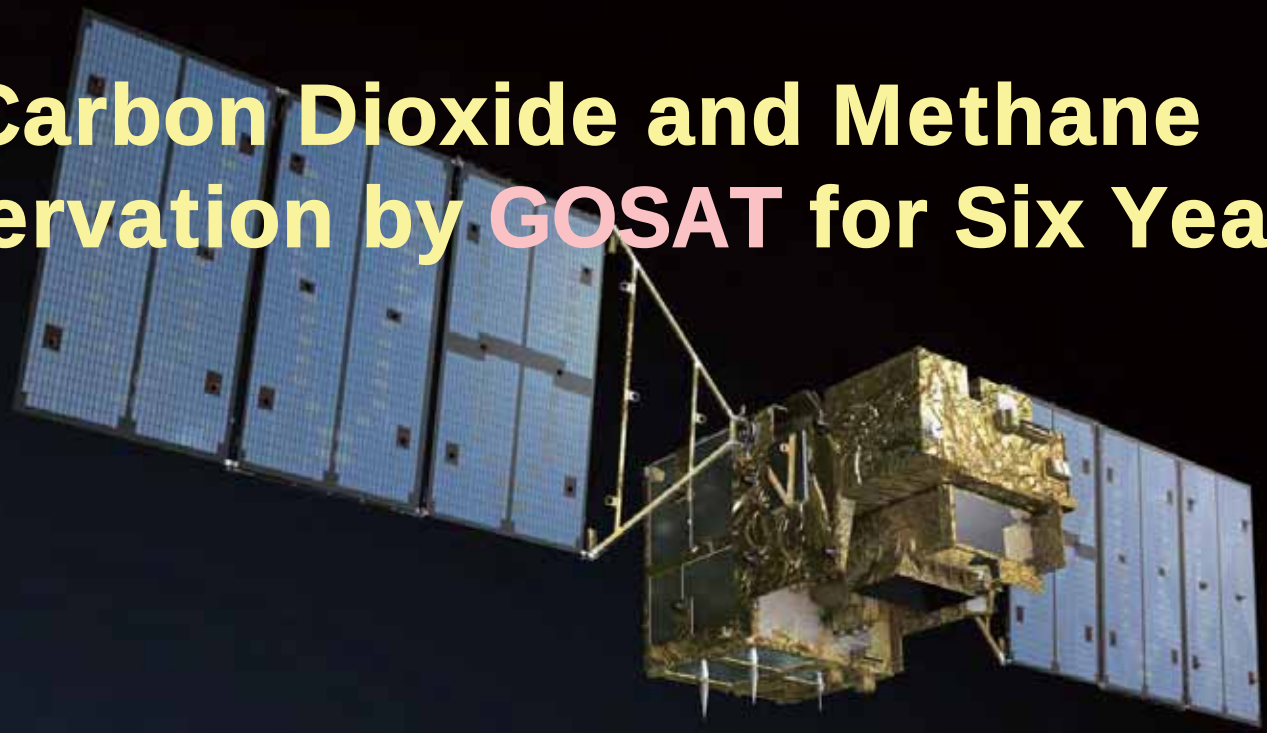
ATMOS 2015 Workshop, 8-12 June 2015, Univ. of Crete, Heraklion, Greece

Carbon Dioxide and Methane Observation by GOSAT for Six Years



T. Yokota, N. Kikuchi, Y. Yoshida, M. Inoue, I. Morino,
O. Uchino, H-S Kim, H. Takagi, M. Saito,
S. Maksyutov, F. Kawazoe, and M. Ajiro

Center for Global Environmental Research (CGER)

National Institute for Environmental Studies (NIES), Japan

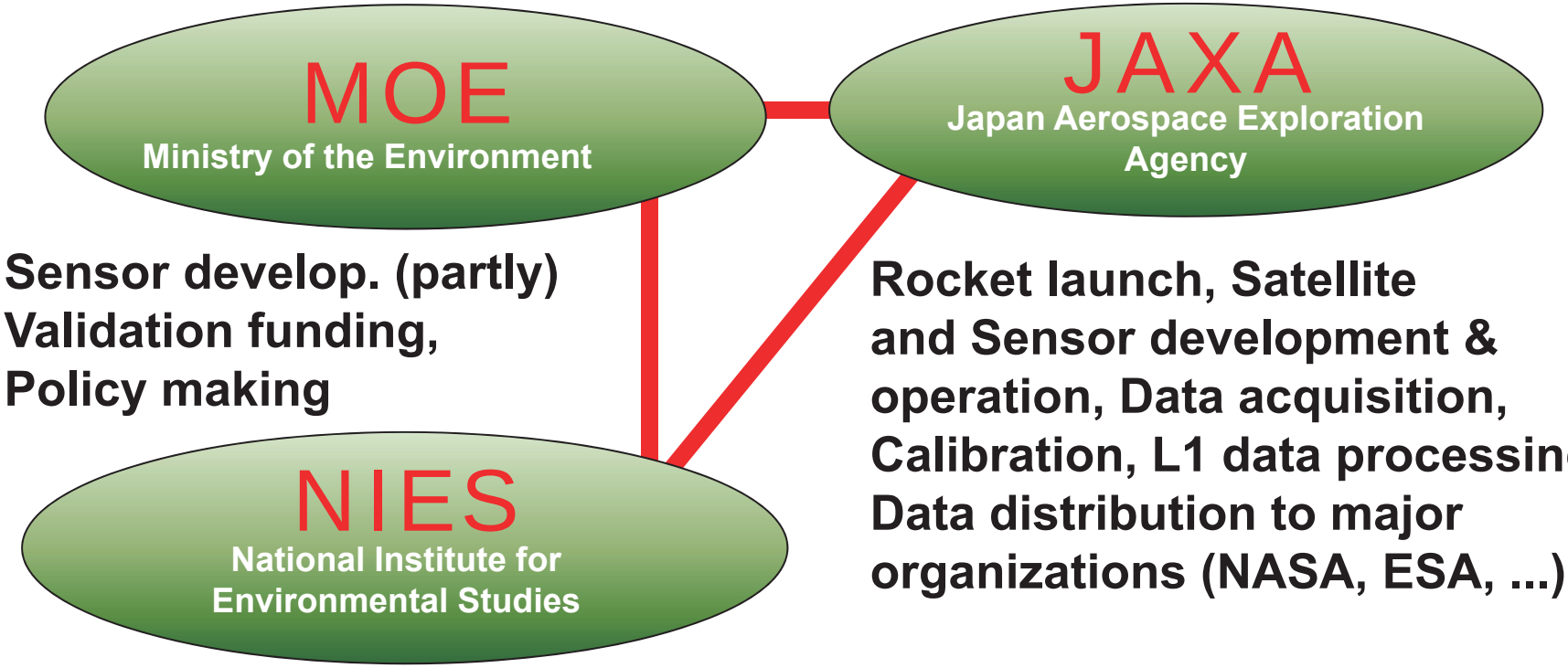
Contents

- Introduction
  - GOSAT mission overview
- Resent remarkable events in 2014 & 2015
- Six years of the GOSAT project
  - Observation of columnar CO_2 & CH_4 amounts
  - Monthly regional flux estimation of CO_2 and CH_4 by using GOSAT data for three years
- Future perspective
  - GOSAT-2 project

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

Organizations Promoting the GOSAT Project

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



**Sensor develop. (partly)
Validation funding,
Policy making**

Rocket launch, Satellite and Sensor development & operation, Data acquisition, Calibration, L1 data processing, Data distribution to major organizations (NASA, ESA, ...)

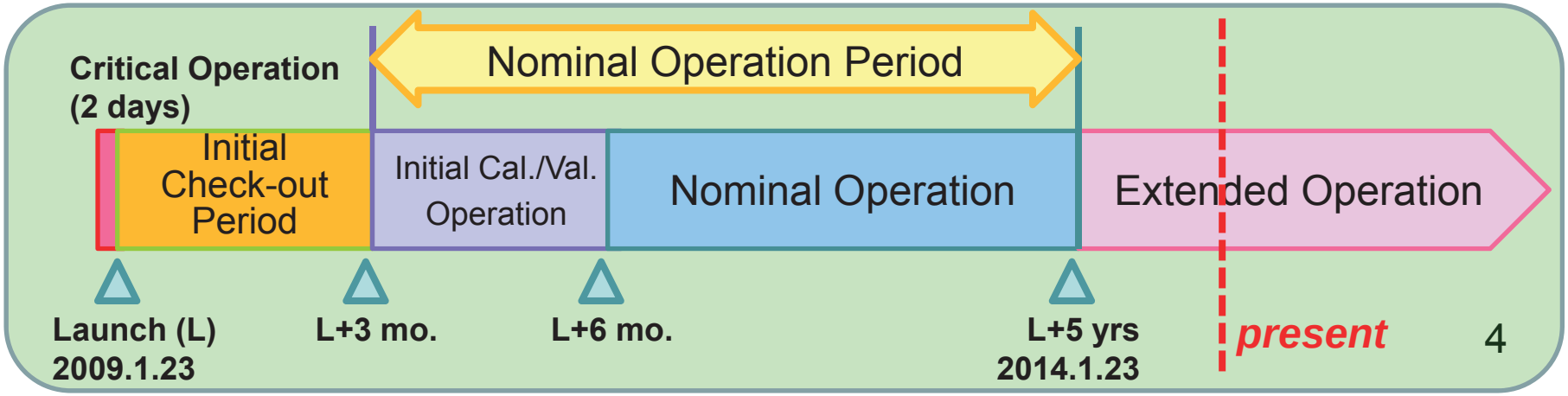
Developing & improving GHG retrieval algorithms, L2 and higher level data processing, Data validation, Estimating carbon fluxes, Data product distribution

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 –present status -

- **GOSAT** was launched on January 23, 2009 and has been in operation for more than six 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.

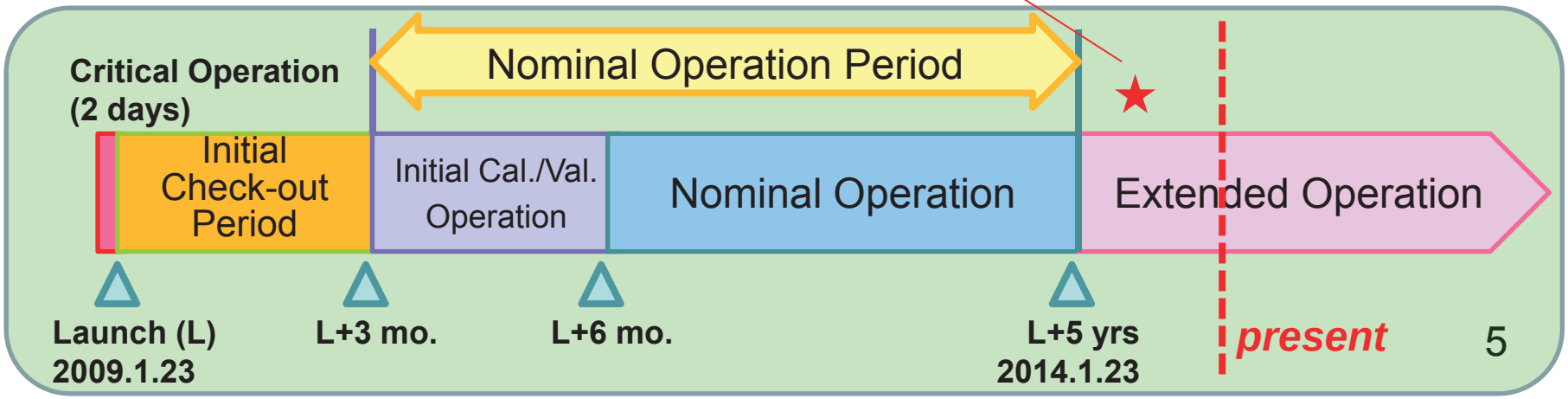


GOSAT Project –present status -

On 25 May 2014, rotation of one of the two solar paddles stopped. However, electric power supplied from a single paddle is sufficient enough to operate all of the onboard equipment nominally.

