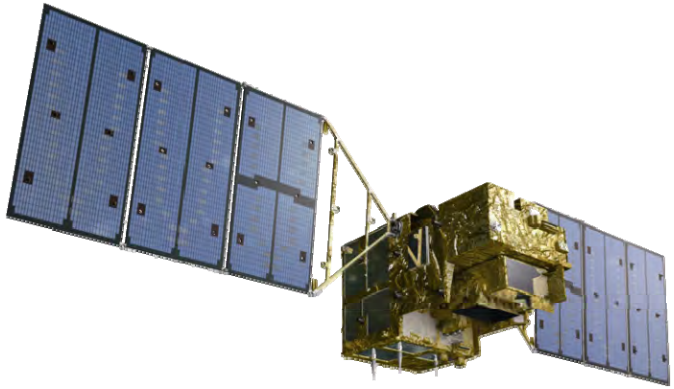
IWGGMS-12
Kyoto University, Kyoto, Japan
June 7 – 9, 2016

Summary of NIES GOSAT Project: Activities Over the Past Seven Years and Plans for the Next Five Years



T. Yokota (NIES GOSAT Project Acting Leader)
Y. Yoshida, I. Morino, H. Noda, O. Uchino, H. Takagi, M. Saito, S. Maksyutov, M. Ajiro, and T. Matsunaga

Center for Global Environmental Research (CGER)
National Institute for Environmental Studies (NIES), Japan

Contents

- Seven years of the NIES GOSAT project
  - Observation of columnar CO_2 & CH_4 amounts
  - Many versions of GOSAT data products
  - Monthly regional flux estimation of CO_2 and CH_4 by using GOSAT data for three/four years
- Next five-year plan of GOSAT data processing and distribution at NIES GOSAT DHF

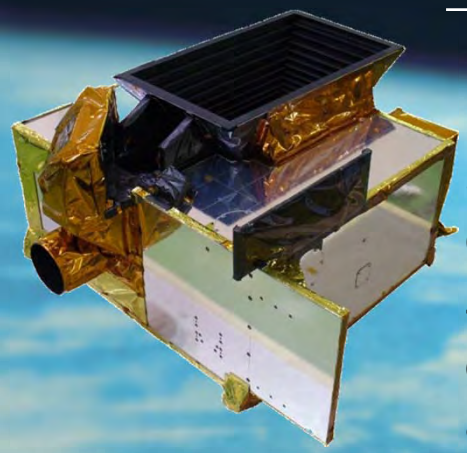
GOSAT (IBUKI) launched by H-IIA F-15 vehicle on January 23, (Photo by NIES)

TANSO onboard GOSAT

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=Thermal And Near infrared Sensor for carbon Observation

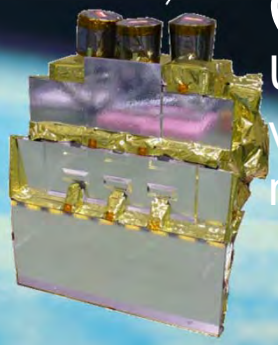
TANSO (炭素) = Carbon



TANSO-FTS (Fourier Transform Spectrometer)

SWIR reflected on the earth's surface

-TIR radiated from the ground and the atmosphere



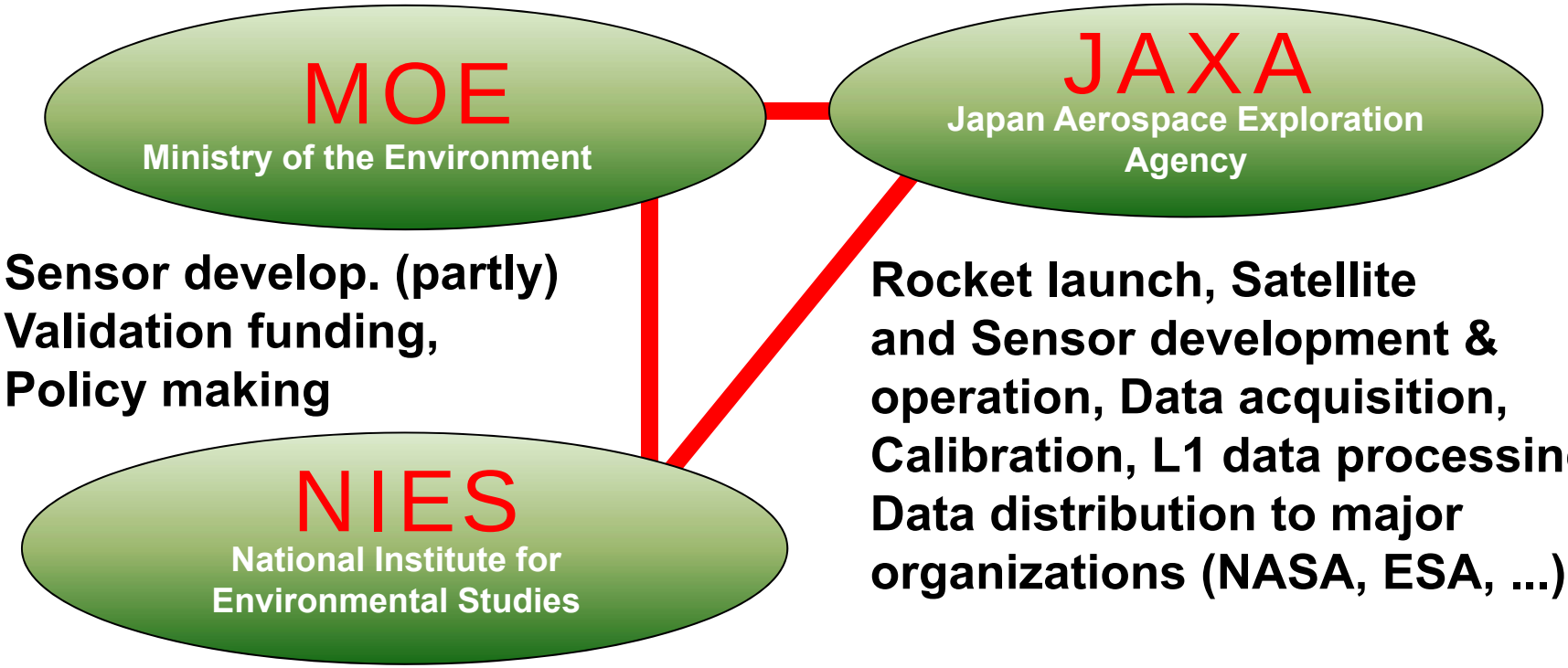
TANSO-CAI (Cloud and Aerosol Imager)

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

(Courtesy of JAXA)

Organizations Promoting the GOSAT Project

◆ Mission promoted by **JAXA**, **MOE**, and **NIES**.

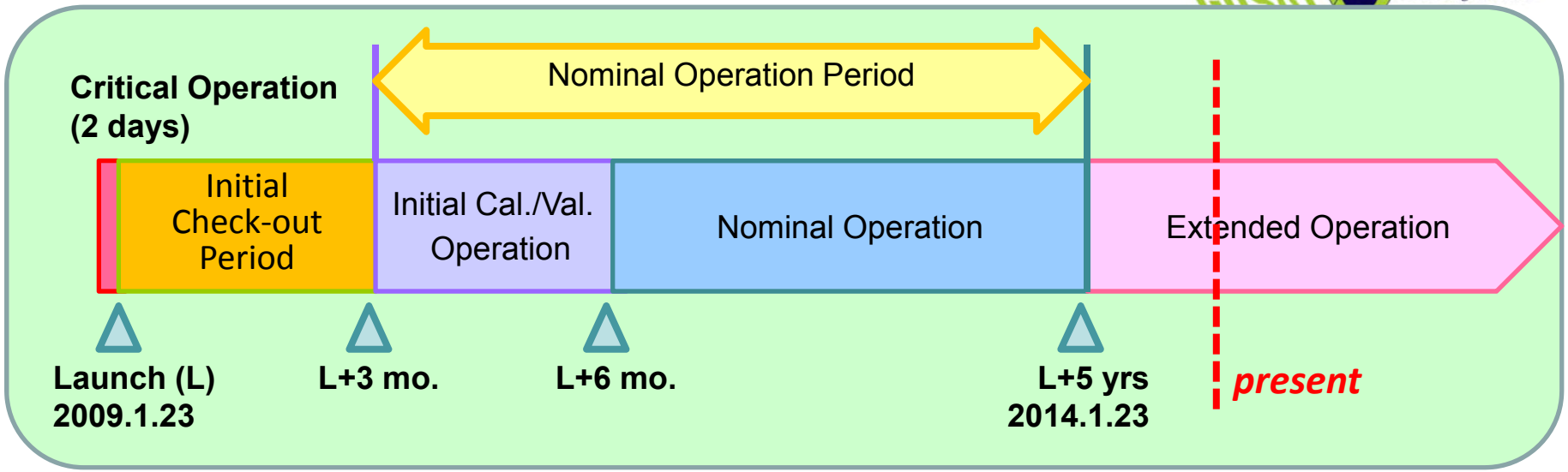


Developing & improving GHG retrieval algorithms, L2 and higher level data processing, Data validation, Estimating carbon fluxes, Data product distribution

