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GOSAT Data Products Generated in Collaborative Effort with NOAA/GMD

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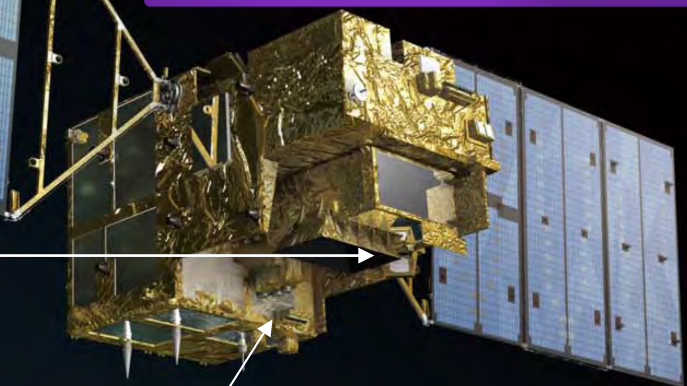
***National Institute for Environmental Studies (NIES), Japan**

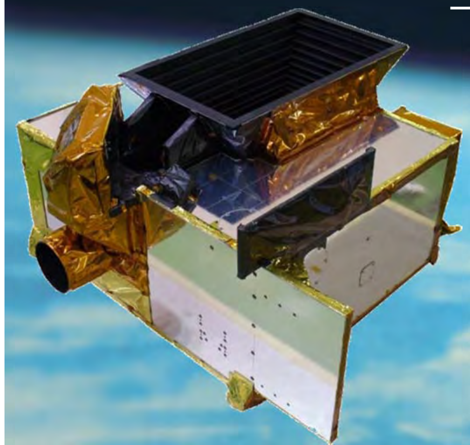
Size	Main body	3.7 m x 1.8 m x 2.0 m (Wing Span 13.7m)
Mass	Total	1750kg
Power	Total	3.8 KW (EOL)
Life Time		5 years
Orbit		sun synchronous orbit
	Local time	13:00+/-0:15
	Altitude	666km
	Inclination	98deg
	Repeat	**3 days**
Launch	Vehicle	H-IIA
	Schedule	Jan. 23 2009

TANSO onboard GOSAT

TANSO=Thermal And Near infrared Sensor for carbon Observation

TANSO (炭素) = Carbon

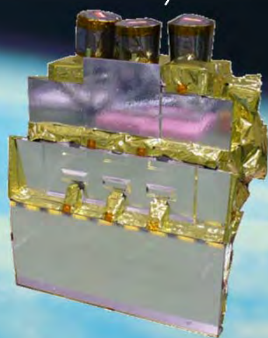




TANSO-FTS (Fourier Transform Spectrometer)

SWIR reflected on the earth's surface

-TIR radiated from the ground and the atmosphere



TANSO-CAI (Cloud and Aerosol Imager)

Ultraviolet (UV) (0.38 micron), visible (0.67 micron), NIR (0.87 micron), and SWIR (1.6 micron)

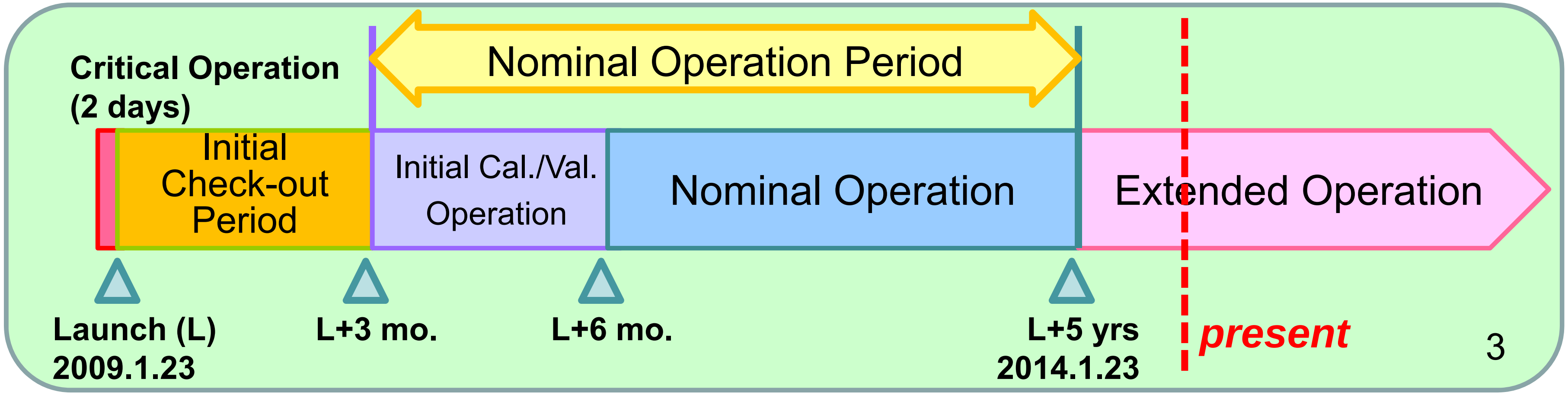
(Courtesy of JAXA)

Objectives of the GOSAT Project

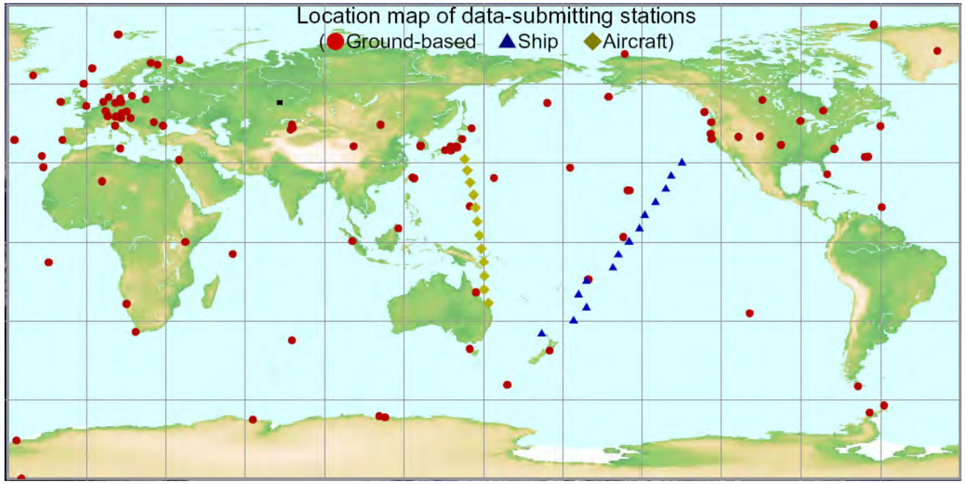
1. To obtain the global distributions of greenhouse gas (GHG) concentrations (CO_2 and CH_4) and their temporal variations
   - To **visualize** changing GHG global distributions
   - To fill out the gaps in the network of ground monitoring stations
2. To improve accuracy (decrease uncertainty) of the carbon flux (net sources and sinks) estimation on a sub-continental scale
3. To develop technologies for future GHG observing satellite ⇒ GOSAT-2