Observation recovered on 1 June 2014. GOSAT still survives with its single lung.

- Uncertainties in monthly regional flux estimates of CO_2 and CH_4 have been decreased by using **GOSAT** data.

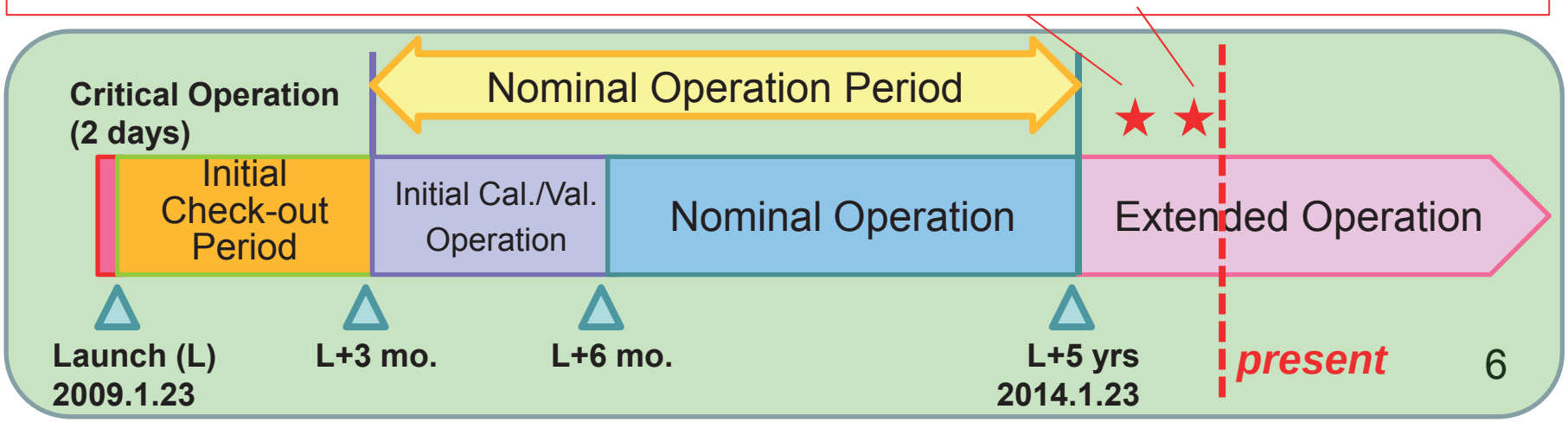


GOSAT Project –present status -

On 25 May 2014, rotation of one of the two solar paddles stopped.

The FTS pointing mechanism became unstable since September 2014. JAXA ceased TANSO-FTS observation on 16 December 2014, and made careful discussions and ground-based tests, and finally switched the gimbal mirror system to the redundant sub-system on 26 January 2015 with consent of MOE, NIES, and GOSAT Science team members.

TANSO-FTS data have been renewed since February 2015 (with a different sensor characteristics).

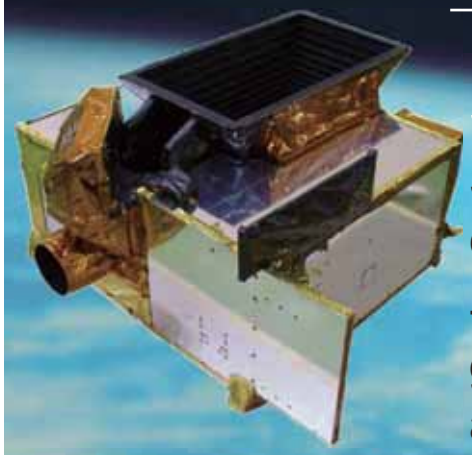


TANSO onboard GOSAT

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

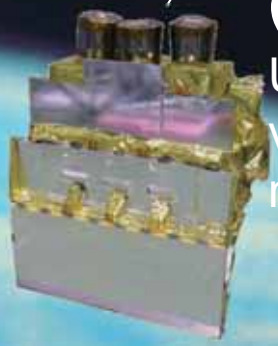
TANSO (炭素) = Carbon



TANSO-FTS (Fourier Transform Spectrometer)

SWIR reflected on the earth's surface

-TIR radiated from the ground and the atmosphere

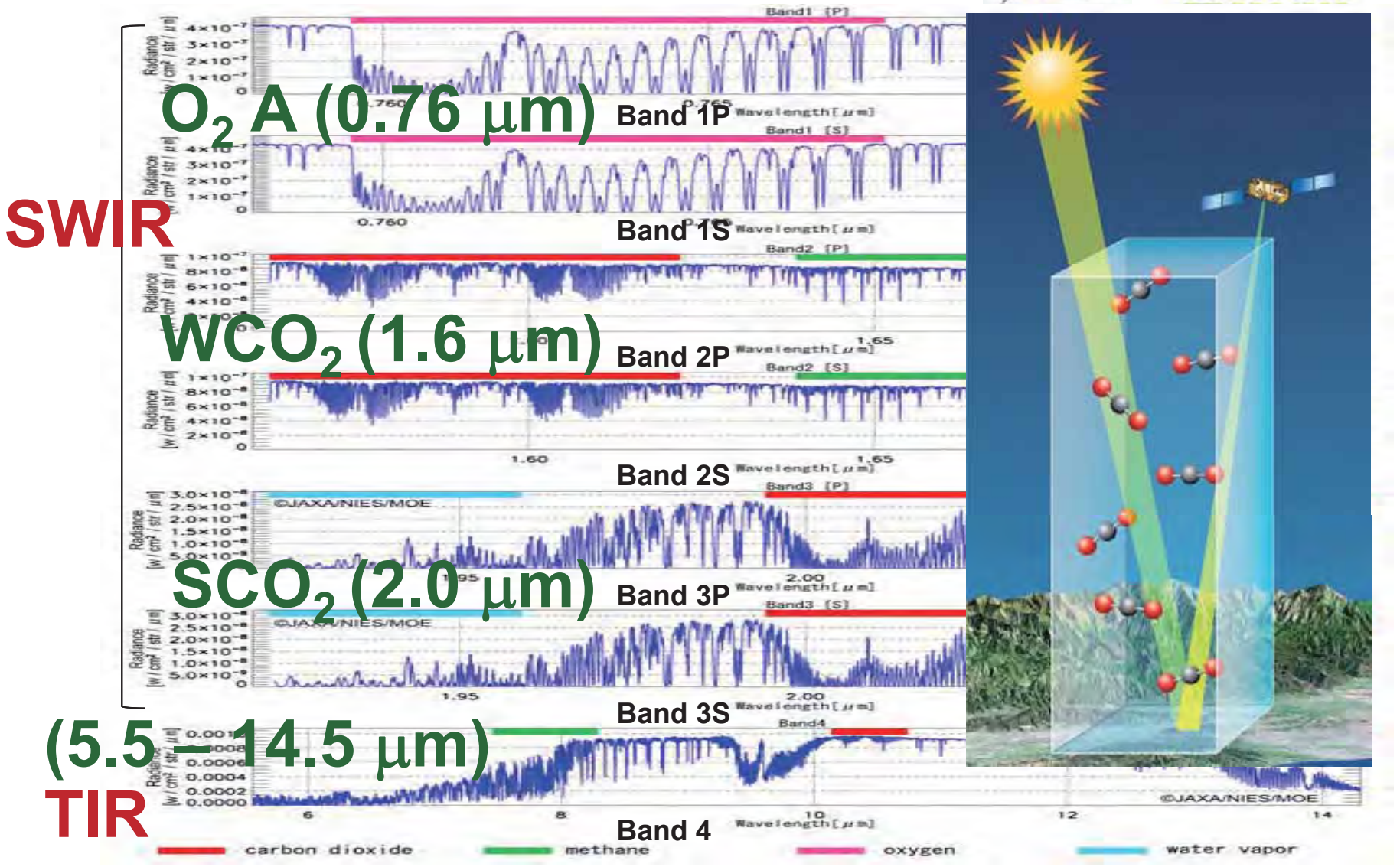


TANSO-CAI (Cloud and Aerosol Imager)

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

(Courtesy of JAXA)

TANSO-FTS Level 1B spectra



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

9

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
		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
		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)	
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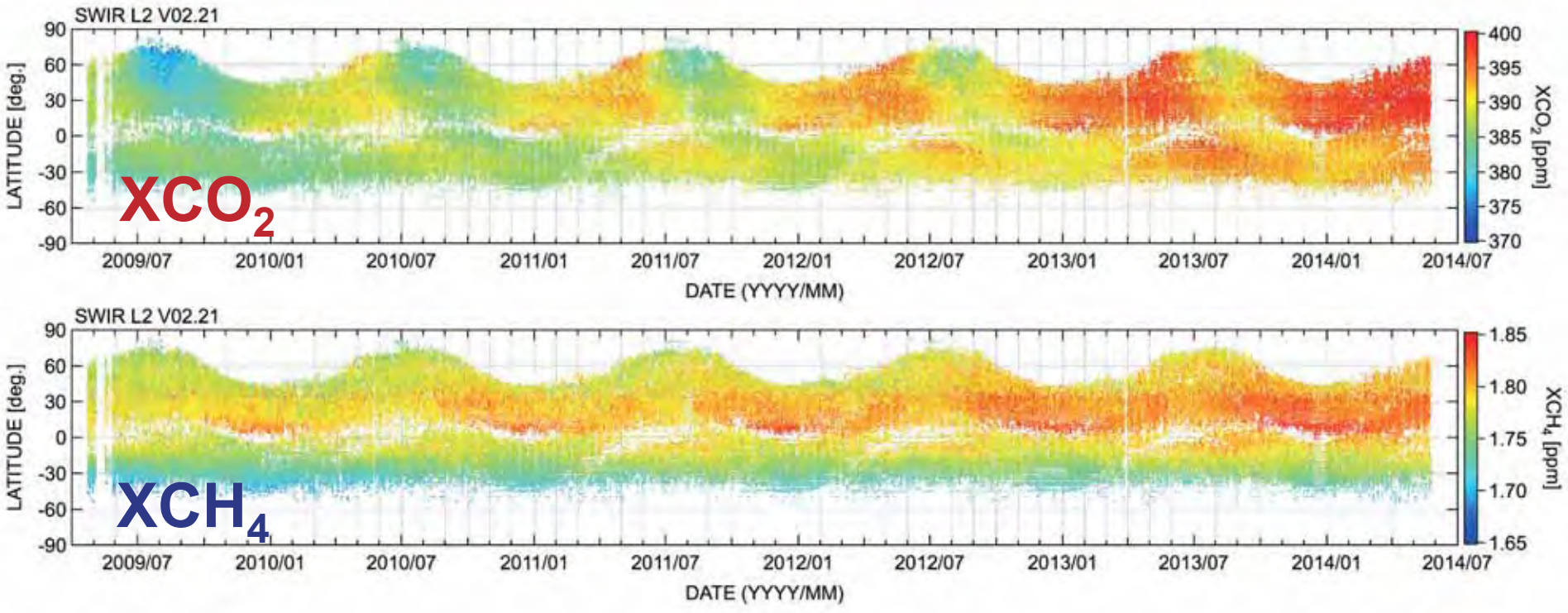
			L3 global NDVI	Vegitation index global distribution data (cloudy segments excluded)	per 15 days 30° × 60° (lat. × lon.)	
Level 4	L4A	-	L4A global CO_2 flux	CO_2 flux per each of 64 global regions (monthly average)	year (global)	Text/NetCDF
			L4A global CH_4 flux	CH_4 flux per each of 43 global regions (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		