Objectives of the GOSAT Project

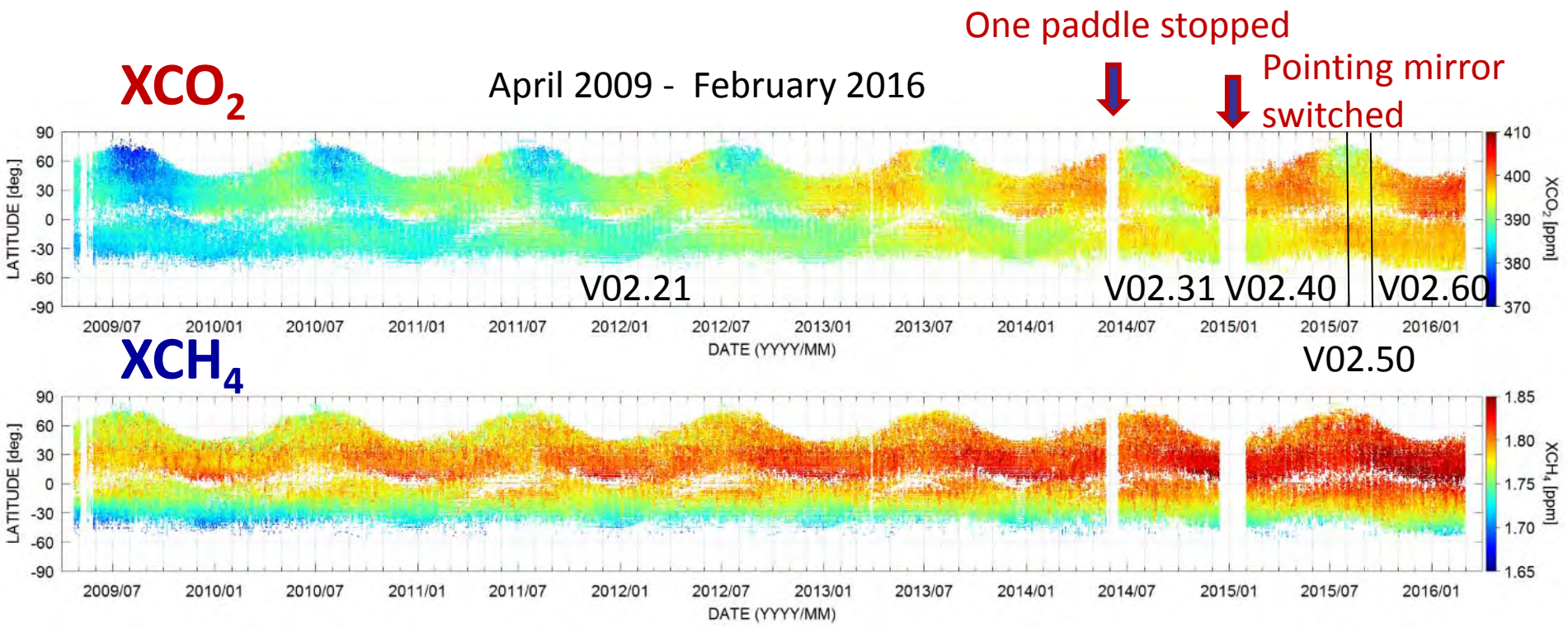
1. To obtain the global distributions of greenhouse gas (GHG) concentrations (CO_2 and CH_4) and their temporal variations
   - To **visualize** changing GHG global distributions
   - To fill out the gaps in the network of ground monitoring stations
2. To improve accuracy of the carbon flux (net sources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

GOSAT Project History



- ★05/2014: One of the two solar paddles stopped.
- ★01/2015: JAXA switched the GOSAT Pointing mechanism of the TANSO-FTS from the main system to the sub-system due to occurrence of the unstable pointing.
- ★08/2015: GOSAT thermal Infrared observation was suspended due to the cryo--cooler anomaly. TANSO-FTS SWIR and TANSO-CAI observations were nominal. The cryo-cooler restarted on Sept. 14, and the TIR measurement has been recovered.

TANSO-FTS SWIR Level 2 (Vers. 02.21, 02.31, 02.40, 02.50, 02.60) XCO_2 & XCH_4



XCO_2, XCH_4: Column-averaged volume mixing ratios are the ratio of the total amount of CO_2 or CH_4 to the total amount of dry air contained in a vertical column from ground surface to the top of the atmosphere.

Settled in 2005

GOSAT Standard Data Products

	Product Level	Sensor / Band	Product Designation	Description	Product Provision Unit	Data Format
Level 1	L1B	FTS	FTS L1B data	Radiance spectral data obtained by performing Fourier transform on interferogram data	per FTS scene	HDF5
		CAI	CAI L1B data	Radiance data (band-to-band and geometric corrections applied / data mapping not performed)	per CAI frame	
	L1B+	CAI	CAI L1B+ data	Radiance data (band-to-band and geometric corrections applied / data mapping performed)		
Level 2	L2	FTS SWIR	L2 CO_2 column amount (SWIR)	CO_2 column abandance data retrieved from SWIR radiance spectral data	can be selected	HDF5
			L2 CH_4 column amount (SWIR)	CH_4 column abandance data retrieved from SWIR radiance spectral data		
		FTS TIR	L2 CO_2 profile (TIR)	CO_2 vertical profile data retrieved from TIR radiance spectral data		
			L2 CH_4 profie (TIR)	CH_4 vertical profile data retrieved from TIR radiance spectral data		
		CAI	L2 cloud flag	Cloud coverage data	per CAI frame	
Level 3	L3	FTS SWIR	L3 global CO_2 distribution (SWIR)	CO_2 column-averaged mixing ratio data projected on a global map	per month (global)	
			L3 global CH_4 distribution (SWIR)	CH_4 column-averaged mixing ratio data projected on a global map		
		FTS TIR	L3 global CO_2 distribution (TIR)	Monthly-averaged CO_2 concentration at each vertical level projected on a global map		
			L3 global CH_4 distribution (TIR)	Monthly-averaged CH_4 concentration at each vertical level projected on a global map		
		CAI	L3 global radiance distribution	Global radiance distribution data (3 days worth, including data for cloudy segments)	per 3 days (global)	
			L3 global reflectance distribution (clear sky)	Clear-sky radiance data (composed only of clear-sky segments selected from a month worth of data)		
			L3 global NDVI	Vegitation index global distribution data (cloudy segments excluded)	per 15 days 30° × 60° (lat. × lon.)	
Level 4	L4A	-	L4A global CO_2 flux	CO_2 flux per each of the 64-divided global regions (monthly average)	per year (64 regions)	Text
	L4B	-	L4B global CO_2 distribution	Three-dimentional, global distribution of CO_2 concentration	per month 2.5° × 2.5° grid (lat. × lon.)	NetCDF