GOSAT Project –present status -

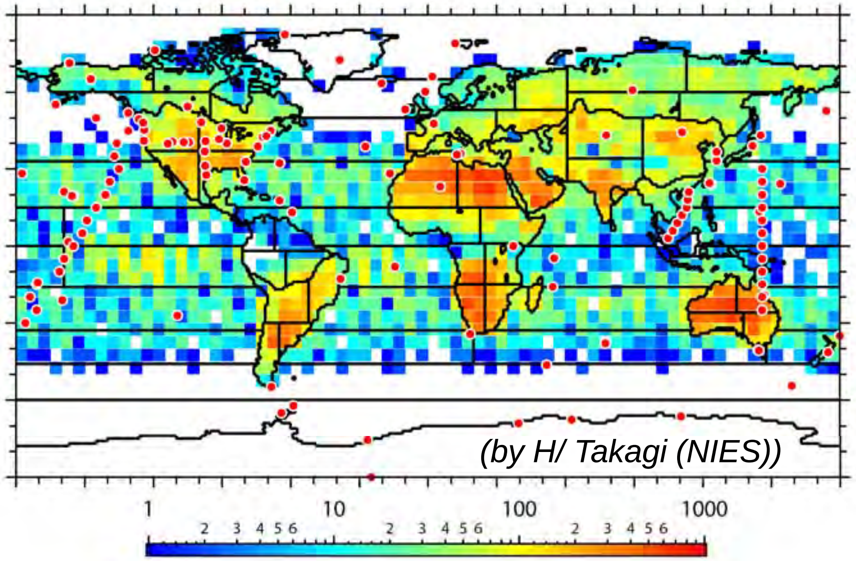
- **GOSAT** was launched on January 23, 2009 and has been in operation for more than five years.
- **GOSAT** observations successfully filled out the gaps in the ground-based monitoring network, except for around the equator and the high-latitude regions.
- Uncertainties in monthly regional flux estimates of CO_2 and CH_4 have been decreased by using **GOSAT** data.



Records of the GOSAT Observation Locations for Valid Data Retrieved



Locations of GHG monitoring stations
(from WDCGG, as of May. 11, 2015)
Total: **330**
CO_2 measurement: **226**
CH_4 measurement: **213**

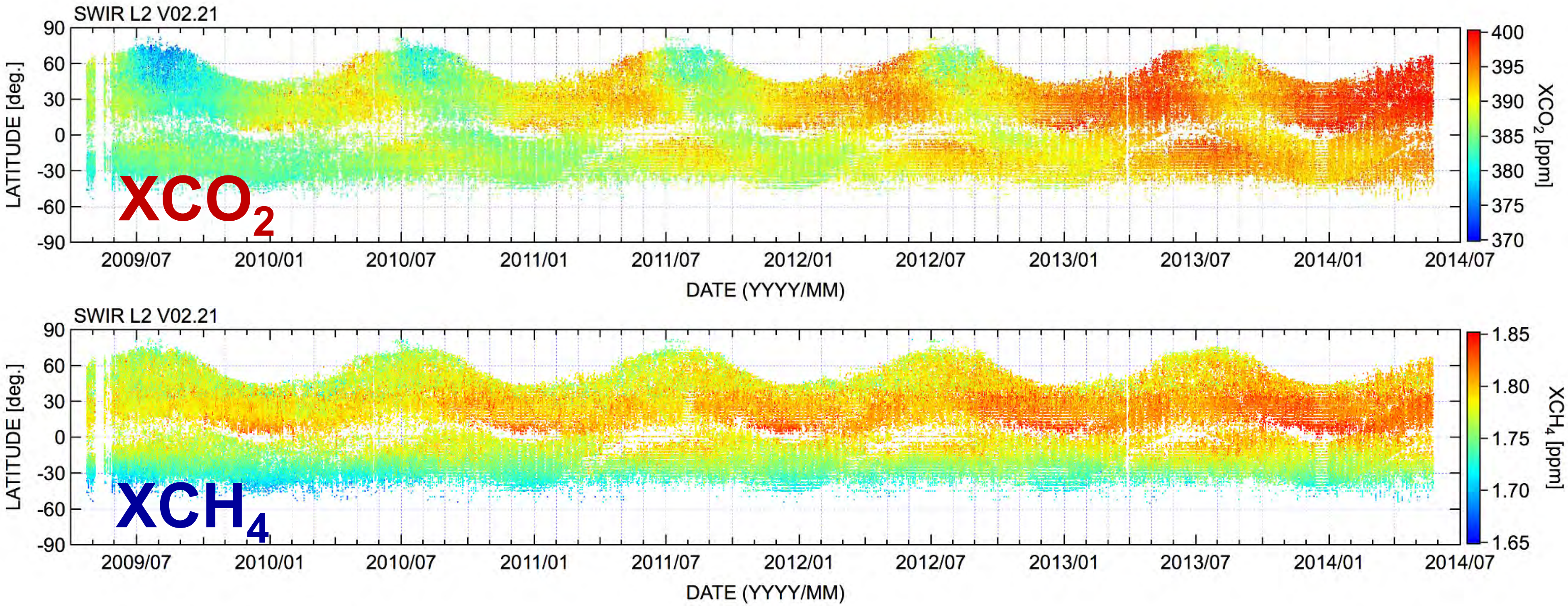


The number of **GOSAT** Level2 (Ver. 2) XCO_2 data in a year (2009.6-2010.5).
Red-white : 200 – 1000 data/year
Green-orange: 20 – 100 data/year
Blue : 0 – 10 data/year

Satellites can fill the gaps in the ground-based monitoring network with several exceptions.