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

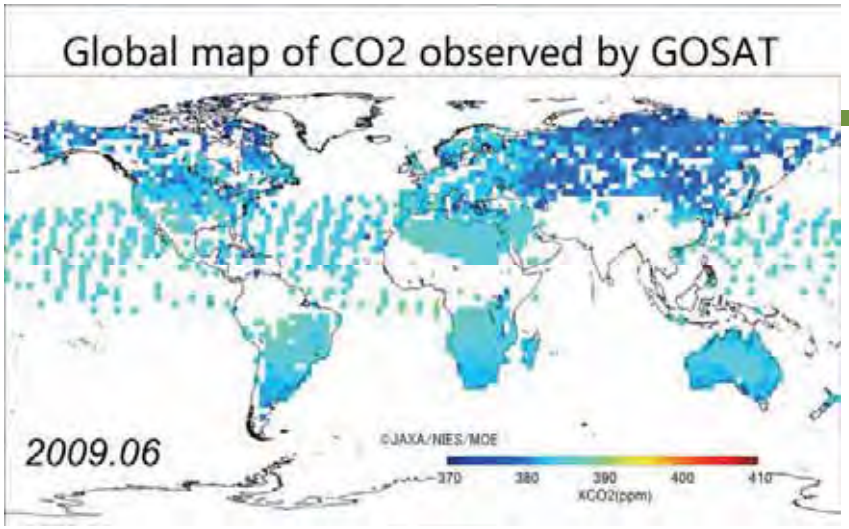
April 2009 - May 2014

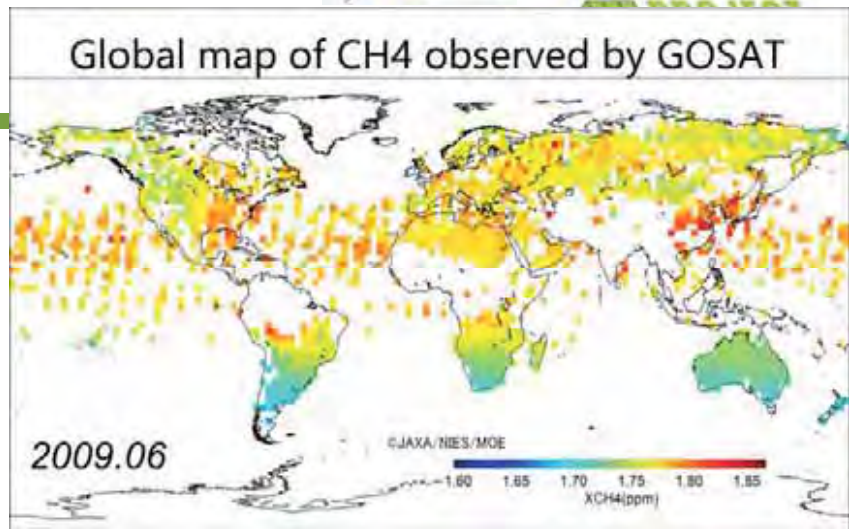


(by Y. Yoshida (NIES))

55-month-long GOSAT XCO_2 and XCH_4

(June 2009 – December 2013)

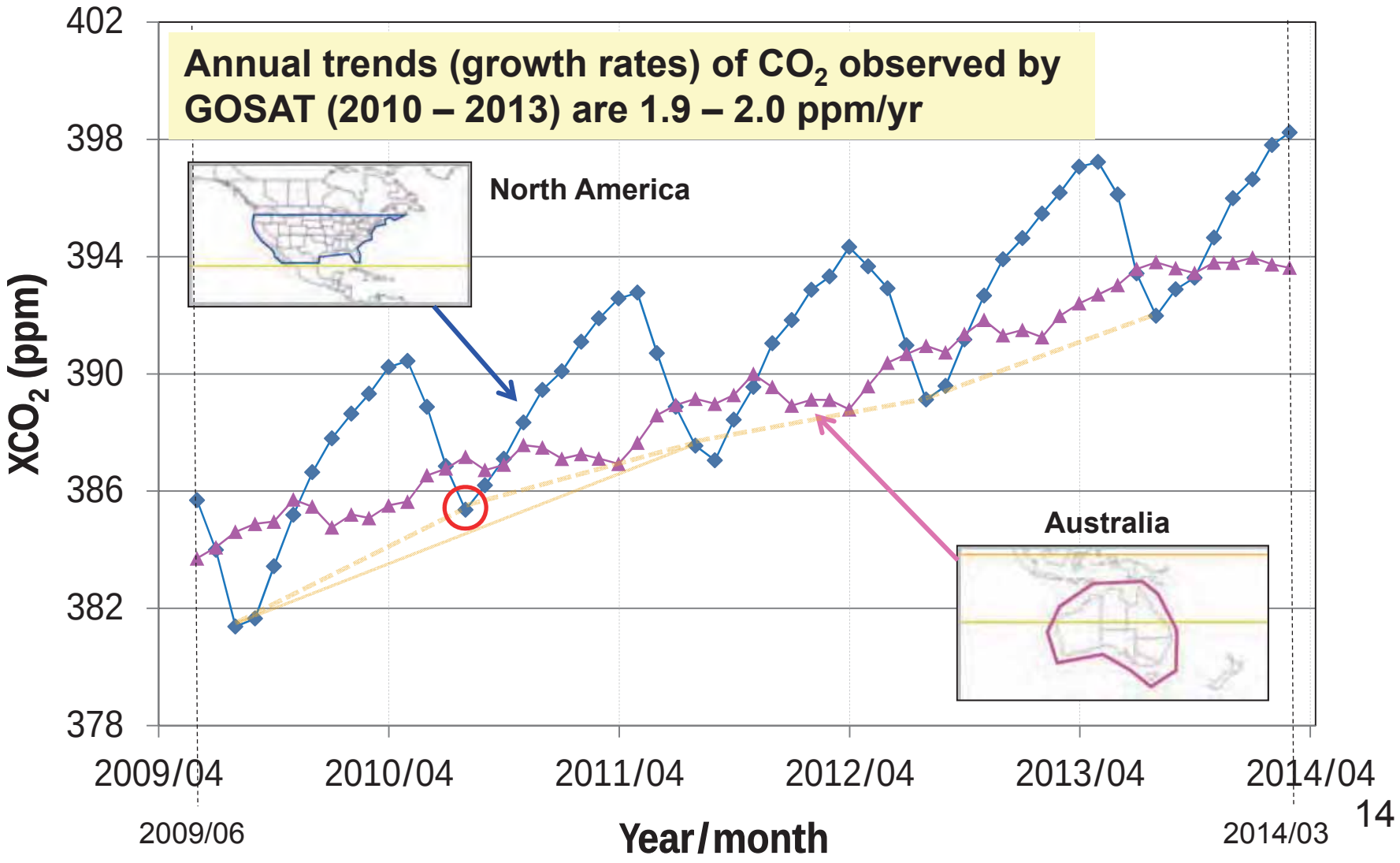




- Above movies are 1-month-moving average GOSAT XCO_2 and XCH_4 with three-day interval. The mesh size is 2.5 degree.
- Various interesting features are shown in these movies such as annual and seasonal variations of XCO_2 and localized anomalies of XCH_4.
- GOSAT obtained XCO_2 and XCH_4 data for more 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.