7

L4 CH_4 added in March 2014

GOSAT Standard Data Products

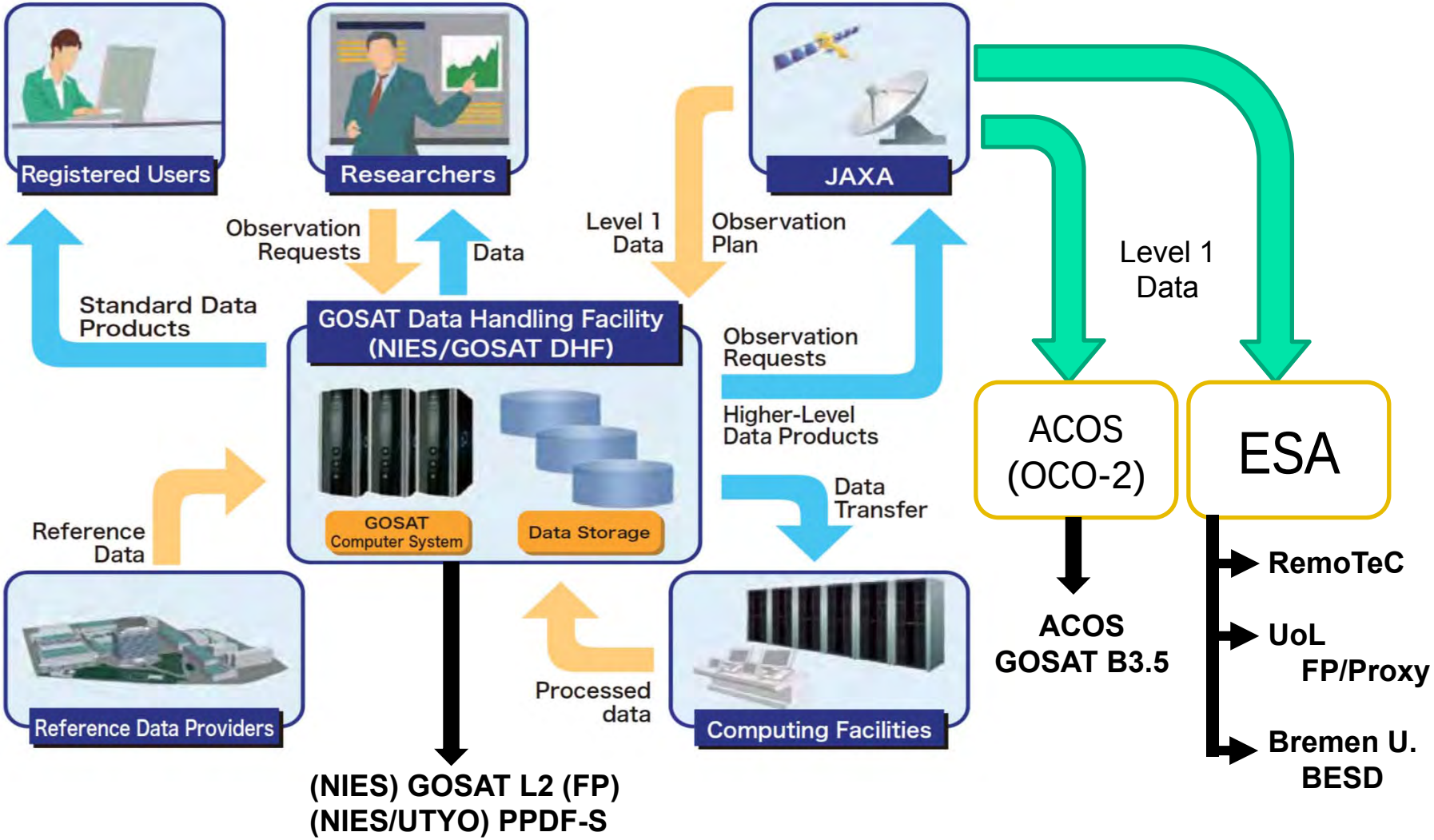
	Product Level	Sensor / Band	Product Designation	Description	Product Provision Unit	Data Format
Level 1	L1B	FTS	FTS L1B data	Radiance spectral data obtained by performing Fourier transform on interferogram data	per FTS scene	HDF5
	L1B	CAI	CAI L1B data	Radiance data (band-to-band and geometric corrections applied / data mapping not performed)	per CAI frame	
	L1B+	CAI	CAI L1B+ data	Radiance data (band-to-band and geometric corrections applied / data mapping performed)		
Level 2	L2	FTS SWIR	L2 CO_2 column amount (SWIR)	CO_2 column abandance data retrieved from SWIR radiance spectral data	can be selected	HDF5
			L2 CH_4 column amount (SWIR)	CH_4 column abandance data retrieved from SWIR radiance spectral data		
		FTS TIR	L2 CO_2 profile (TIR)	CO_2 vertical profile data retrieved from TIR radiance spectral data		
			L2 CH_4 profie (TIR)	CH_4 vertical profile data retrieved from TIR radiance spectral data		
		CAI	L2 cloud flag	Cloud coverage data	per CAI frame	
Level 3	L3	FTS SWIR	L3 global CO_2 distribution (SWIR)	CO_2 column-averaged mixing ratio data projected on a global map	per month (global)	
			L3 global CH_4 distribution (SWIR)	CH_4 column-averaged mixing ratio data projected on a global map		
		FTS TIR	L3 global CO_2 distribution (TIR)	Monthly-averaged CO_2 concentration at each vertical level projected on a global map		
			L3 global CH_4 distribution (TIR)	Monthly-averaged CH_4 concentration at each vertical level projected on a global map		
		CAI	L3 global radiance distribution	Global radiance distribution data (3 days worth, including data for cloudy segments)	per 3 days (global)	
			L3 global reflectance distribution (clear sky)	Clear-sky radiance data (composed only of clear-sky segments selected from a month worth of data)		
			L3 global NDVI	Vegitation index global distribution data (cloudy segments excluded)	per 15 days 30° × 60° (lat. × lon.)	
Level 4	L4A	-	L4A global CO_2 flux	CO_2 flux per each of 64 global regions (monthly average)	year (global)	Text/NetCDF
			L4A global CH_4 flux	CH_4 flux per each of 43 global regions (monthly average)		
	L4B	-	L4B global CO_2 distribution	Three-dimentional global distribution of CO_2 concentration	month (global) 2.5°×2.5°grid (lat.× lon.)	NetCDF
			L4B global CH_4 distribution	Three-dimentional global distribution of CH_4 concentration		

Revised in March 2015

GOSAT Standard Data Products

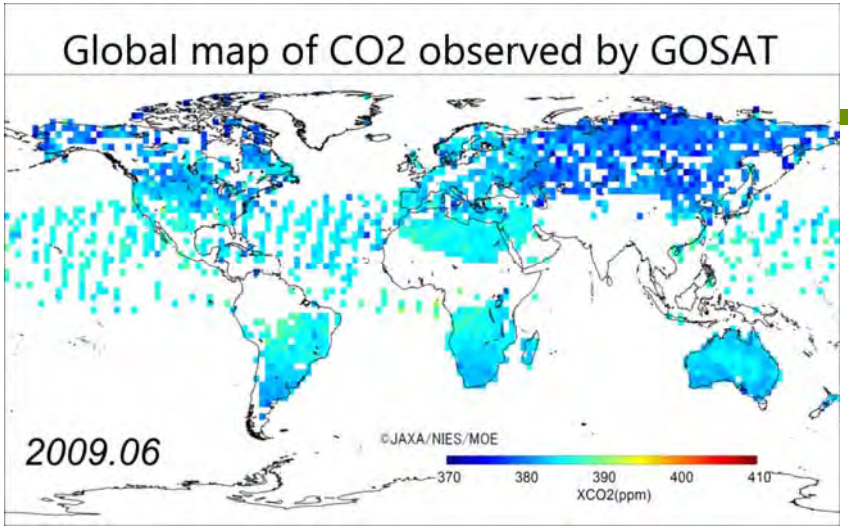
	Product Level	Sensor / Band	Product Designation	Description	Product Provision Unit	Data Format
Level 1	L1B	FTS	FTS L1B data	Radiance spectral data obtained by performing Fourier transform on interferogram data	per FTS scene	HDF5
	L1B	CAI	CAI L1B data	Radiance data (band-to-band and geometric corrections applied / data mapping not performed)	per CAI frame	
	L1B+	CAI	CAI L1B+ data	Radiance data (band-to-band and geometric corrections applied / data mapping performed)		
Level 2	L2	FTS SWIR	L2 CO_2 column amount (SWIR)	CO_2 column abandance data retrieved from SWIR radiance spectral data		HDF5
			L2 CH_4 column amount (SWIR)	CH_4 column abandance data retrieved from SWIR radiance spectral data		
		SWIR	L2 H_2O column amount (SWIR)	H_2O column abundance data retrieved from SWIR radiance spectral data		
		FTS TIR	L2 CH_4 profie (TIR)	CH_4 vertical profile data retrieved from TIR radiance spectral data		
		CAI	L2 cloud flag	Cloud coverage data	per CAI frame	
Level 3	L3	FTS SWIR	L3 global CO_2 distribution (SWIR)	CO_2 column-averaged mixing ratio data projected on a global map	per month (global)	
			L3 global CH_4 distribution (SWIR)	CH_4 column-averaged mixing ratio data projected on a global map		
		FTS TIR	L3 global CO_2 distribution (TIR)	Monthly-averaged CO_2 concentration at each vertical level projected on a global map		
			L3 global CH_4 distribution (TIR)	Monthly-averaged CH_4 concentration at each vertical level projected on a global map		
		CAI	L3 global radiance distribution	Global radiance distribution data (3 days worth, including data for cloudy segments)	per 3 days (global)	
			L3 global reflectance distribution (clear sky)	Clear-sky radiance data (composed only of clear-sky segments selected from a month worth of data)		
			L3 global NDVI	Vegitation index global distribution data (cloudy segments excluded)	per 15 days 30° × 60° (lat. × lon.)	
Level 4	L4A	-	L4A global CO_2 flux	CO_2 flux per each of 64 global regions (monthly average)	year (global)	Text/NetCDF
			L4A global CH_4 flux	CH_4 flux per each of 43 global regions (monthly average)		
	L4B	-	L4B global CO_2 distribution	Three-dimentional global distribution of CO_2 concentration	month (global) 2.5°×2.5°grid (lat.× lon.)	NetCDF
			L4B global CH_4 distribution	Three-dimentional global distribution of CH_4 concentration		