TANSO-FTS SWIR Level 2 (V02.21) XCO_2 & XCH_4

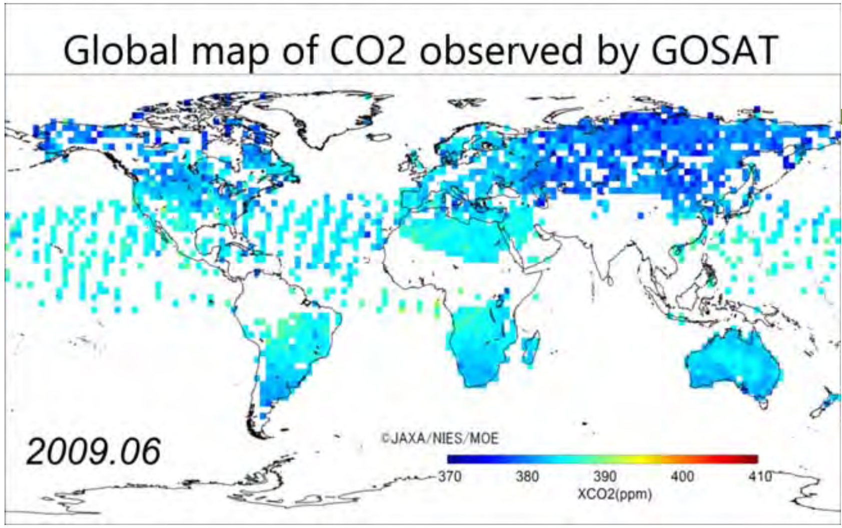
April 2009 - May 2014

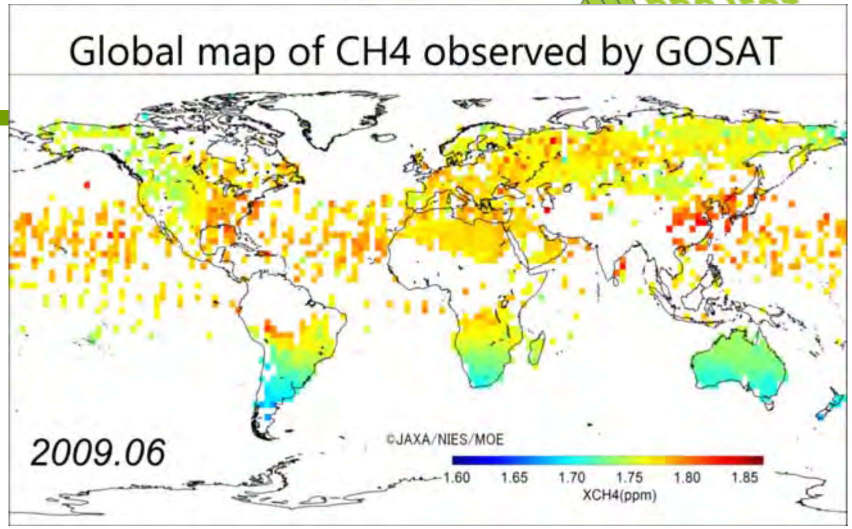


(by Y. Yoshida (NIES))

55-month-long GOSAT XCO_2 and XCH_4

(June 2009 – December 2013)





- Above movies are 1-month-moving average GOSAT XCO_2 and XCH_4 with three-day interval. The mesh size is 2.5 degree.
- Various interesting features are shown in these movies such as annual and seasonal variations of XCO_2 and localized anomalies of XCH_4.
- GOSAT obtained XCO_2 and XCH_4 data for more than 6 years. Validation results suggest that relative accuracies (variations) of XCO_2 and XCH_4 are ≈ 2 ppm (≈ 0.5%) and 12 ppb (≈ 0.7%), respectively.

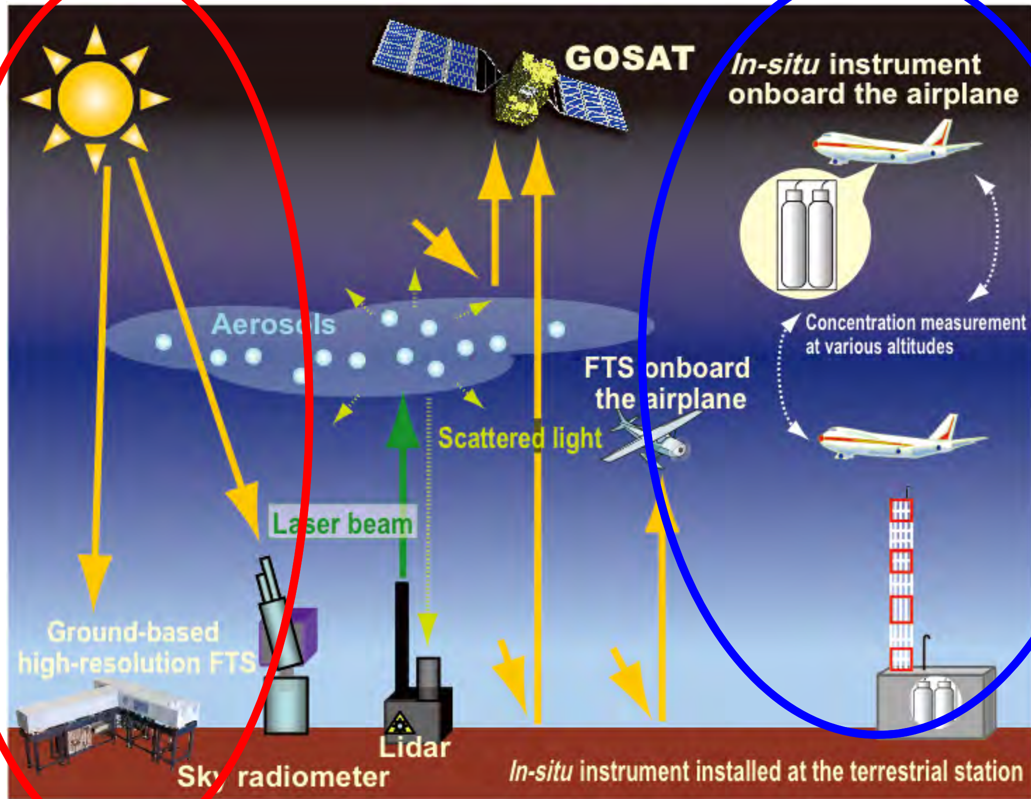
Schematic illustration of the GOSAT validation

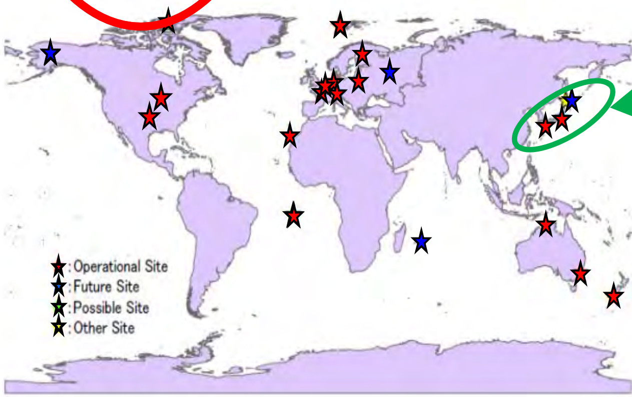
Ground-based high-resolution FTS

Aircraft measurements

Morino et al. (2011, AMT)
Yoshida et al. (2013, AMT)

in NIES (Tsukuba)

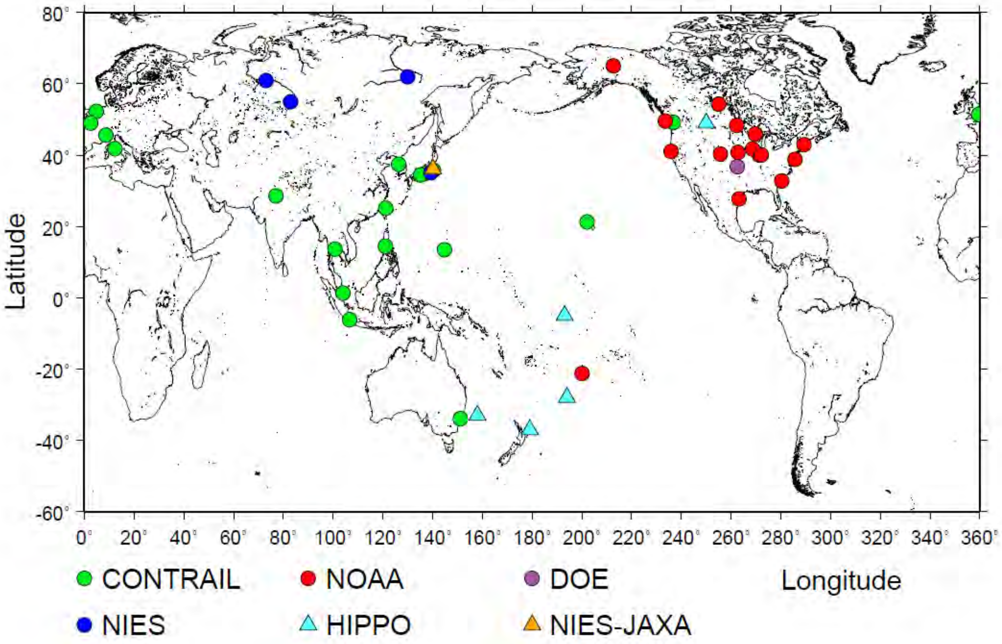




Tsukuba, Rikubetsu, Saga

A worldwide network of ground-based FTS (TCCON; over 20 sites in the world)