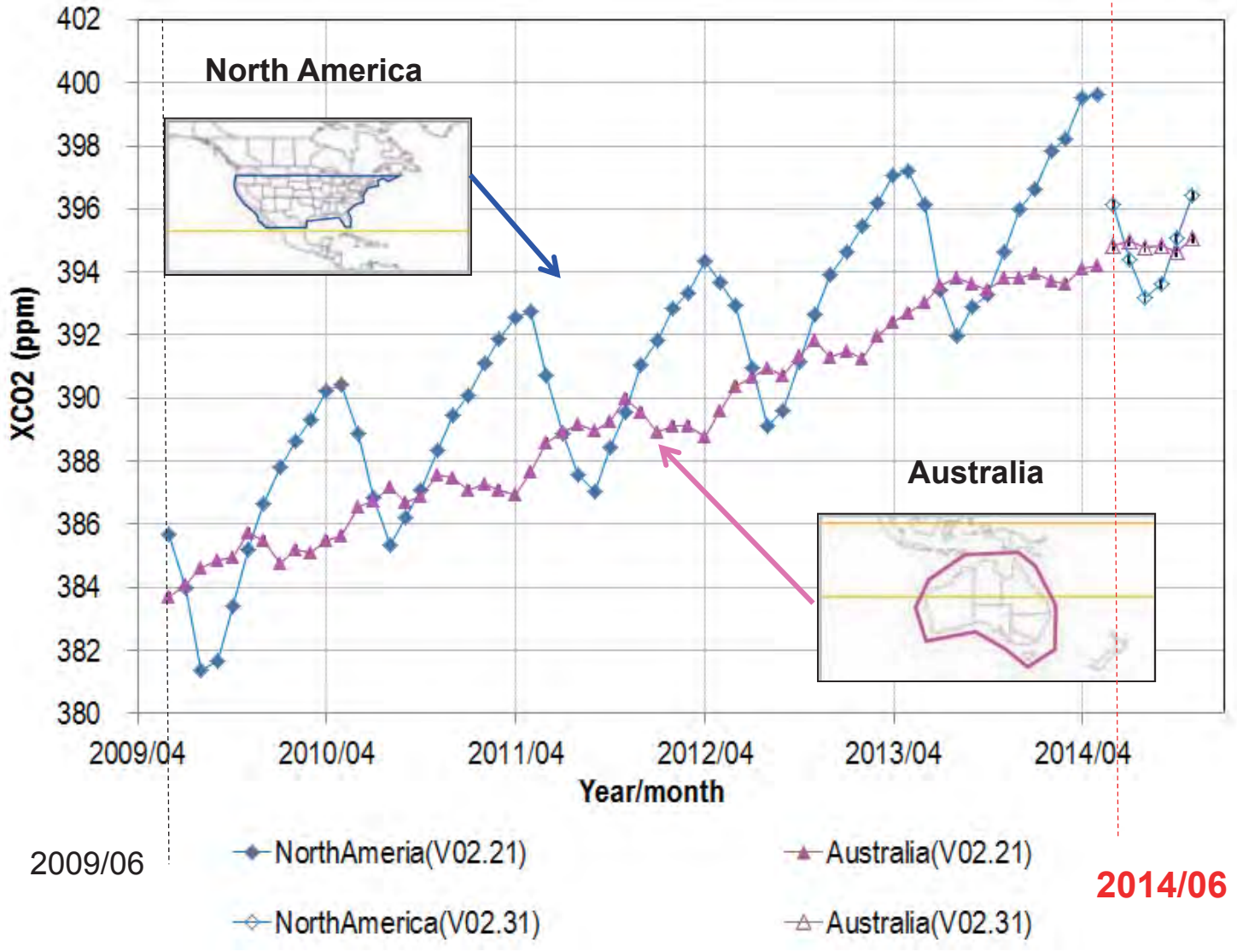
Monthly Regional Averages of XCO_2

(TANSO-FTS SWIR Level 2 (Ver.02.2*)



Monthly Regional Averages of XCO_2

(TANSO-FTS SWIR Level 2 (Ver.02.2*)

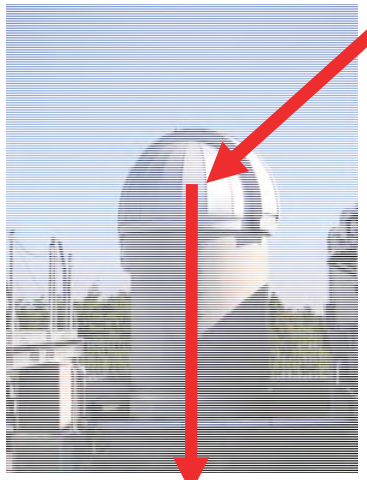


Schematic illustration of the GOSAT validation

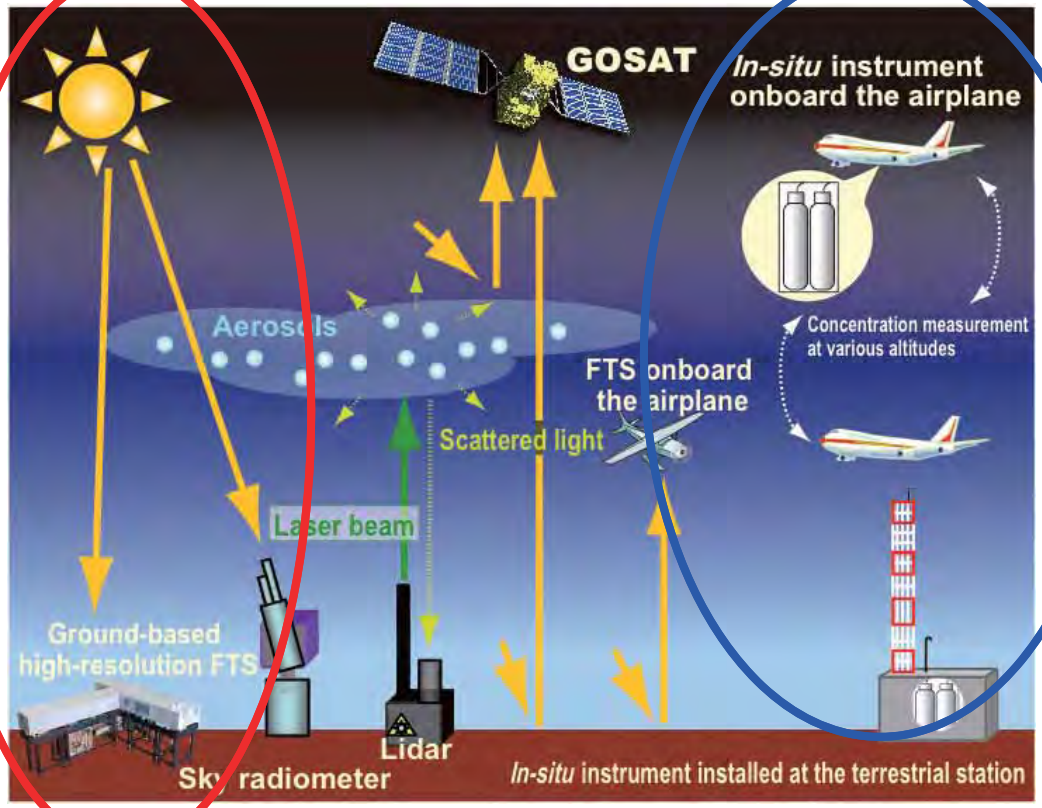
Ground-based high-resolution FTS

Aircraft measurements

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



in NIES (Tsukuba)



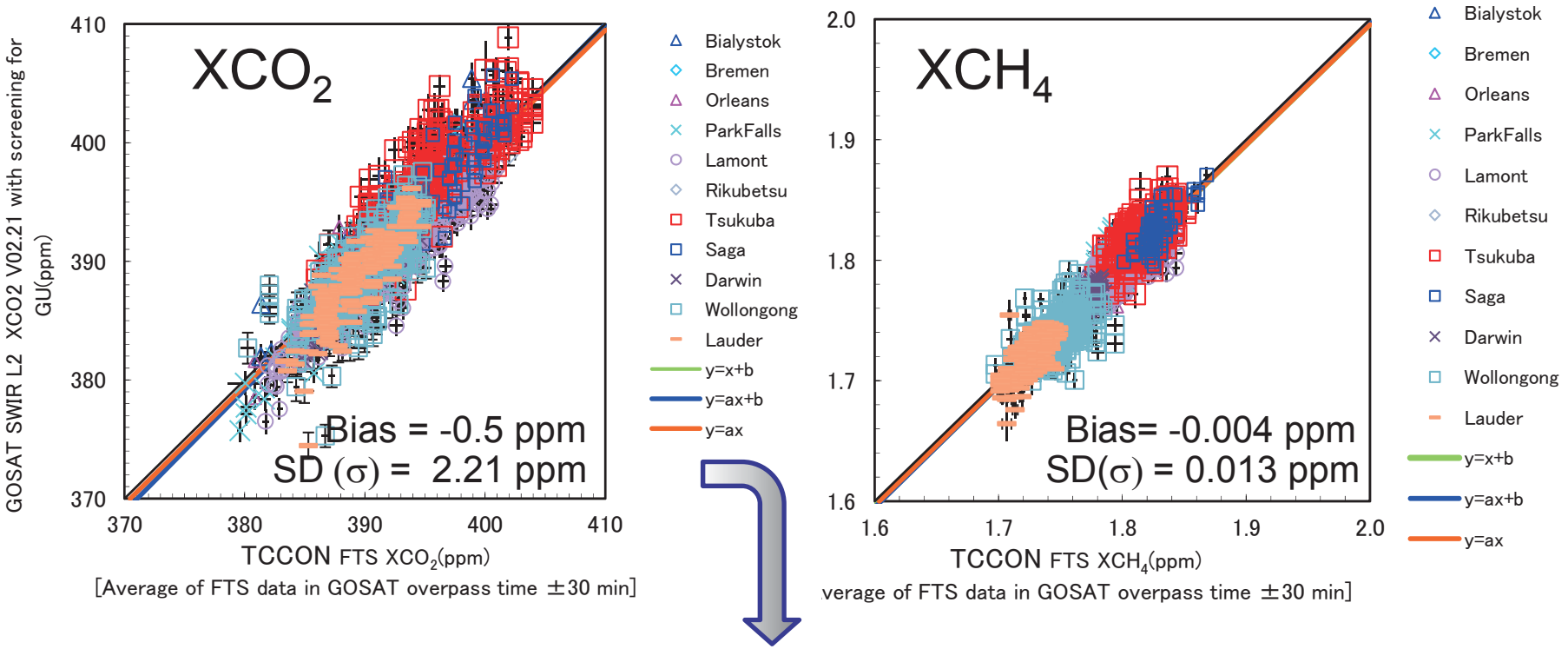
Tsukuba, Rikubetsu, Saga

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）

(Apr. 2009 – May 2014, N > 1800, as of March 2015)

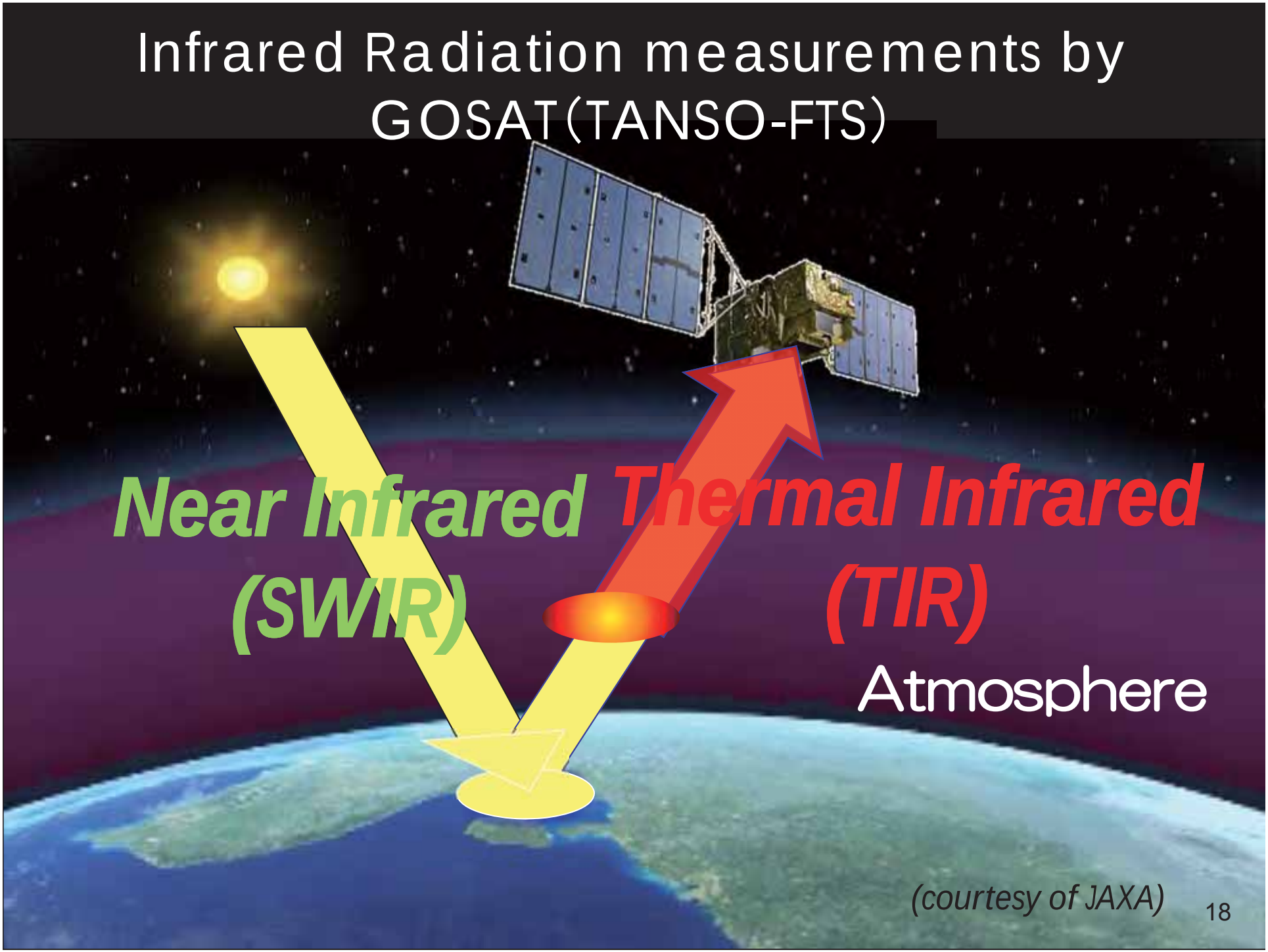
(cf。Yoshida, et al. (2013) amt-6-1533-2013)