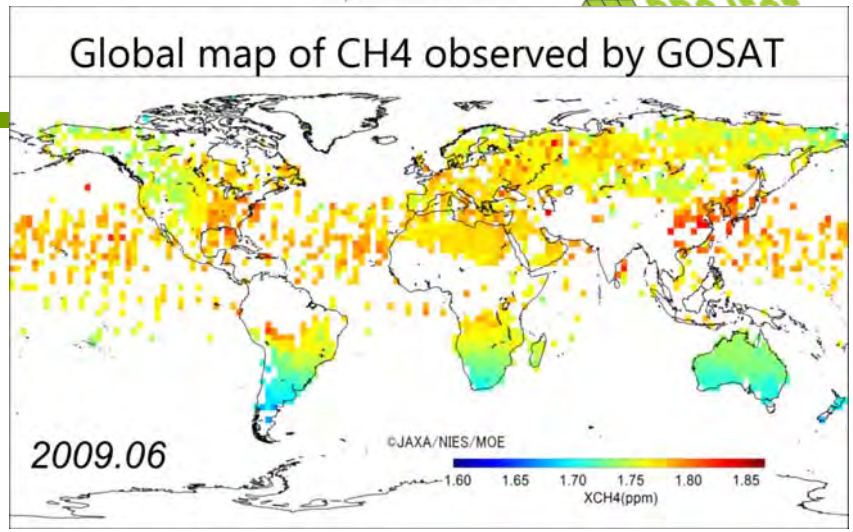
GOSAT Data Processing



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.

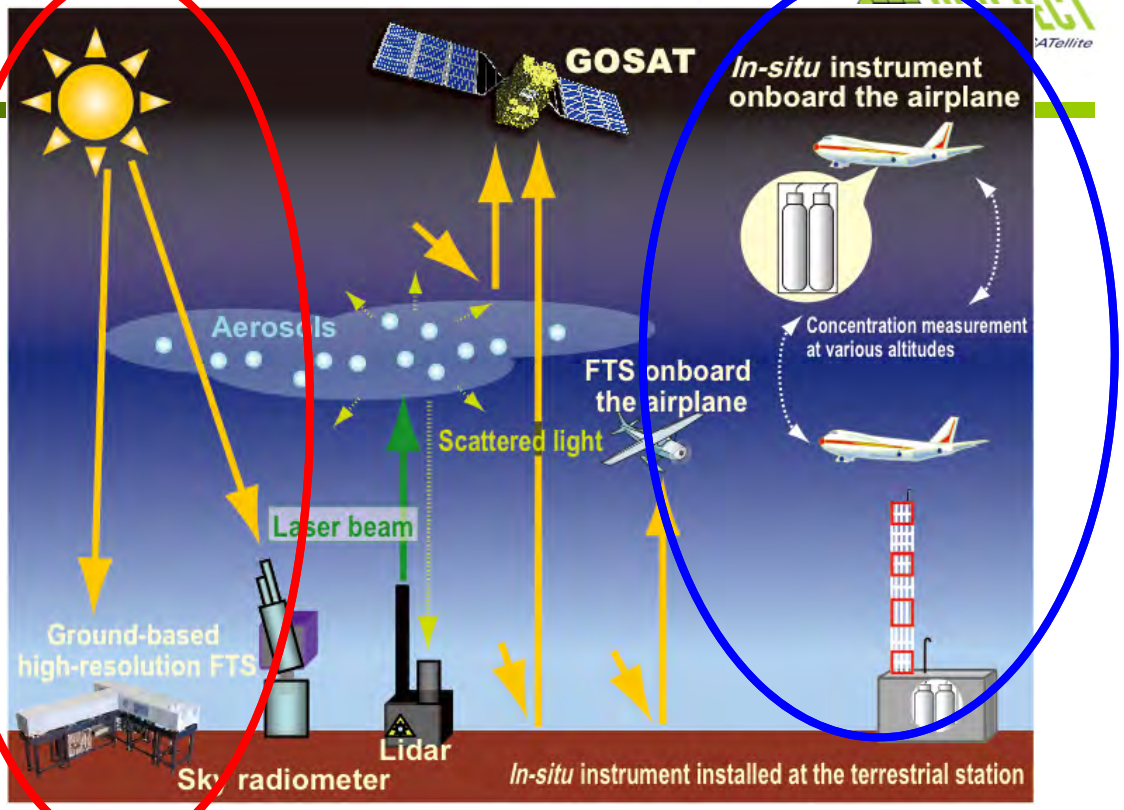
Schematic illustration of the GOSAT validation

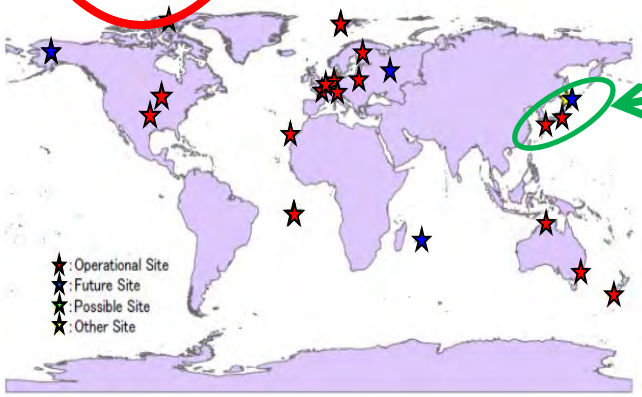
Ground-based high-resolution FTS

Aircraft measurements

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

in NIES (Tsukuba)