Aircraft measurement by CONTRAIL, NOAA, DOE, NIES, HIPPO and NIES-JAXA



Inoue et al. (2013, ACP)

CONTRAIL: continuous measurements
NOAA, DOE, NIES, NIES-JAXA: Flask sampling

CO_2 (47 sites)

Measurement uncertainty in CO_2 ~ 0.2 ppm

Uncertainty in calculating XCO_2 ~ 1 ppm

A paper for basic parts on profiles to derive X : Araki et al. (2010, ACP) Miyamoto et al. (2013, ACP)

CH_4 (28 sites)

Measurement uncertainty in CH_4 ~ 2 ppb

Uncertainty in calculating XCH_4 ~ 15 ppb

Observation sites used in this study

- CONTRAIL data (Machida et al., 2008): 20 sites (2007 - 2010)
- NOAA/DOE data: 17 sites (2007 - 2011)
- NIES data: 4 sites (2008 - 2010)
- HIPPO data: 5-6 sites (2009 - 2010)
- NIES-JAXA campaign data: 1 site (2010)

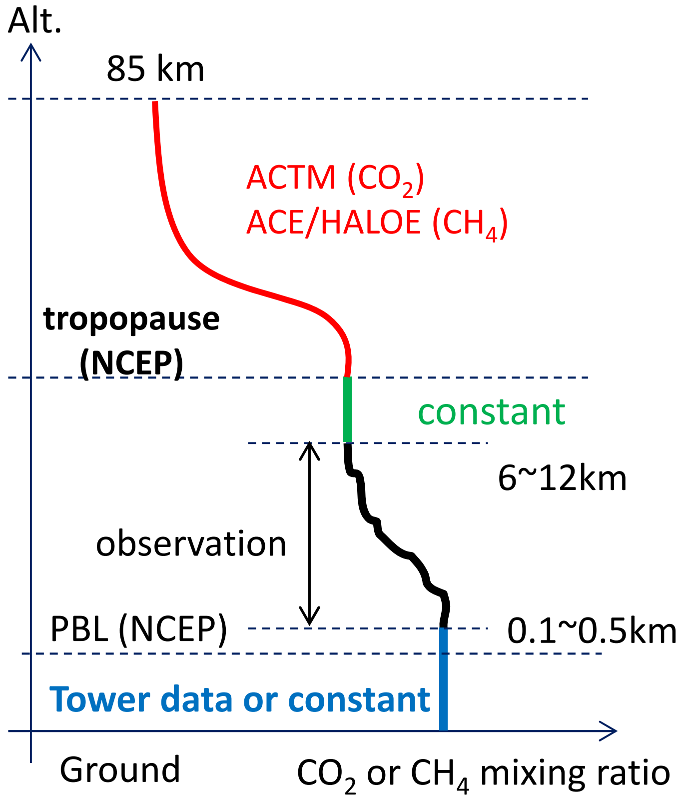
CONTRAIL (JAL project)

XCO_2 and XCH_4 calculation from aircraft data

Stratospheric and mesospheric profile
For XCO_2, ACTM* model outputs (Patra et al., 2009) were used. For XCH_4, Atmospheric Chemistry Experiment (ACE, Jones et al., 2011) and Halogen Occultation Experiment (HALOE, Grooß and Russell, 2005) are used.

Below tropopause
If observing range below tropopause, the value measured at highest altitude was extended to the tropopause.

Near the surface
Complemented by meteorological tower data or extrapolated as a constant value to ground.



$$XCO_2 = \frac{\sum_{0\,km}^{85\,km} [CO_2]^{(i)} \times N_{air}^{(i)}}{\sum_{0\,km}^{85\,km} N_{air}^{(k)}} \qquad XCH_4 = \frac{\sum_{0\,km}^{85\,km} [CH_4]^{(i)} \times N_{air}^{(i)}}{\sum_{0\,km}^{85\,km} N_{air}^{(k)}}$$

$[CO_2]^{(i)}$: CO_2 ratio of *i-th* layer
$[CH_4]^{(i)}$: CH_4 ratio of *i-th* layer
$N_{air}^{(i)}$: Dry air number density of *i-th* layer

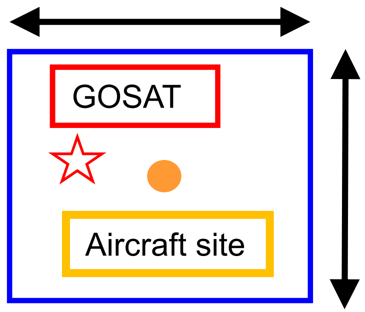
*ACTM: AGCM-based Chemistry Transport Model

(by I. Morino & O. Uchino (NIES))

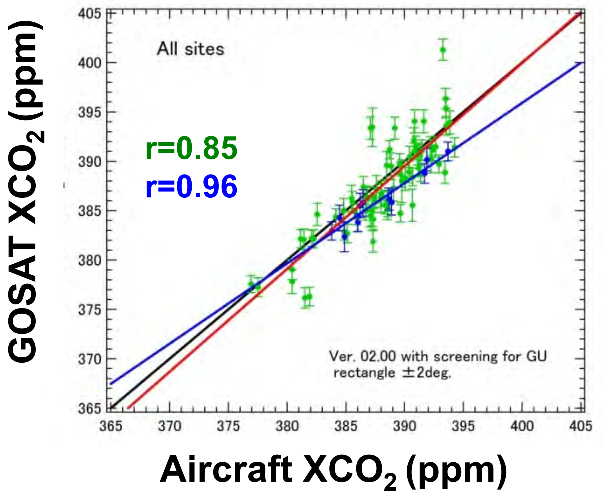
Miyamoto et al. (2013, ACP); Inoue et al. (2014, AMT)

GOSAT vs Aircraft

(by I. Morino & O. Uchino (NIES))



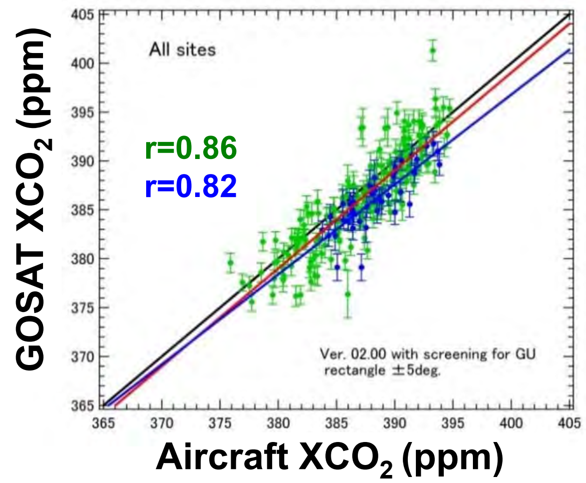
±2 deg.