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

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

Infrared Radiation measurements by GOSAT(TANSO-FTS)

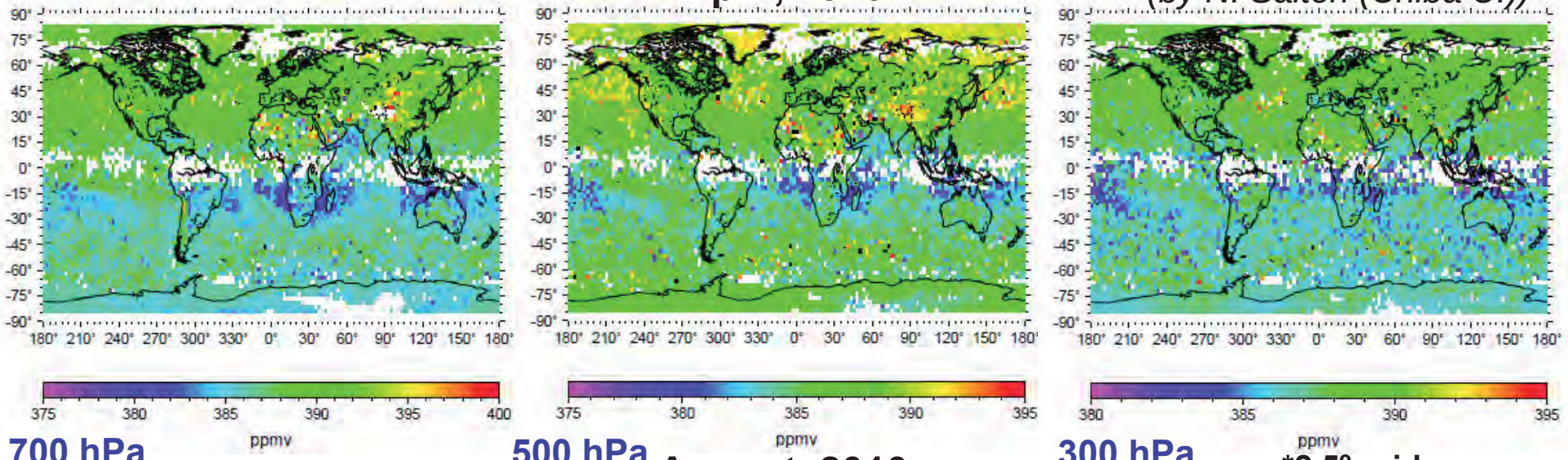


(courtesy of JAXA)

TIR L2 V01.00 CO_2 monthly average

April, 2010

(by N. Saitoh (Chiba U.))



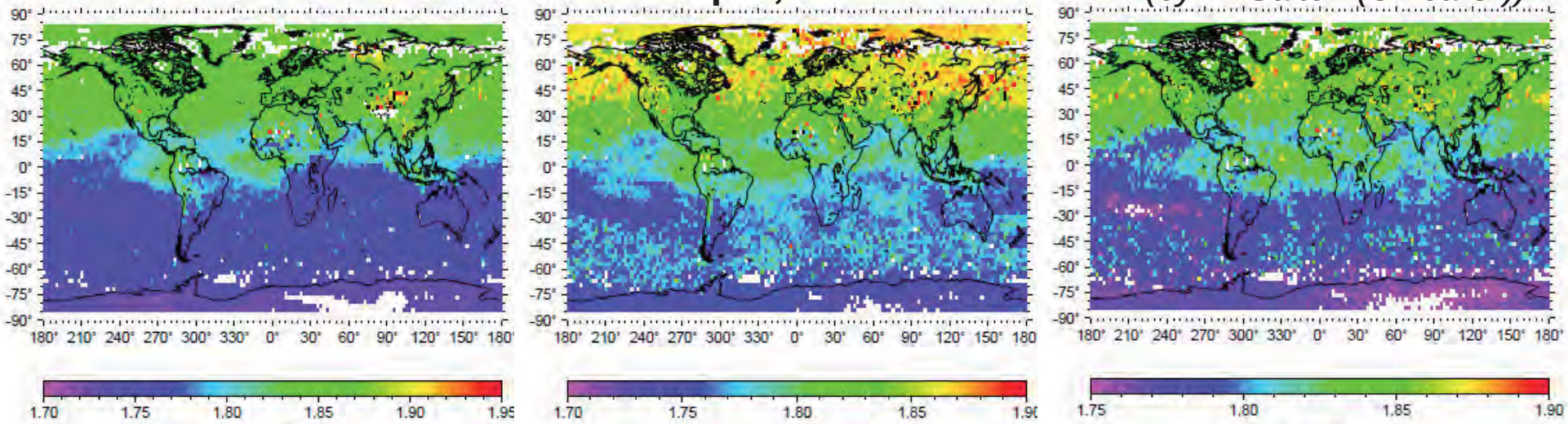
August, 2010

***2.5º grid average**

TIR L2 V01.00 CH_4 monthly average

April, 2010

(by N. Saitoh (Chiba U.))