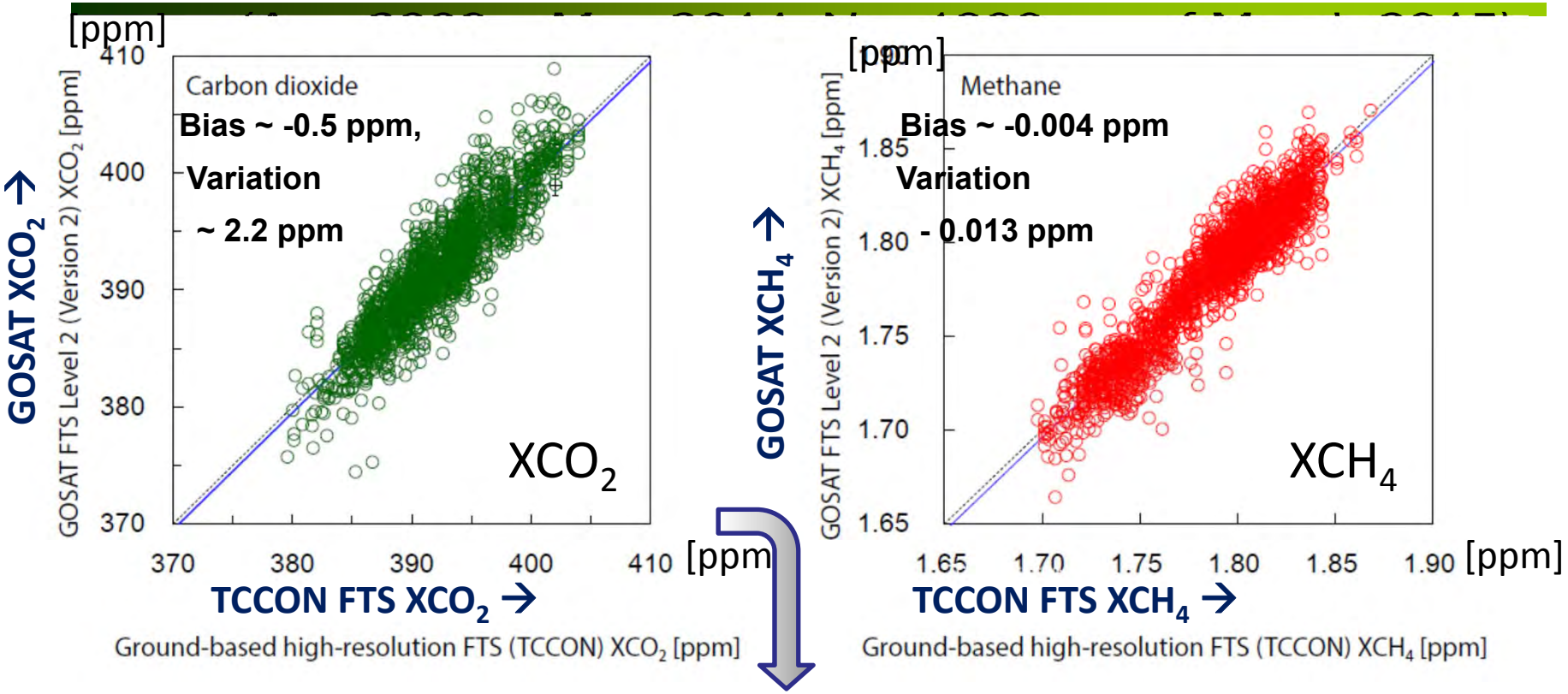




Tsukuba, Rikubetsu, Saga

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

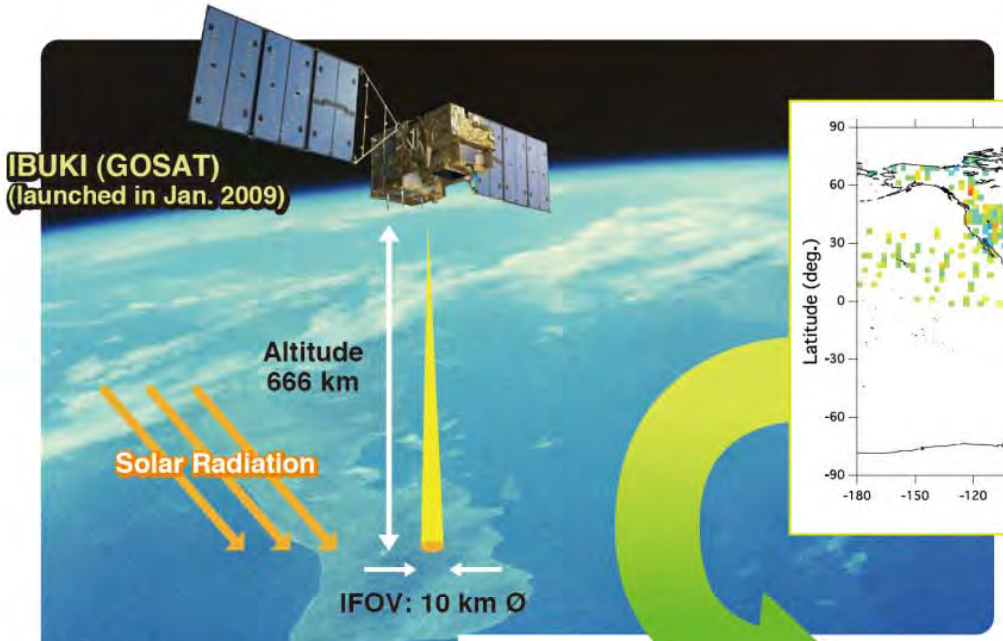
Validation of GOSAT (TANSO-FTS SWIR) Level 2 Data with TCCON data（Ver.02.21）

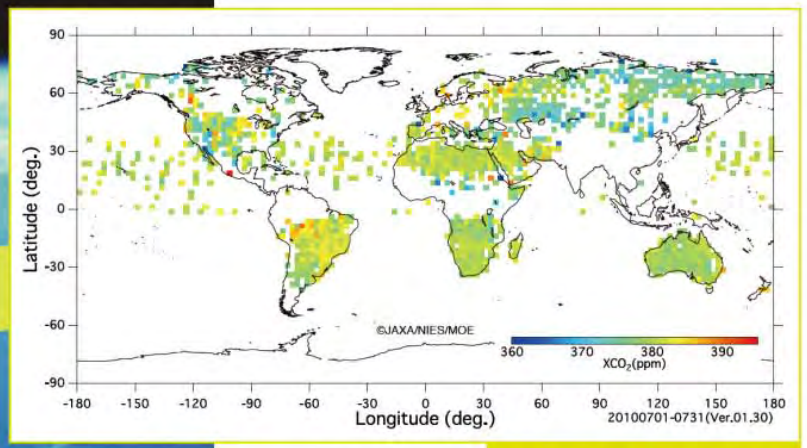


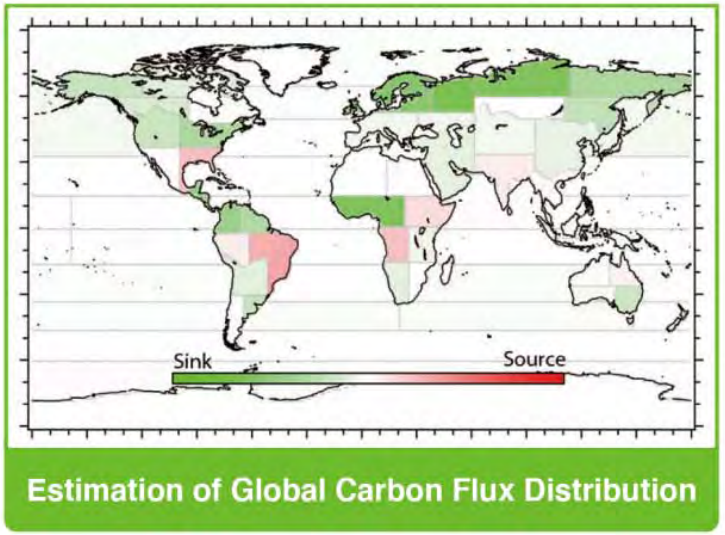
- Slightly lower values (negative biases) of GOSAT
- Standard Deviation is lower than 1 %, respectively

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

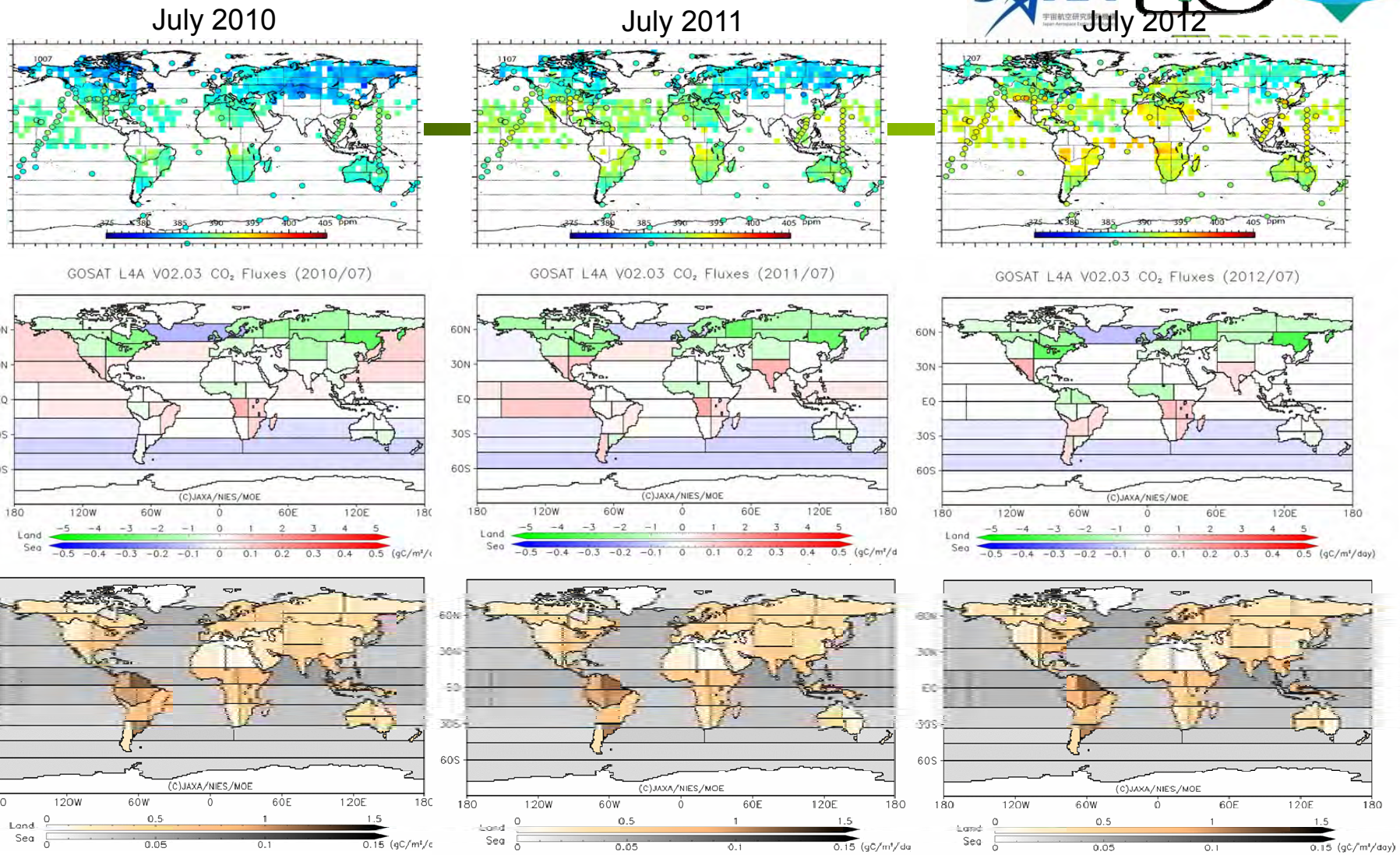
Contribution of satellite data to carbon flux







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

Time series of monthly regional flux estimates

Jun. 2009 – Oct. 2012 (41 months)