Land: 74
-0.68±2.56 ppm

Ocean: 11
-1.82±1.04 ppm

±5 deg.

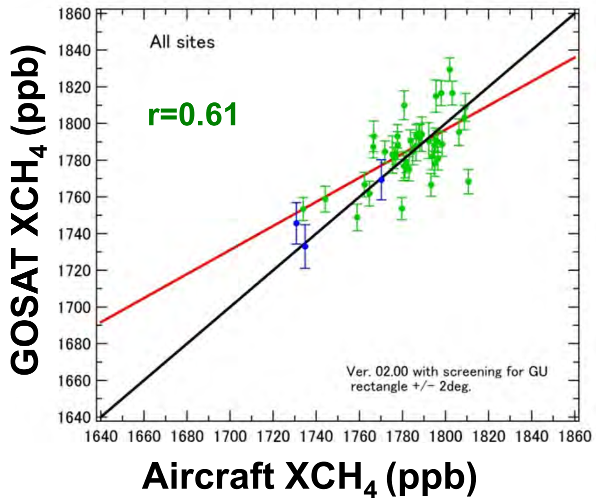


Land: 182
-0.99±2.51 ppm

Ocean: 40
-2.27±1.79 ppm

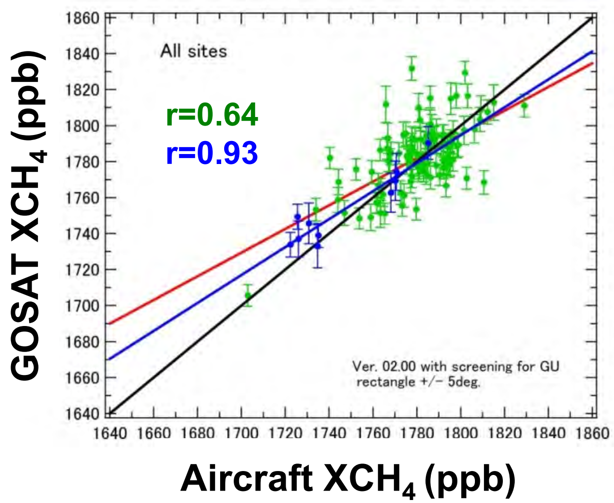
XCO_2

Inoue et al. (2013, ACP)



Land: 43
1.5±14.9 ppb

Ocean: 3
4.1±9.4 ppb



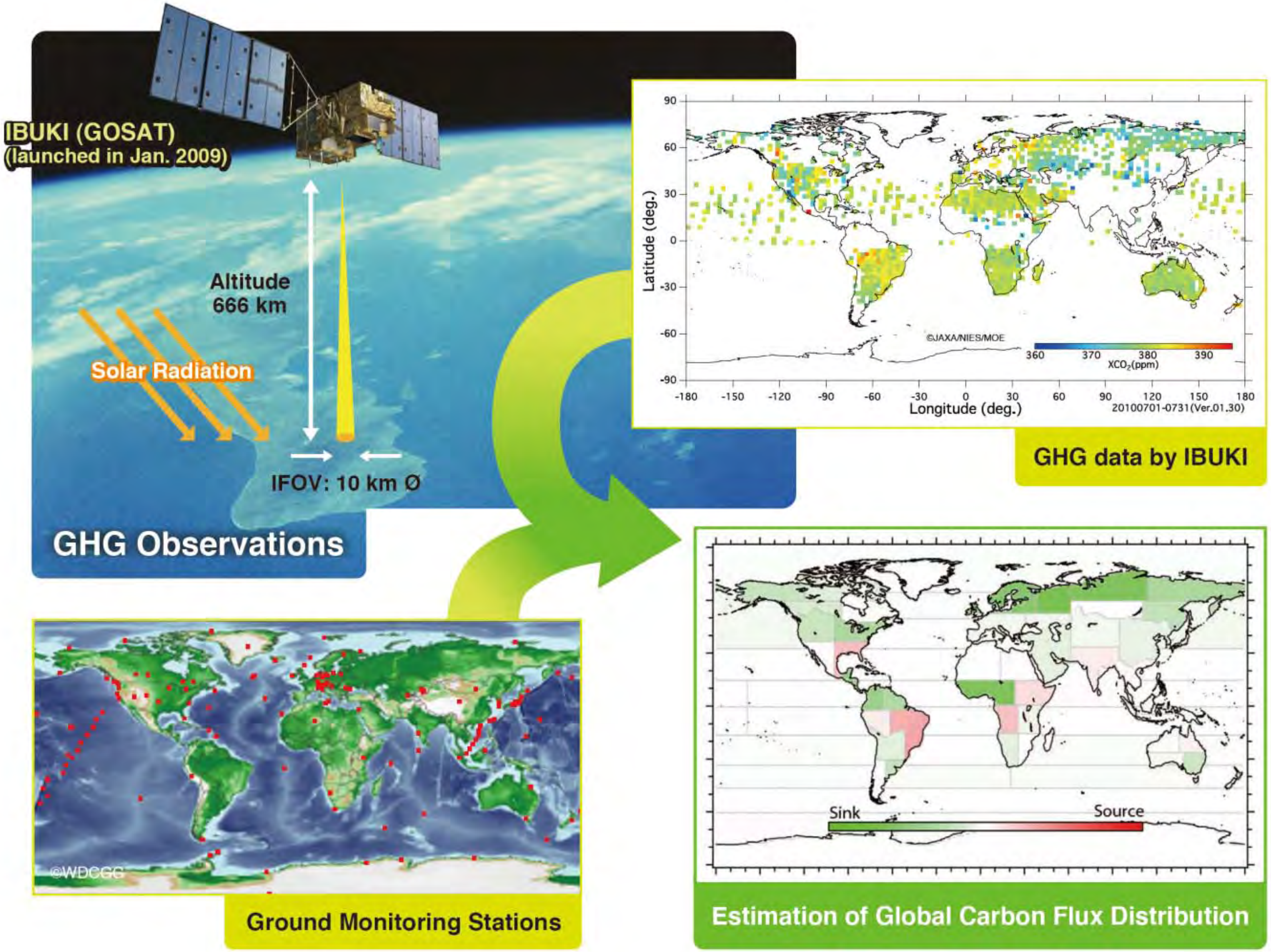
Land: 102
2.0±16.0 ppb

Ocean: 10
6.5±8.8 ppb

XCH_4

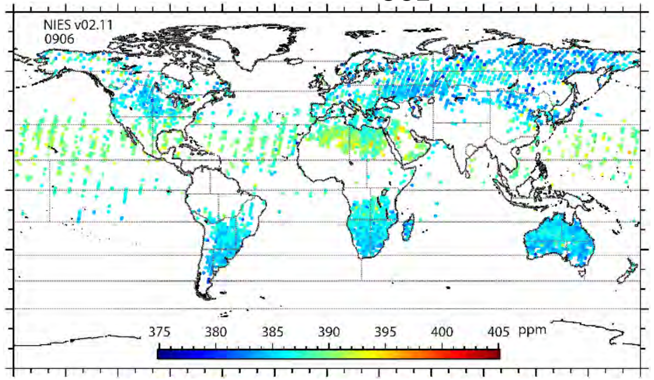
Inoue et al. (2014, AMT)