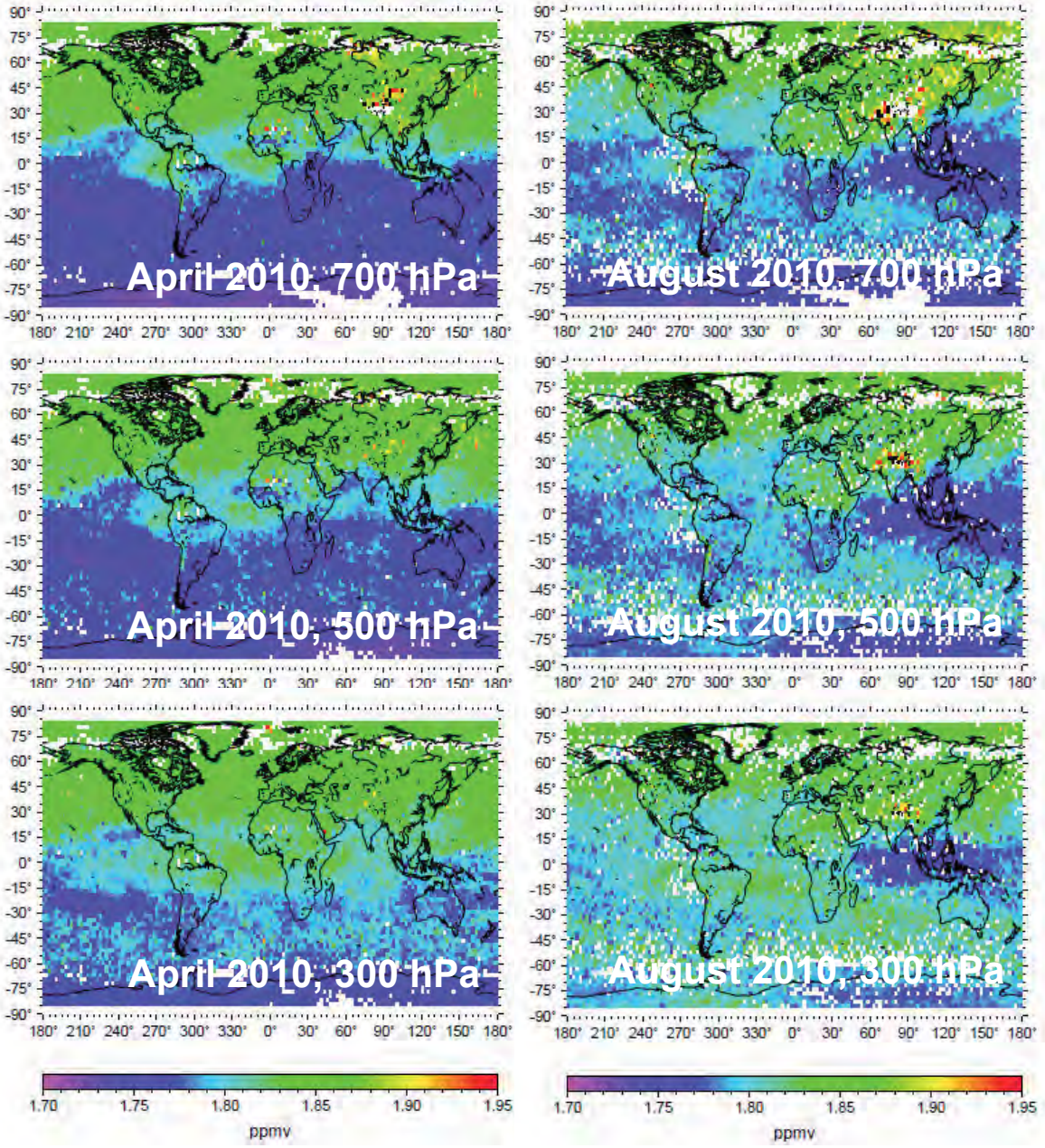


August, 2010

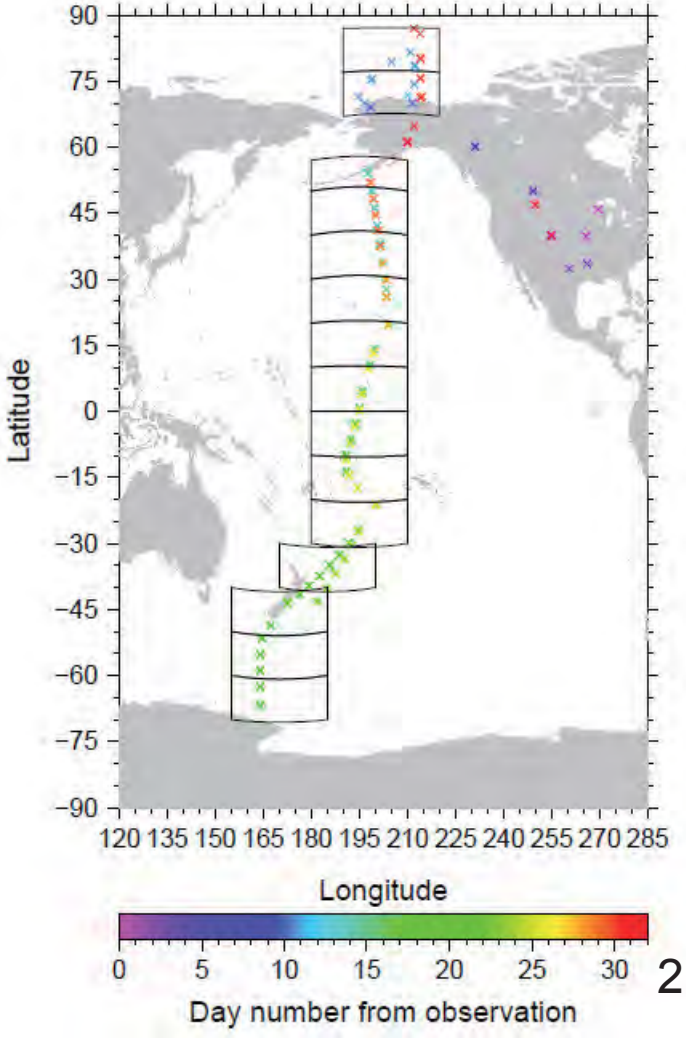
***2.5º grid average**

CH_4 profiles from GOSAT/TIR (V01.0x)

(by N. Saitoh (Chiba U.))



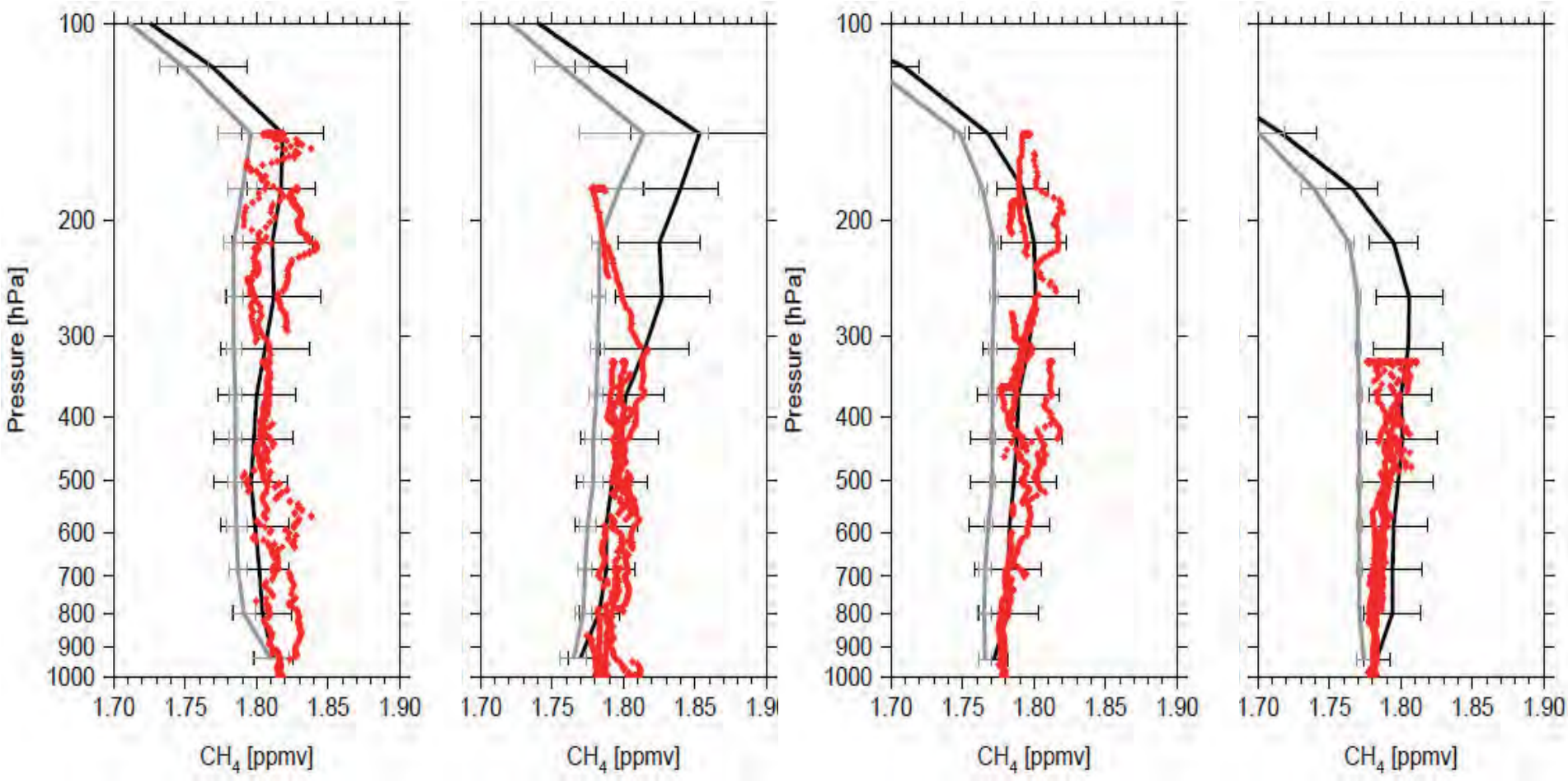
TIR V01.0x CH_4 profiles compared with HIPPO QCLS CH_4 profiles.



TIR V01.0x CH_4 vs. HIPPO5 QCLS CH_4

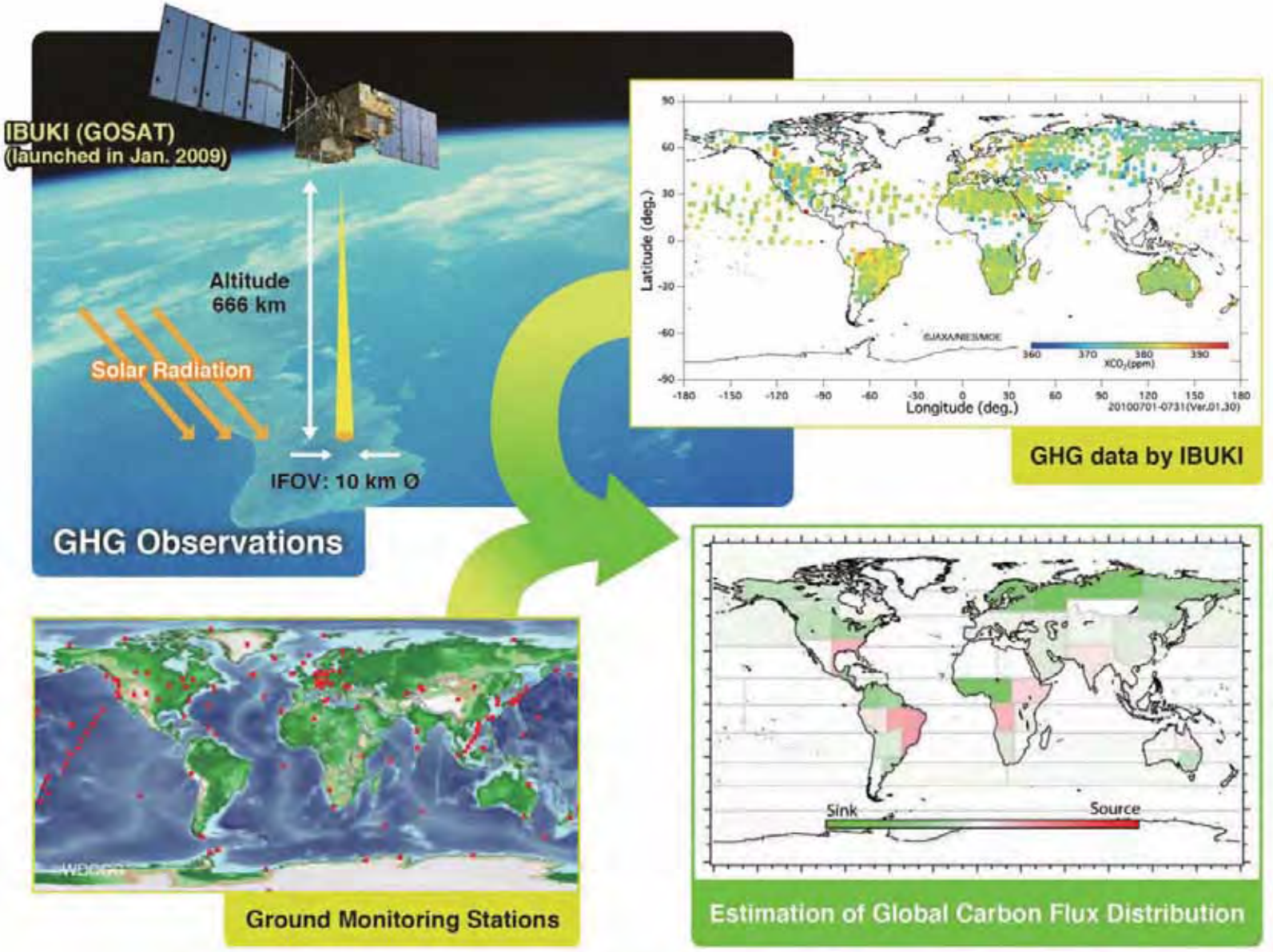
(by N. Saitoh (Chiba U.))