Upper

Green: Prior estimate

Red: Posterior estimate by GV only

Blue: Posterior estimate by GV + GOSAT

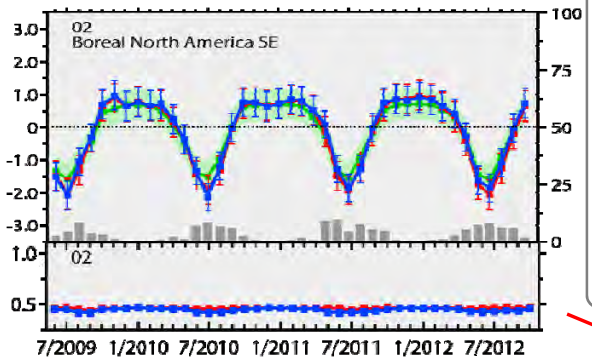
Unit: gC m^{-2} day^{-1}

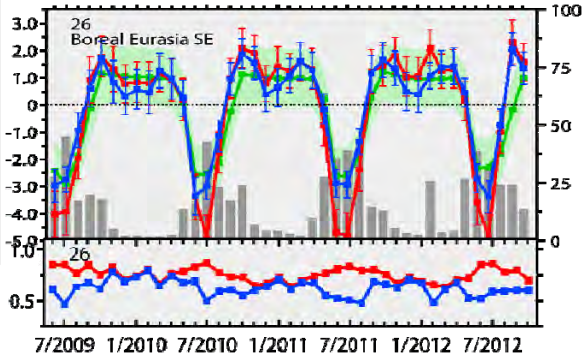
Gray bar: Flux uncertainty reduction (%)

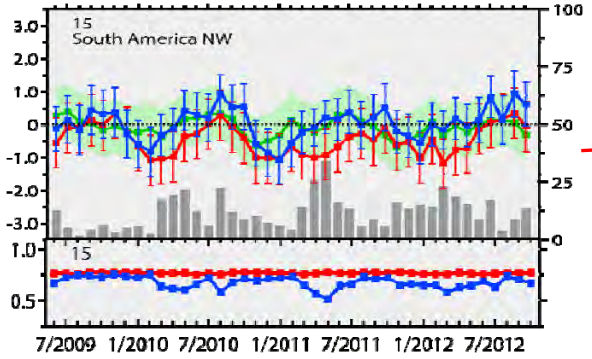
Lower

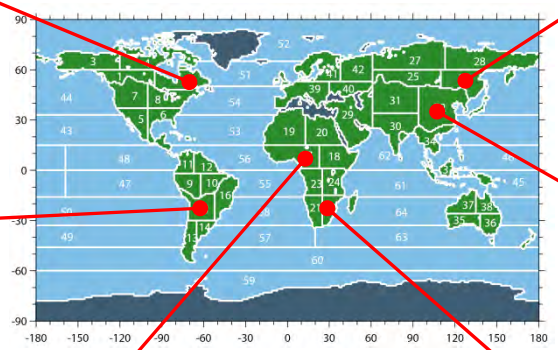
Red: Flux unc. (GV-only estimate)

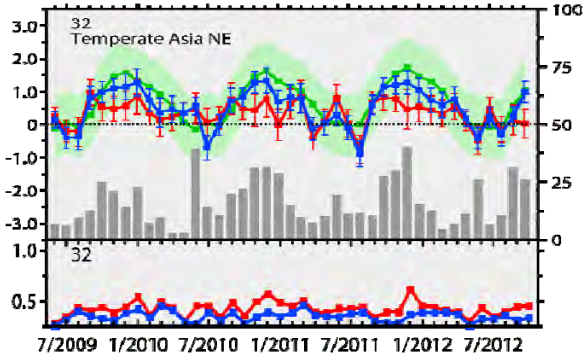
Blue: Flux unc. (GV +GOSAT estimate)

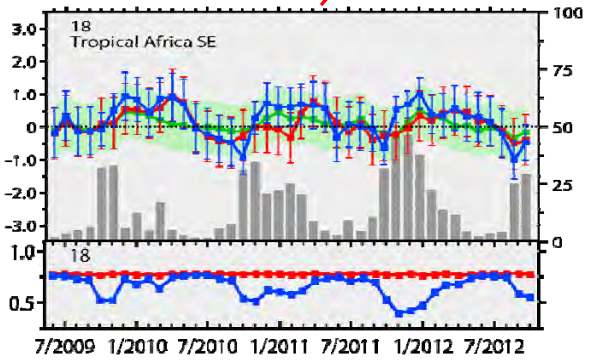


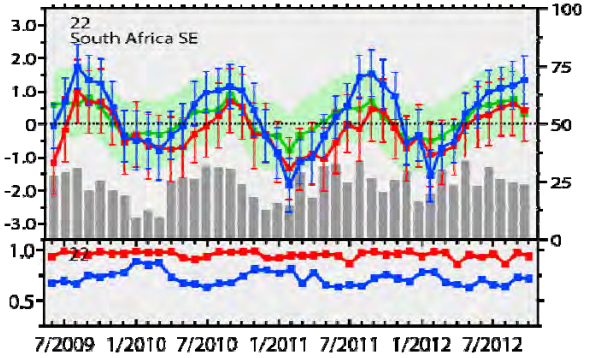










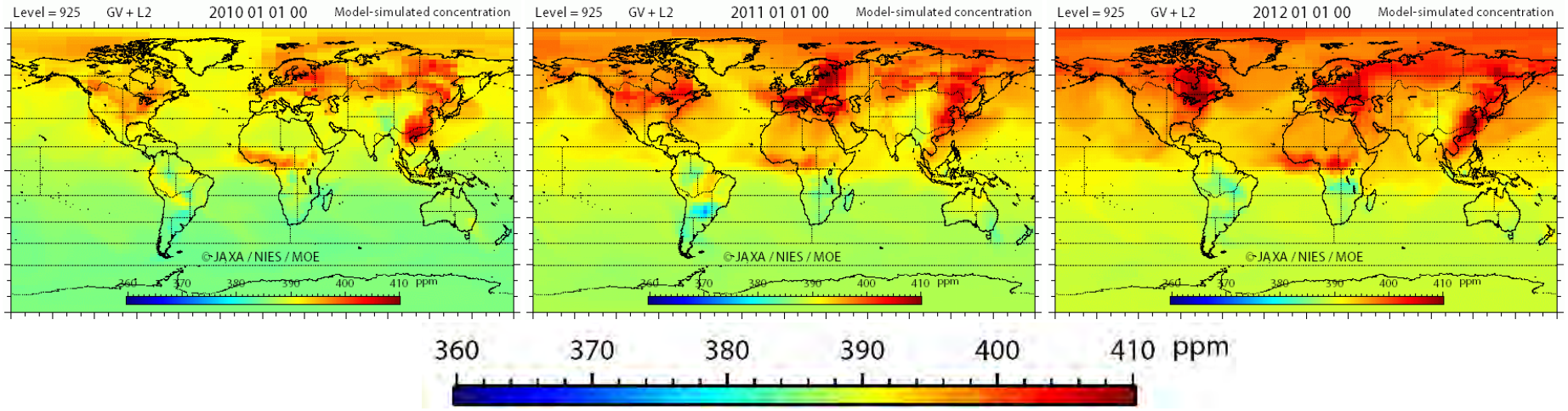


GOSAT L4B Data Product (V02.03)
Model-simulated CO_2 concentration

◆ (6hr-step, 0.925 sigma-level (~ 800m), 2.5° × 2.5° grid)