Contribution of satellite data to carbon flux

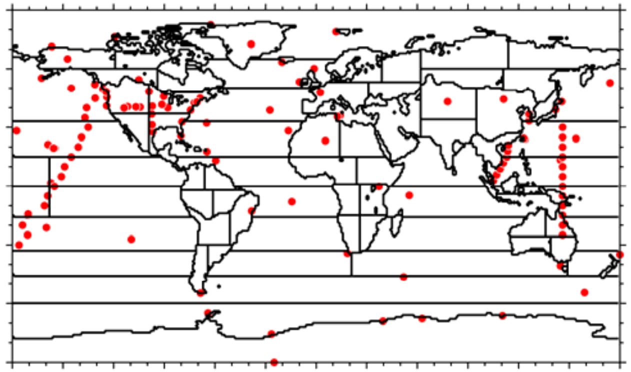


Input to GOSAT Level 4 regional flux estimation (CO_2 v02.03 released in Jan. 2015)

GOSAT Level 2 X_{CO2} v02.11



GLOBALVIEW-CO2 2013 (GV)



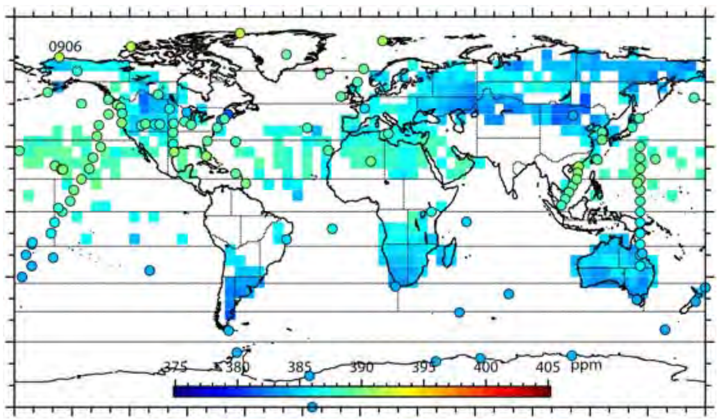
Biases were corrected based on validation result

X_{CO2} retrievals were gridded to 5° × 5° cells and monthly-averaged

Cells with N<3 per month were not used

Combined

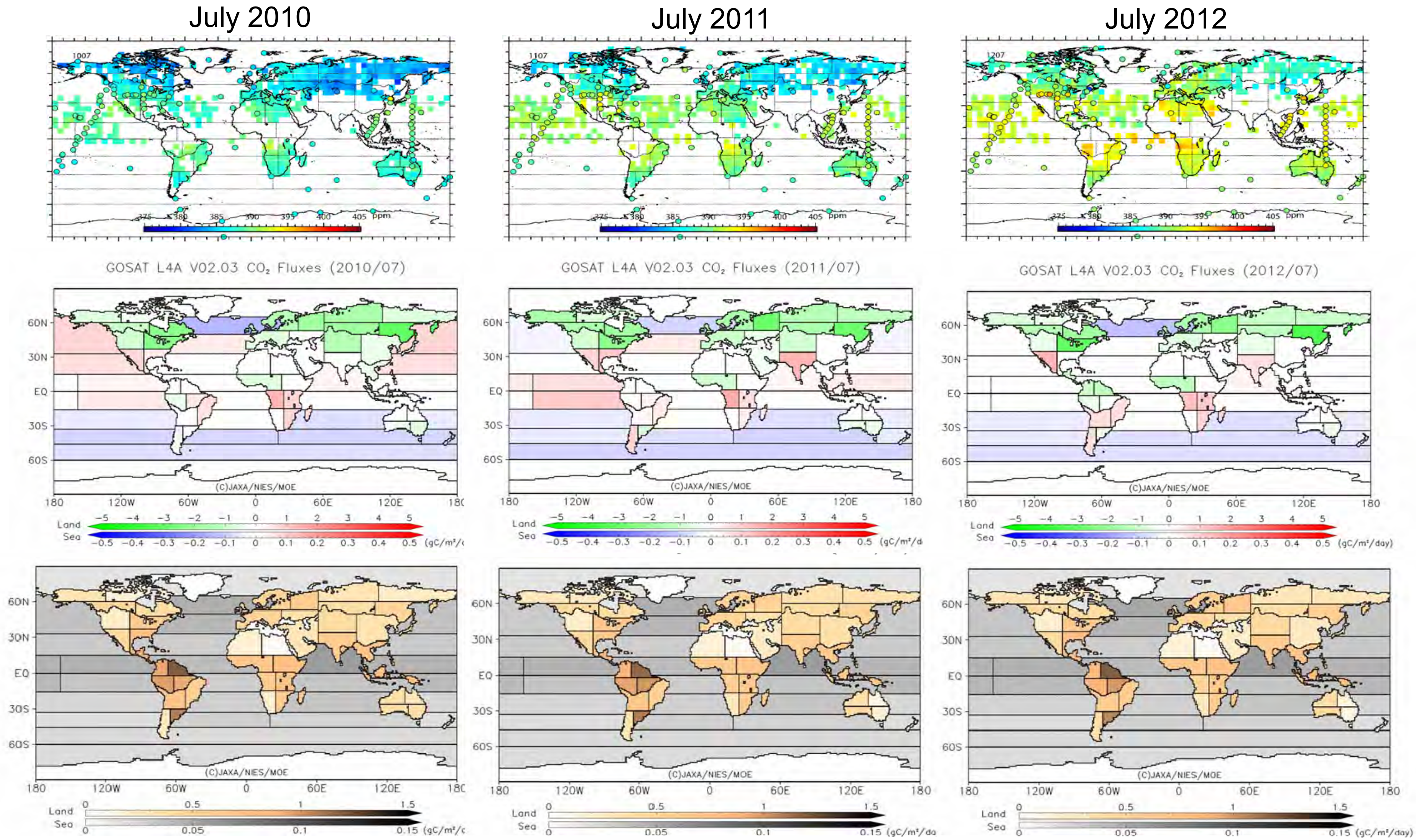
Data from 212 sites were monthly-averaged



GOSAT X_{CO2} retrievals compliment GV data

Input to inverse modeling

Monthly CO_2 Flux Estimates and Uncertainties



Top: monthly-mean CO_2 data (input to flux estimation)