Low latitude: 20ºN-10ºS **Mid-latitude: 10ºS-40ºS**



a priori CH_4 TIR CH_4 V01.0x HIPPO CH_4

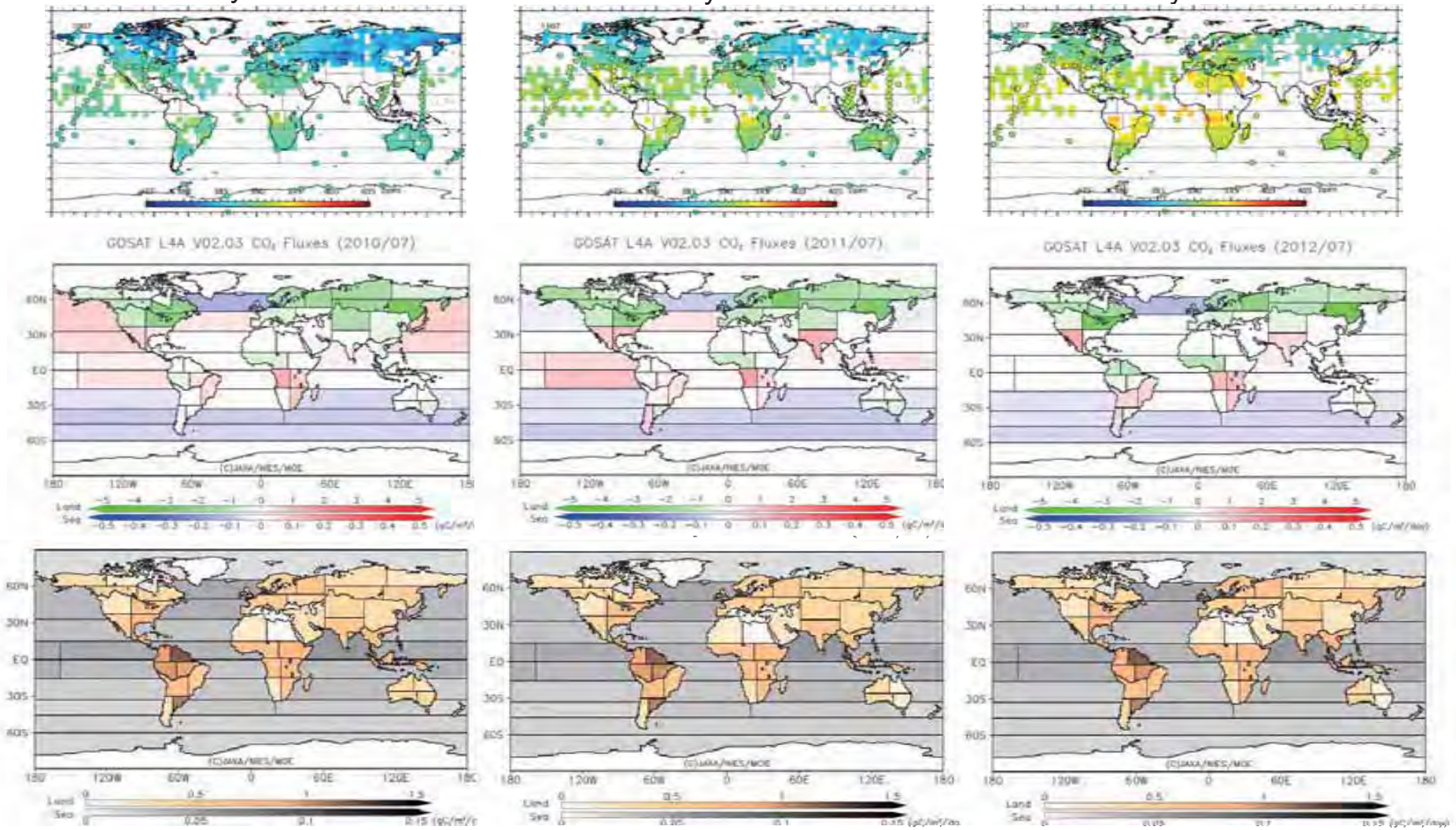
Contribution of satellite data to carbon flux



(CO_2 v02.03 released in Jan. 2015)

Monthly CO_2 Flux Estimates and Uncertainties

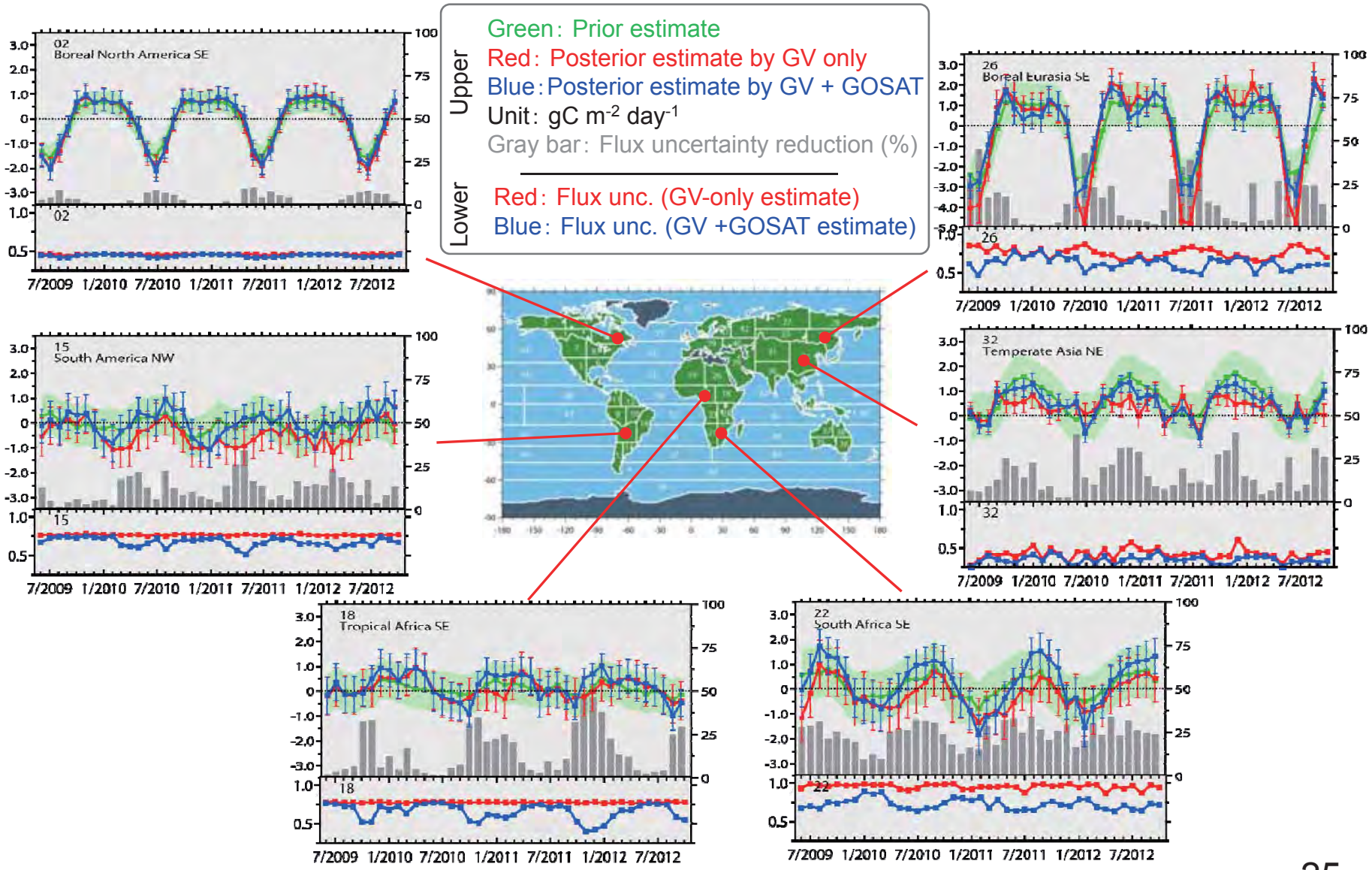
July 2010 | July 2011 | July 2012



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)



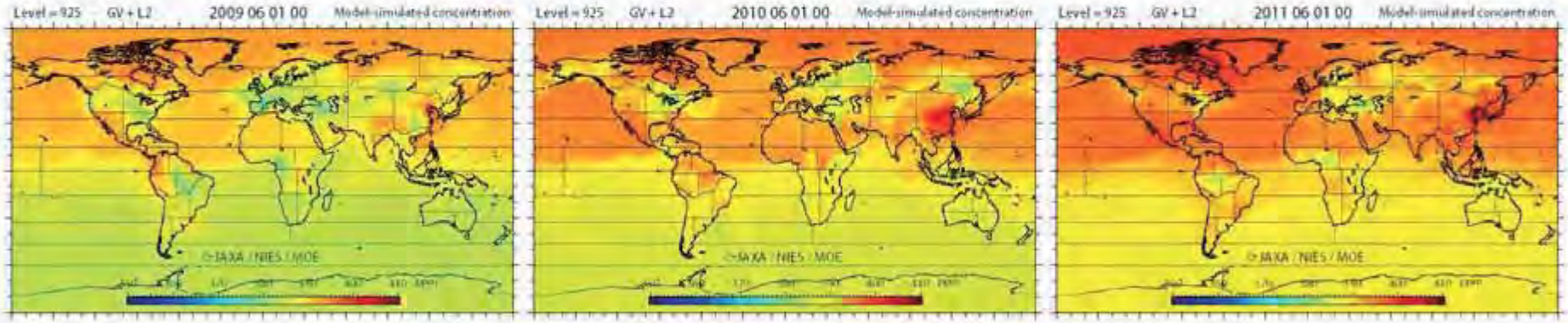
(by H Takagi (NIES))

GOSAT L4B Data Product
Model-simulated concentration

(6hr-step, 0.925 sigma-level, 2.5° × 2.5° grid)

MM DD HH
06 01 00

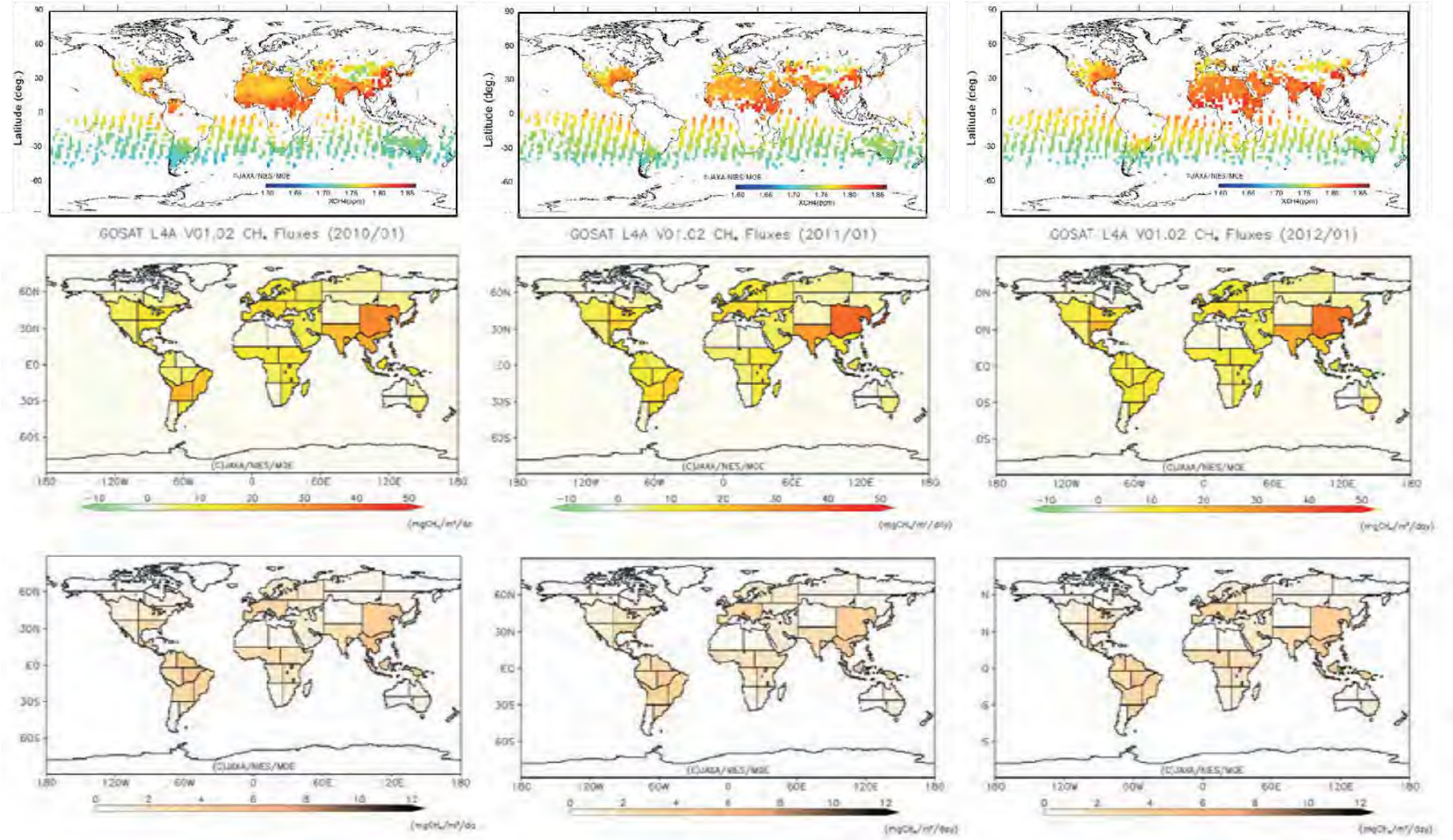
2009.6~2010.5 2010.6~2011.5 2011.6~2011.10