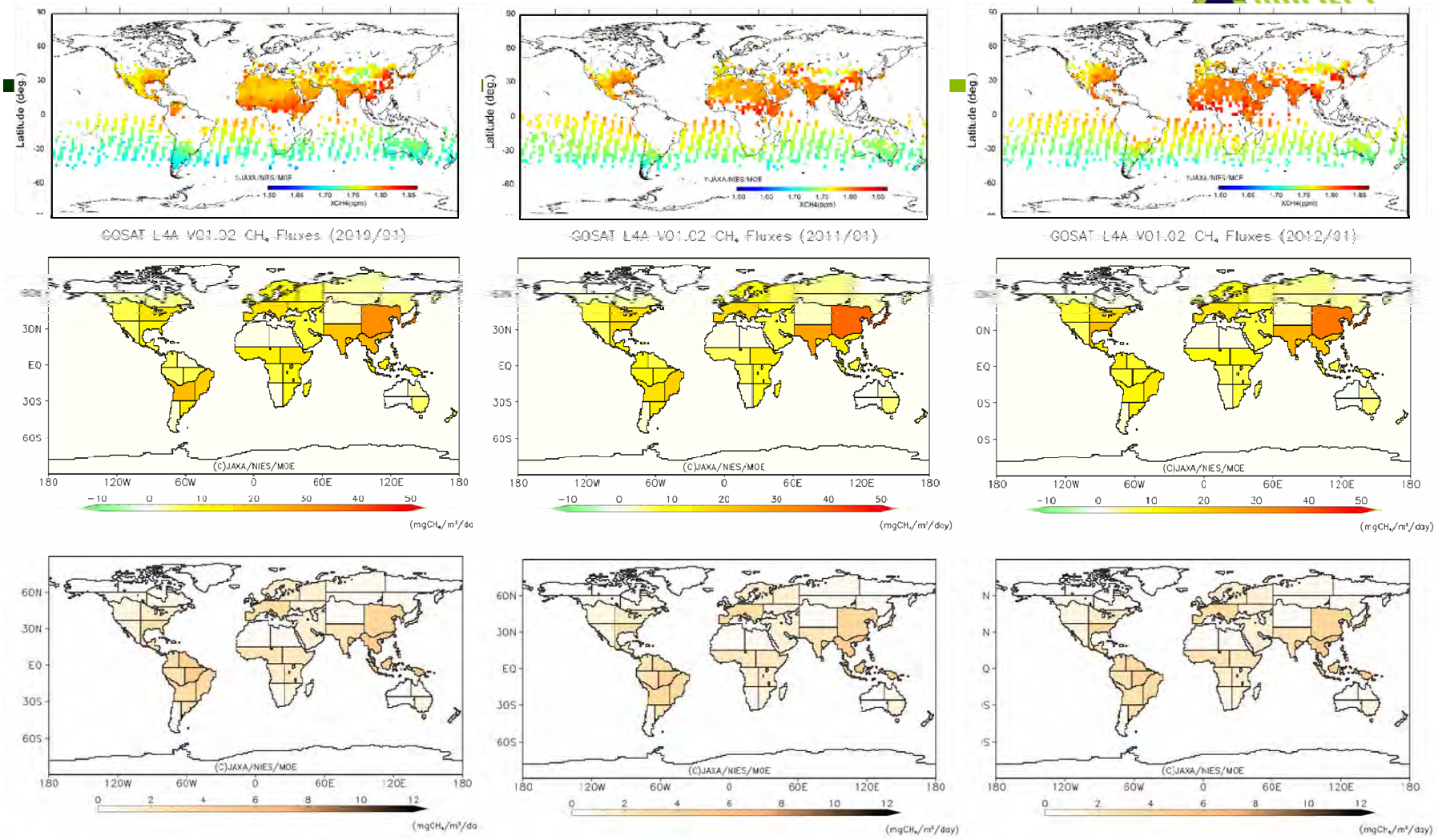
MM DD HH
01 01 00

2010 2011 2012



Monthly CH_4 Flux Estimates and Uncertainties

January 2010 | January 2011 | January 2012

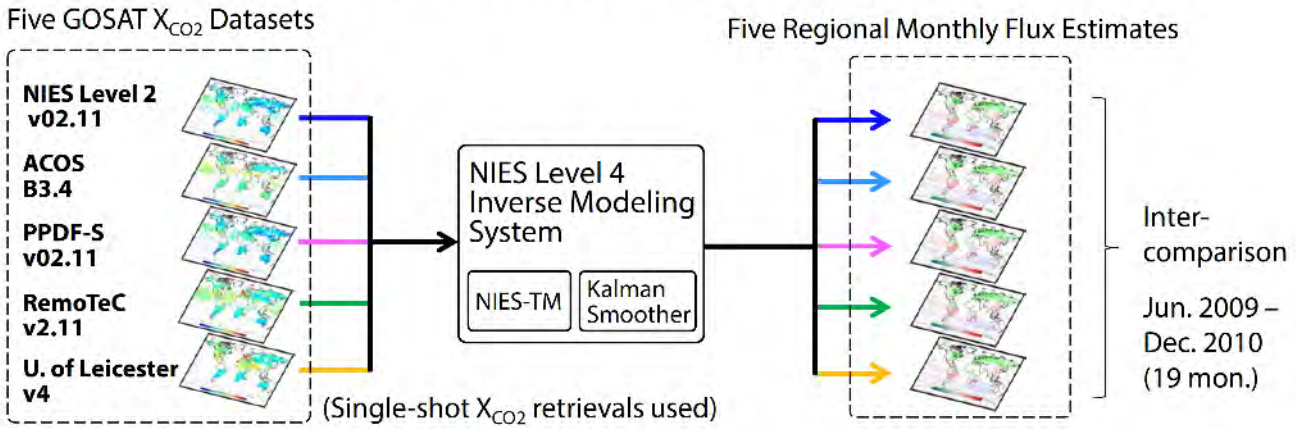


Top: monthly-mean GOSAT XCH_4 data gridded to 2.5° × 2.5° mesh (input to flux estimation)
Middle: Monthly flux estimates (GOSAT Level 4A CH_4)
Bottom: Flux uncertainty

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

Model Intercomparison with international research groups

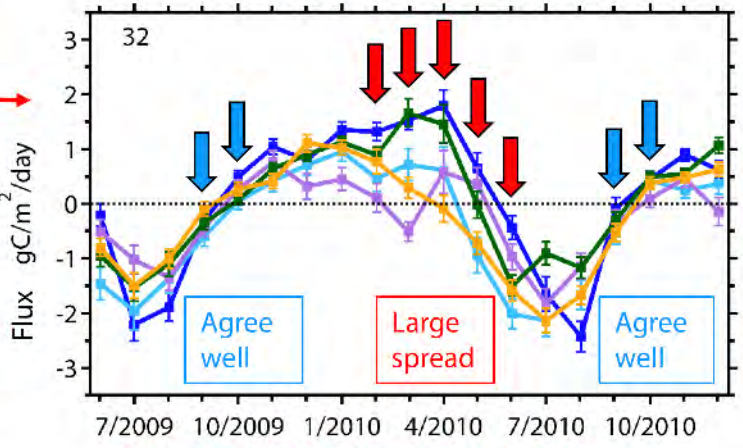
Single-system GOSAT inversion inter-comparison (Transcom 3 subject)



64 Land/Ocean Regions

(~3000 km × ~3000 km mesh)

19-mon. time series: five fluxes estimated for Reg. 32



These monthly spreads add up to > 1GtC/yr differences → not negligible!

(by H. Takagi & S. Maksyutov (NIES))

GOSAT Research Promotion
(International Research Collaboration)

◆Research Announcement

- **Research Topics**
  1) Calibration
  2) Data Processing Algorithm
  3) Validation
  4) Carbon Balance Estimation and Atmospheric Transport Models
  5) Data Application
- **First announcement was issued in March 2008.**
- **10 announcements were issued and 126 research subjects were adopted by now.**
- **46 subjects have been completed.**

Japan Aerospace Exploration Agency (JAXA)

National Institute for Environmental Studies (NIES)

Ministry of the Environment (MOE)

GOSAT Research Announcement (RA) Adopted PI's Country List

	1st RA	2nd RA	3rd RA	4th RA	5th RA	6th RA	7th RA	8th RA	9th RA	10th RA	
Country	**2008**	**2009**	**2010**	**2012**	**2013**	**2013**	**2014**	**2015**	**2015**	**2016**	**Total**
Japan	23	8	1	1	1			1		1	36
USA	7	8	3	1		3					22
Germany	6	2		1	1						10
China	1		2	1	2						6
Canada	3		2								5
France	2	2	1								5
Netherlands	3	1	1								5
UK	2	3									5
Russia	4										4
Finland		2	1		1						4
Australia			2					1			3
India		1	1								2
Indonesia			1				1				2
Italy		2									2
Korea		1	1								2
Malaysia				1						1	2
Norway		1								1	2
Spain		1	1								2
Belgium		1									1
Beralus									1		1
Brazil		1									1
Czech		1									1
NewZealand	1										1
Singapore		1									1
Taiwan, ROC			1								1
Total	**52**	**36**	**18**	**5**	**5**	**3**	**1**	**2**	**1**	**3**	**126**

(PI: Principal Investigator)

GOSAT Research Announcement (RA) Adopted Subject Topics

	1st RA	2nd RA	3rd RA	4th RA	5th RA	6th RA	7th RA	8th RA	9th RA	10th RA	
Research Category	2008	2009	2010	2012	2013	2013	2014	2015	2015	2016	Total
Calibration	4										4
Data Processing Algorithm	11	7	2	1					1		22
Data Validation	15	7	1	2	2	1		1		1	30
Source and Sink Estimation	6	8	3								17
Data Application	16	14	9	2	3	2	1	1		2	50
Data Application/Data Validation			2								2
Data Application/Source and Sink Estimation			1								1
Total	52	36	18	5	5	3	1	2	1	3	126