Squares: GOSAT XCO_2 gridded to 5° × 5° cells

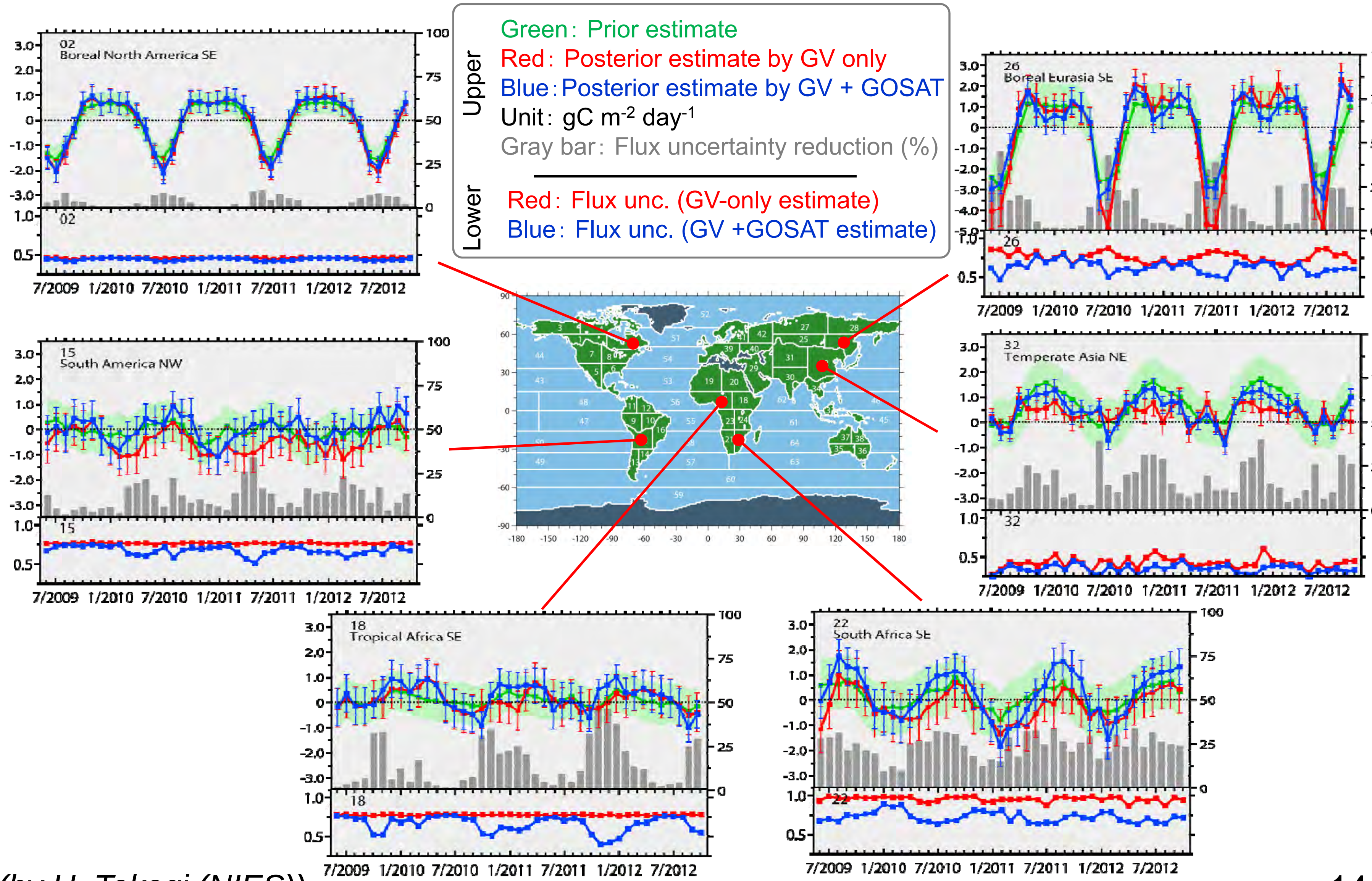
Circles: GLOBALVIEW data (212 sites)

Middle: Monthly flux estimate (GOSAT Level 4A CO_2), Bottom: Flux uncertainty

(by H. Takagi (NIES))

Time series of monthly regional flux estimates

Jun. 2009 – Oct. 2012 (41 months)



(by H. Takagi (NIES))

GOSAT CH_4 inverse modeling, H. Kim & S. Maksyutov, NIES

Interannually varying monthly CH4 emissions

1) Anthropogenic sources by EDGAR v4.2
2) Wetlands, rice paddies and soil sinks by VISIT (Ito and Inatomi, 2011)
   Termites by GISS (Fung et al. 1991)
3) Biomass burning by GFED (van der Werf et al. 2010)

NIES transport model (NIES08)

2.5° by 2.5°, 32 vertical layers
6-hourly JCDAS
photochemical loss of CH4 (TC-CH4)
(Belikov et al., 2012)

Basis functions (43reg × 3cat × 4mon)

Background states
- anthropo.
- wetlands, rice, soils, termites
- biomass burning

CH4 obs.

WDCGG NIES

The World Data Centre for Greenhouse Gases (WDCGG)

Inverse model (Fixed-lag Kalman smoother)

$L_s = (z - Hs)^T R^{-1} (z - Hs) + (s - s_p)^T Q^{-1} (s - s_p)$: *cost function to be minimized*