©JAXA/NIES/MOE

Monthly CH_4 Flux Estimates and Uncertainties

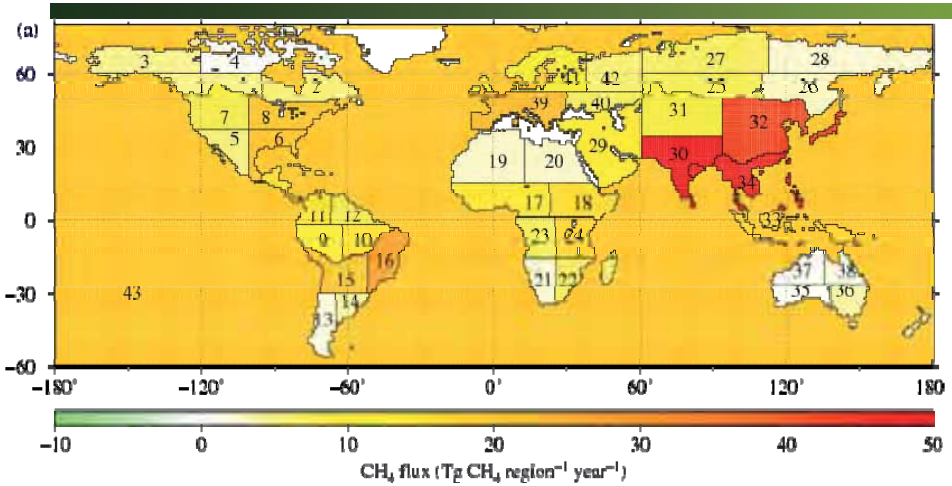
January 2010 | January 2011 | January 2012



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

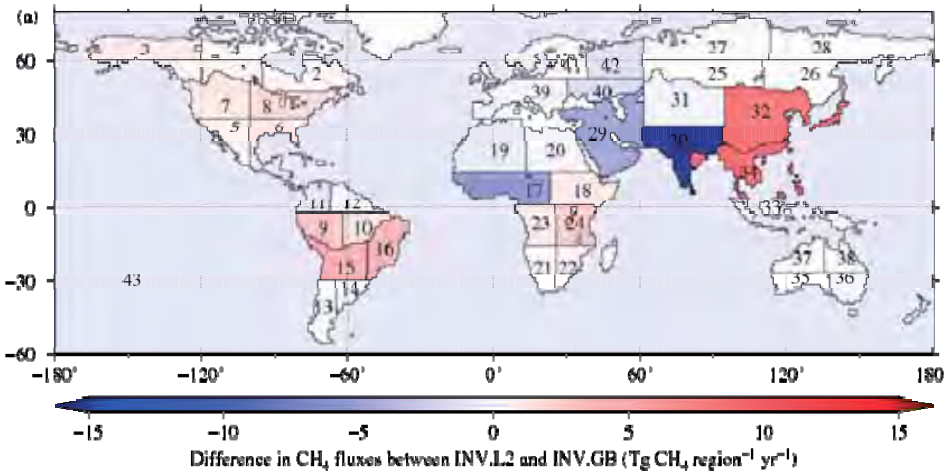
* Anthropogenic, natural, and biomass burning emissions are estimated separately for each region.

The estimated annual CH_4 flux using GOSAT data



Estimation of the annual flux in each region

The methane emissions in East Asia and the Southeast Asia region (Region No. 30, 32, and 34) are significantly high.

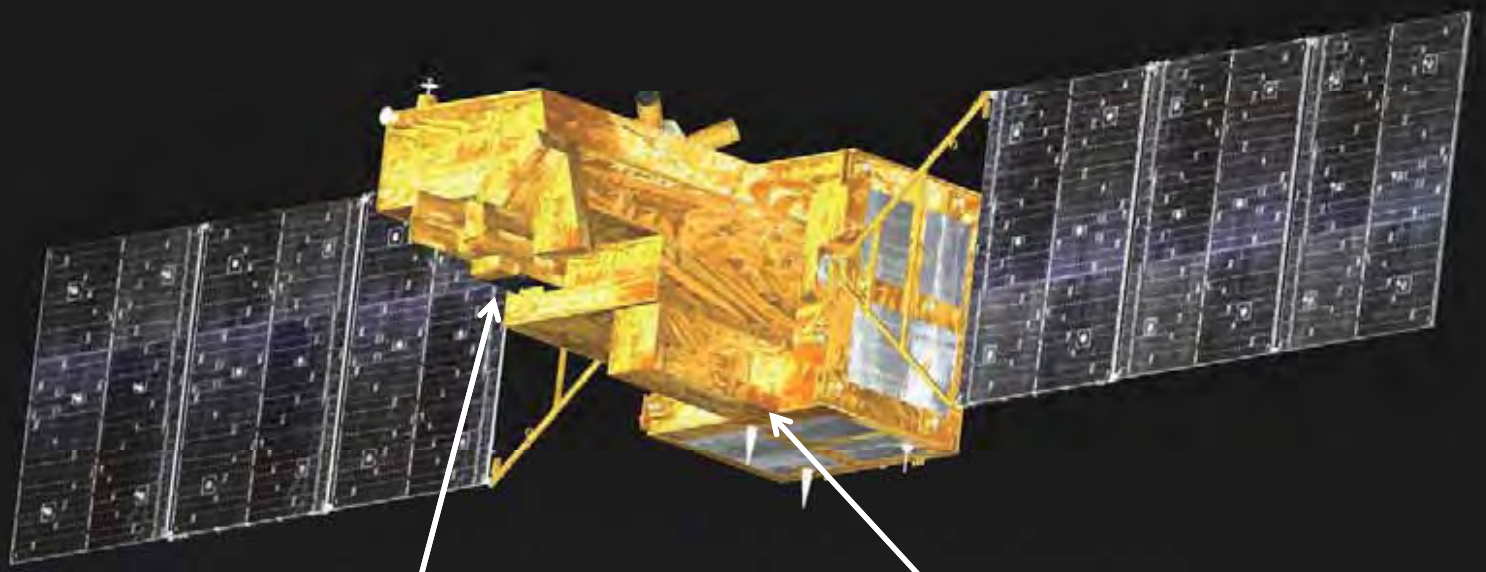


Change in the annual flux of methane per region

The methane emissions from the Asian region (Region No.32 and 34) and the southern subtropical areas of South America (No.9, 10, 15, and 16) and Africa (No. 24) became pronouncedly greater.

GOSAT-2 CG

GOSAT-2 in Space



FTS-2

CAI-2

CDR : May 2015
TRR : August 2016
PSR : May 2017

Expected to be
launched in early 2018

(by T. Matsunaga (NIES))

(c)MELCO

Quick Overview of GOSAT and GOSAT-2

	GOSAT Specifications	GOSAT-2 Requirements
Launch year and life time	Jan. 2009, 5 years	FY2017, 5 years
Satellite (Main body size, mass, power)	3.7 x 1.8 x 2.0 m, 1750kg, 3.8KW (EOL)	5.3 x 2.0 x 2.8 m, <2000kg, 5.0KW
Orbit (Type, altitude, repeat cycle, equator crossing time)	Sun synchronous, 666 km, 3 days, 13:00	Sun synchronous, 613 km, 6 days, 13:00±15 min
Target gases	CO_2, CH_4, O_2, O_3, H_2O	CO_2, CH_4, O_2, O_3, H_2O, CO
Fourier Transform Spectrometer (Spectral coverage and IFOV)	Band 1 : 0.76 – 0.78 μm Band 2 : 1.56 – 1.72 μm Band 3 : 1.92 – 2.08 μm Band 4 : 5.6 – 14.3 μm IFOV = 10.5 kmϕ	Band 1 : 0.75 – 0.77 μm Band 2 : 1.56 – 1.69 μm Band 3 : 1.92 – 2.33 μm Band 4 : 5.5 – 8.4 μm Band 5 : 8.4 – 14.3 μm IFOV = 9.7 kmϕ
Cloud and Aerosol Imager (Viewing geometry, band center wavelength, spatial resolution, and swath)	Nadir B1 = 380 nm B2 = 674 nm B3 = 870 nm B4 = 1600 nm B1-B3 = 500 m / 1000 km, B4 = 1.5 km / 750 km	B1-5: forward, B6-10:backward B1 = 343 nm B6 = 380 nm B2 = 443 nm B7 = 550 nm B3 = 674 nm B8 = 674 nm B4 = 869 nm B9 = 869 nm B5 = 1630 nm B10= 1630 nm B1-B4, B6-B9=460 m / 920 km B5, B10 = 920 km / 920 km
New features of GOSAT-2 FTS-2	Intelligent pointing using FTS-2 FOV camera, fully programmable (target mode) observation, extended AT pointing angle range, and improved SNR.	

(by T. Matsunaga (NIES))

Concluding Remarks

- Global distributions of greenhouse gases (GHGs) such as CO_2 and CH_4 has been measured by GOSAT and analyzed in sufficient precision (less than 1%).
- These data are used to estimate regional monthly CO_2 and CH_4 fluxes, and also used to detect GHG's temporal and spatial changes.
- Most of the GOSAT data products have been released to the general users.
- GOSAT has been operating more than six years, and now in the extended operation period. It is strongly expected that GOSAT will survive for several more years. Long term GOSAT data will contribute to GHG transport and carbon cycle sciences.