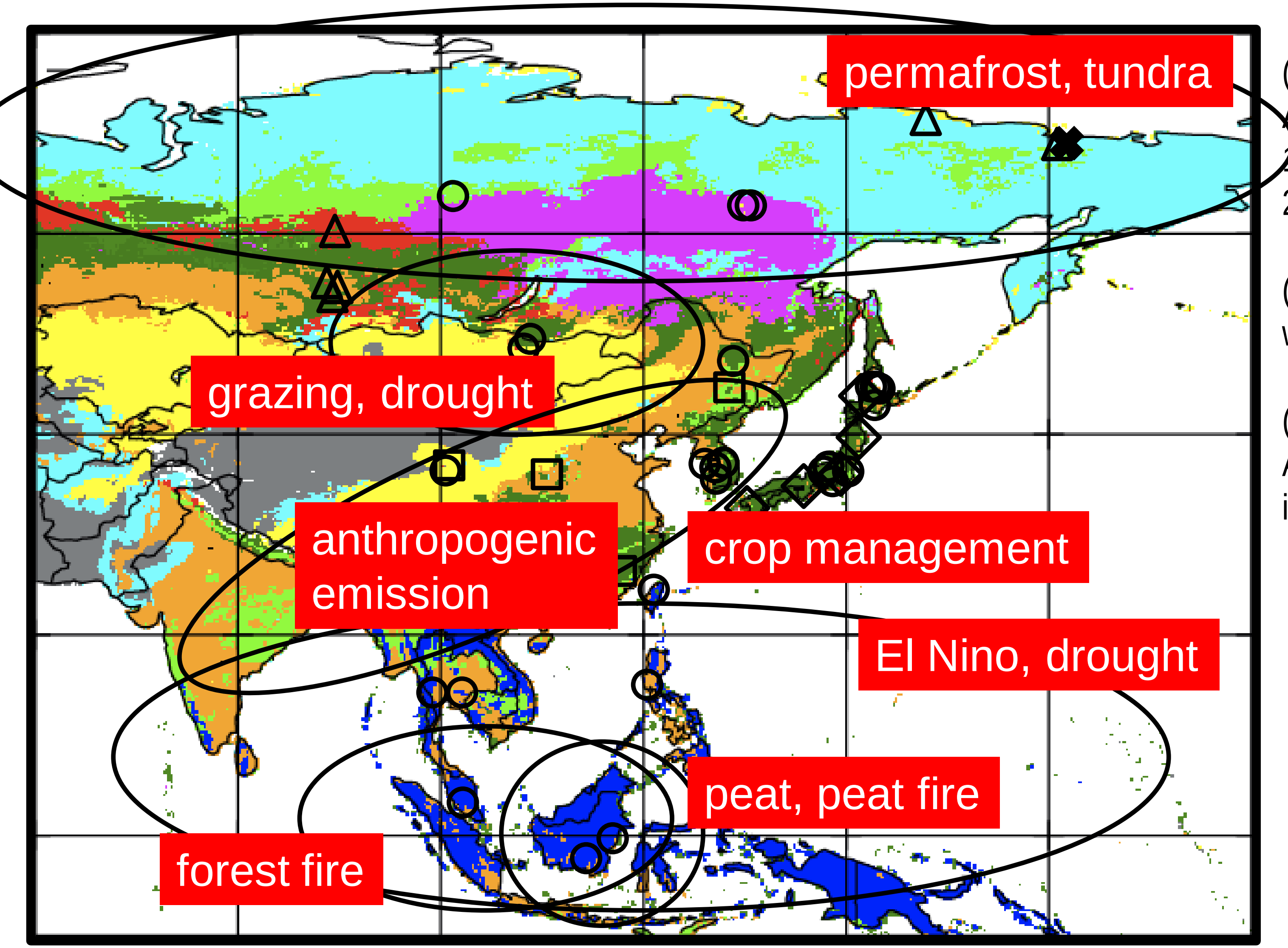
- Integrated operational carbon monitoring system
- Better estimation of spatio-temporal variation of GHGs (+fluxes)
- National & regional estimates of CO2 budget
- Early detection of drastic C cycle changes in Asia-Pacific.

New Project: Integrated carbon observation and analysis system for early detection of carbon cycle change in global and Asia-Pacific region
Suishinhi 2-1401 (H26-H28) PI: Dr. Saigusa



New Project: Integrated carbon observation and analysis system for early detection of carbon cycle change in global and Asia-Pacific region
Suishinhi 2-1401 (H26-H28) PI: Dr. Saigusa

Any signs of changes or potential hotspots?



Research targets?

(1) C-cycle in S- & SE-Asia (El Nino, fire): 1997/98, 2002, 2006, 2009/10, 2014/15?

(2) Effects of global warming in Siberia:

(3) Others: Anthropogenic emission in mid-latitudes, etc.