$s' = s_p + QH^T (R + HQH^T)^{-1} (z - Hs_p)$

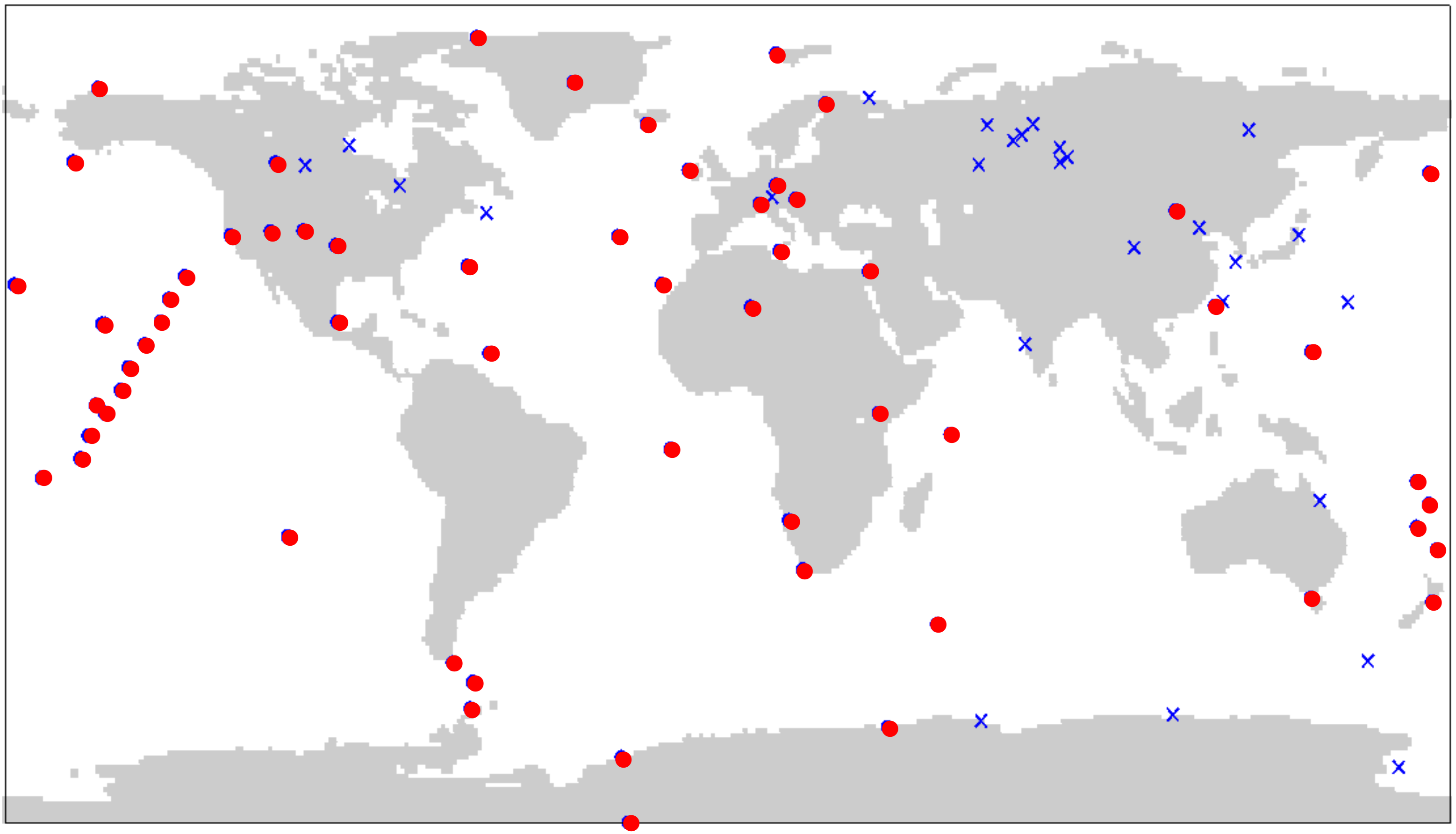
$Q' = Q - QH^T (R + HQH^T)^{-1} HQ$

H : basis functions
v : data uncertainty
R : data uncertainty covariance
z : model-observation mismatch
s : source strengths to be estimated
s_p : the priori source
Q : the prior flux uncertainty covariance

3

cf). GOSAT L4 CH_4 product release note (http://data.gosat.nies.go.jp)

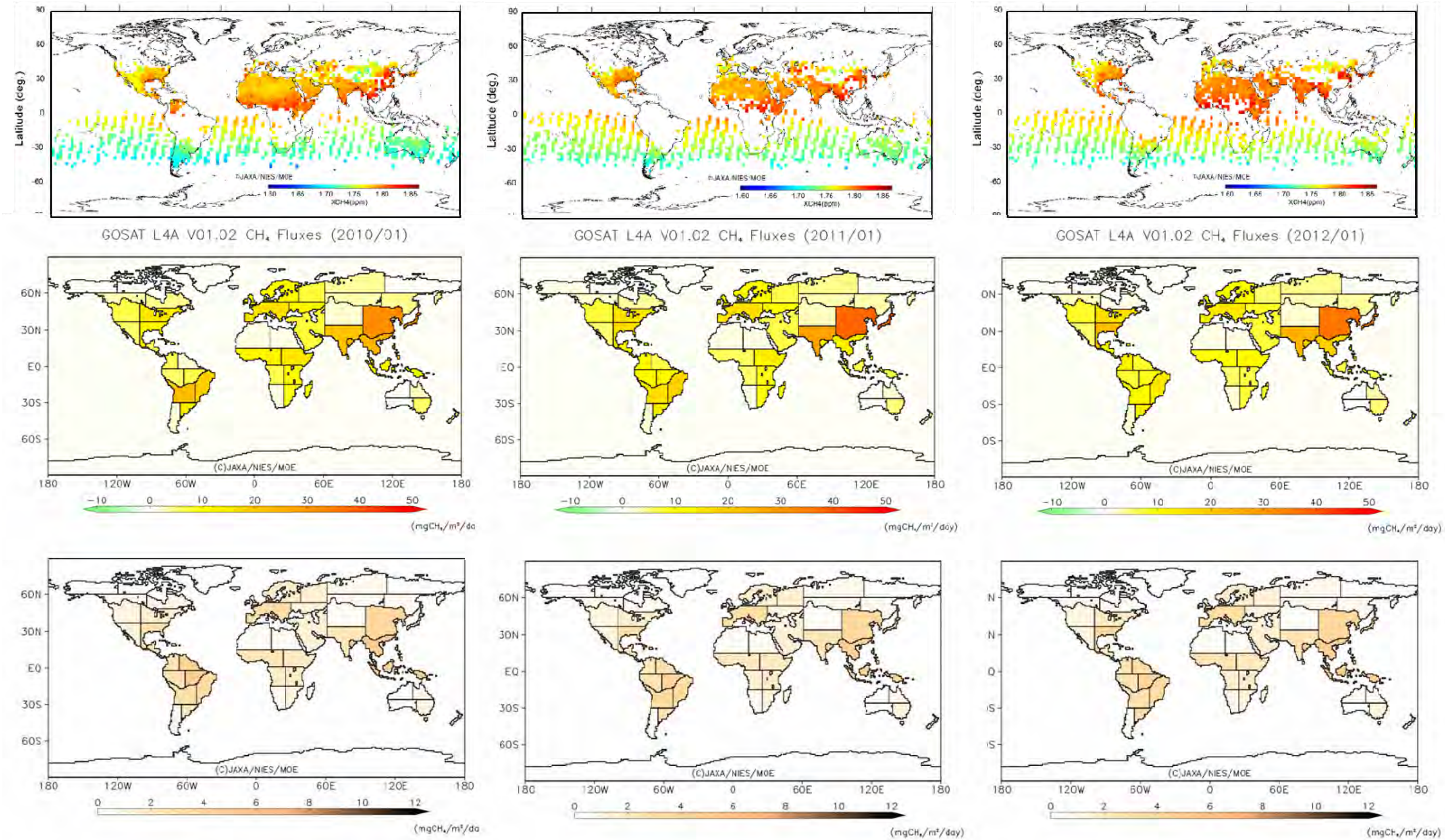
Location of CH_4 measurement sites used in GOSAT L4 CH_4 (v01.02)



We are using CH_4 monitoring data via the World Data Centre for Greenhouse Gases (WDCGG) site.
Many of them are originated from the NOAA ESRL/GMD.

Monthly CH_4 Flux Estimates and Uncertainties

January 2010 | January 2011 | January 2012



Top: monthly-mean GOSAT XCH_4 data gridded to 2.5º × 2.5º mesh (input to flux estimation)
Middle: Monthly flux estimates (GOSAT Level 4A CH_4)
Bottom: Flux uncertainty

* Anthropogenic, natural, and biomass burning emissions are estimated separately for each region.

Concluding Remarks

- GOSAT Project has released almost all of its standard data products to registered researchers and the general public.
- The GOSAT Level 2 XCO_2 and XCH_4 data products have been validated with TCCON FTS data, NOAA and DOE airborne data, CONTRAIL data, and other reference data.
- The Level 4A CO_2 and CH_4 data product (monthly regional source-sink estimates) have been generated with GOSAT Level 2 data, selected GlobalView data, and NOAA ESRL/GMD observational data provided via the WDCGG.
- In this way, the six-year-long GHG observation by GOSAT have been performed by collaborative effort with the ESRL/GMD groups in data validation and surface flux estimation. We express special thanks to the NOAA ESRL/GMD members.