Rights and duty of the RA PIs

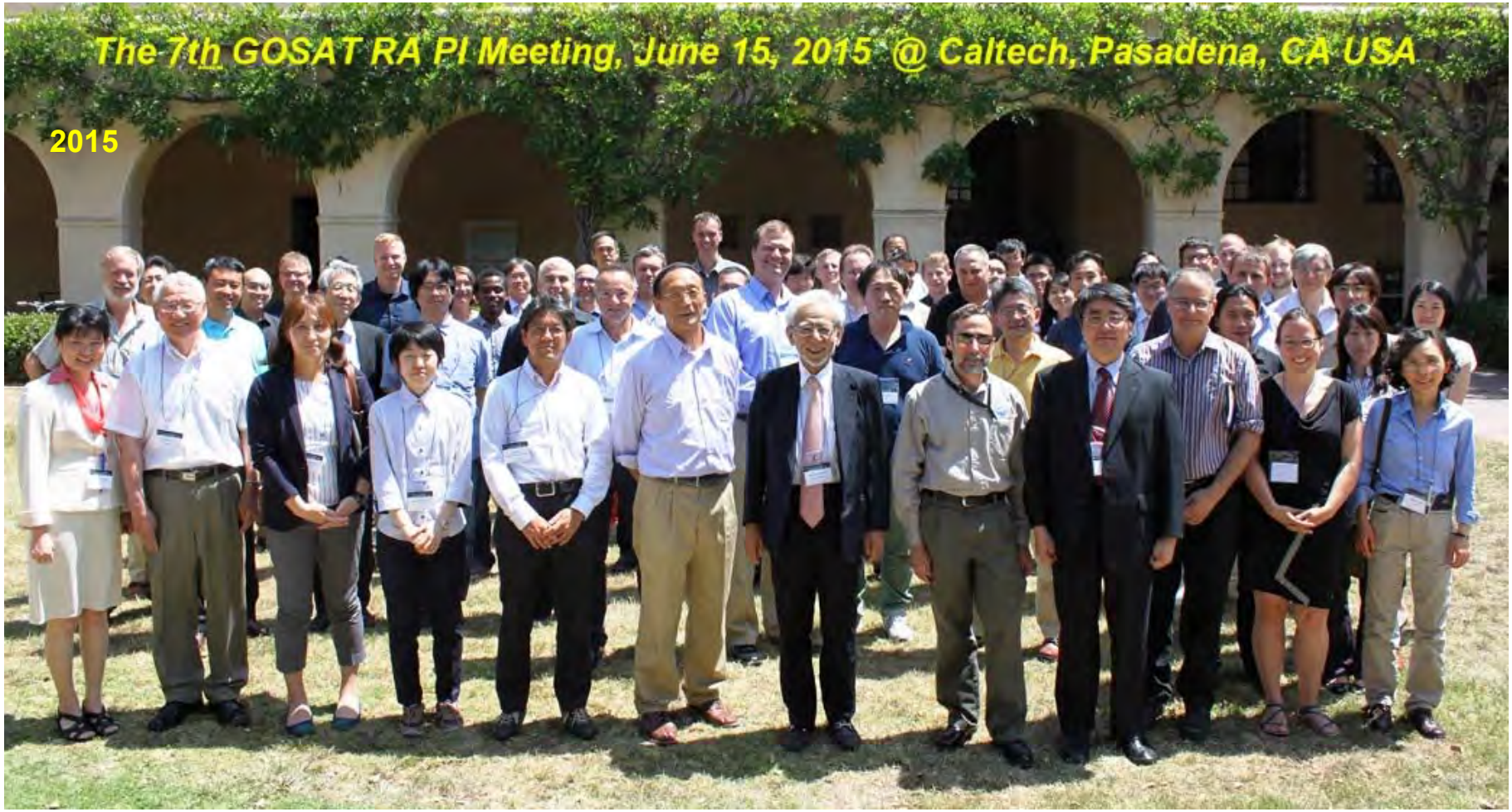
◆ Rights

1. To submit the GOSAT observation requests.
2. To request the delivery of standard and research products without any cost prior to their release to the general users.
3. To request to process FTS SWIR L2 data products without any screening criteria of the data quality.
4. To obtain additional information of the FTS SWIR L2 data products (column abundances of CO_2, CH_4, and H_2O (SWIR)), so-called the “sub-datasets” of the FTS L2 data products.
5. To participate in the GOSAT RA PI Meeting (closed meeting)

◆ Duty

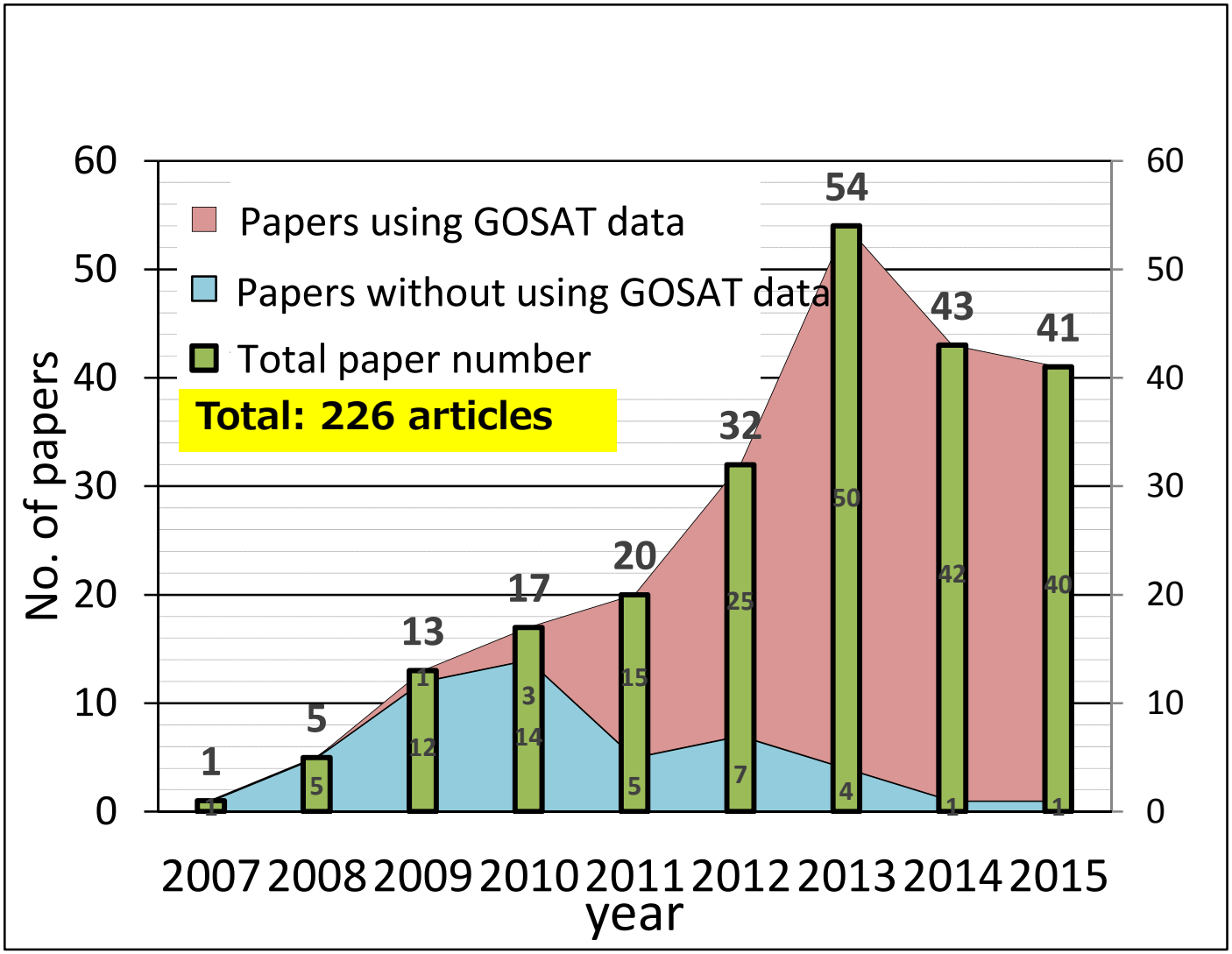
1. To write a progress report and an interim report once in a year.
2. The final report and a summary report should be written after completion.
3. These reports will be evaluated by the GOSAT RA Selection and Evaluation Committee.

GOSAT RA PI Meetings



GOSAT-related Published Papers

(as of December 2015)



Plans for the Next Five Years

- At the first stage of the GOSAT project, we have designed the data handling facility (DHF) to process, re-process, store, distribute, and improve processing codes for 5-year nominal mission period.
- But GOSAT is still operating, and now in 8th year operation. Therefore, we have prepared equipment to process for five years more, and will update the DHF system under the condition of keeping operation.
- From this year, we will re-process the CAI data, minimum-surface reflectance, cloud flag, and then FTS SWIR L2 X_{CO2} and X_{CH4} by using an assimilation – SPRINTARS (aerosol transport model) for the data during April 2009 – May 2014.