Line Parameters and Forward Calculation for Rertrieving Carbon Dioxide and Methane (CO_2 & CH_4) from "GOSAT" Data

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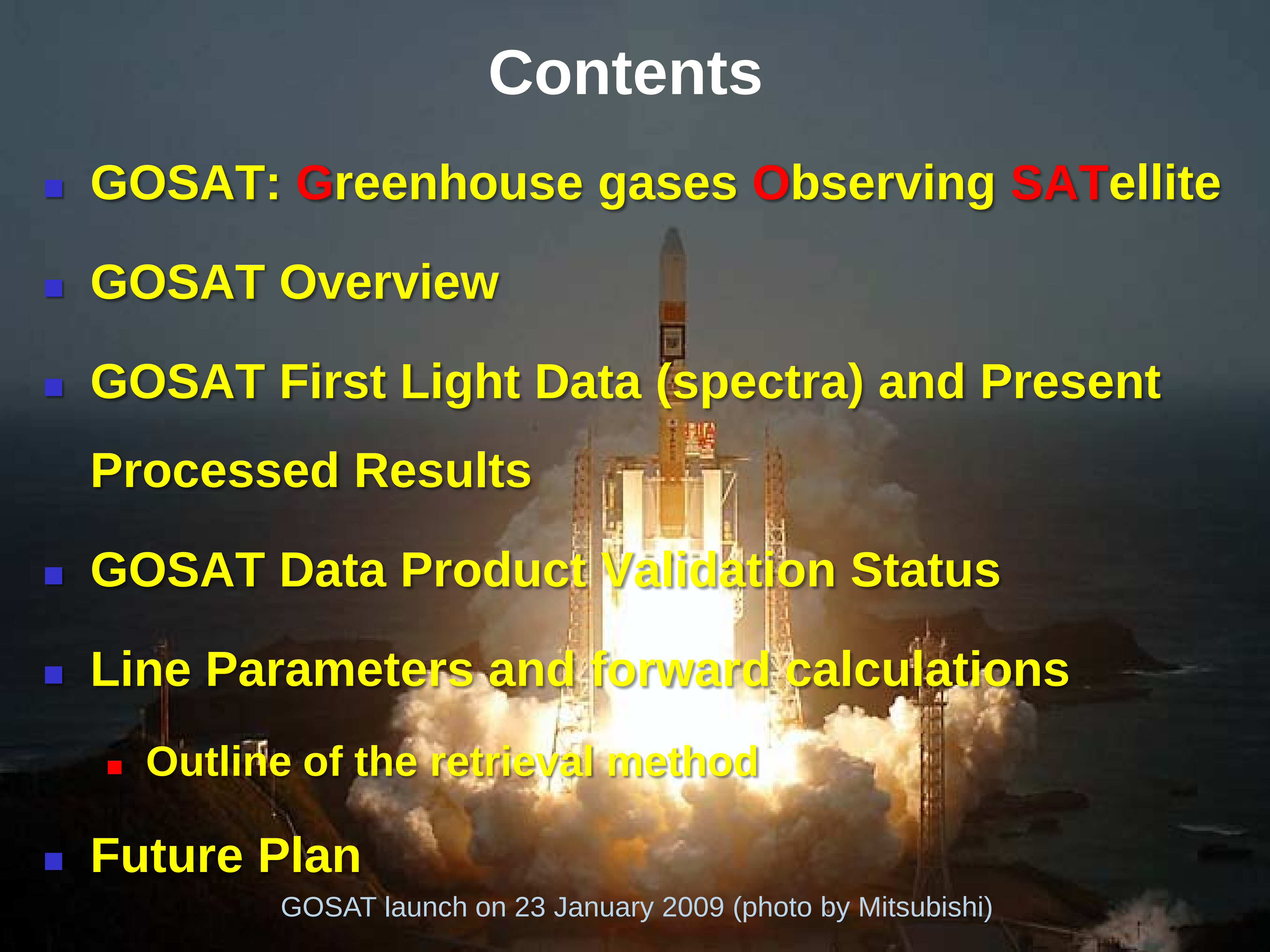
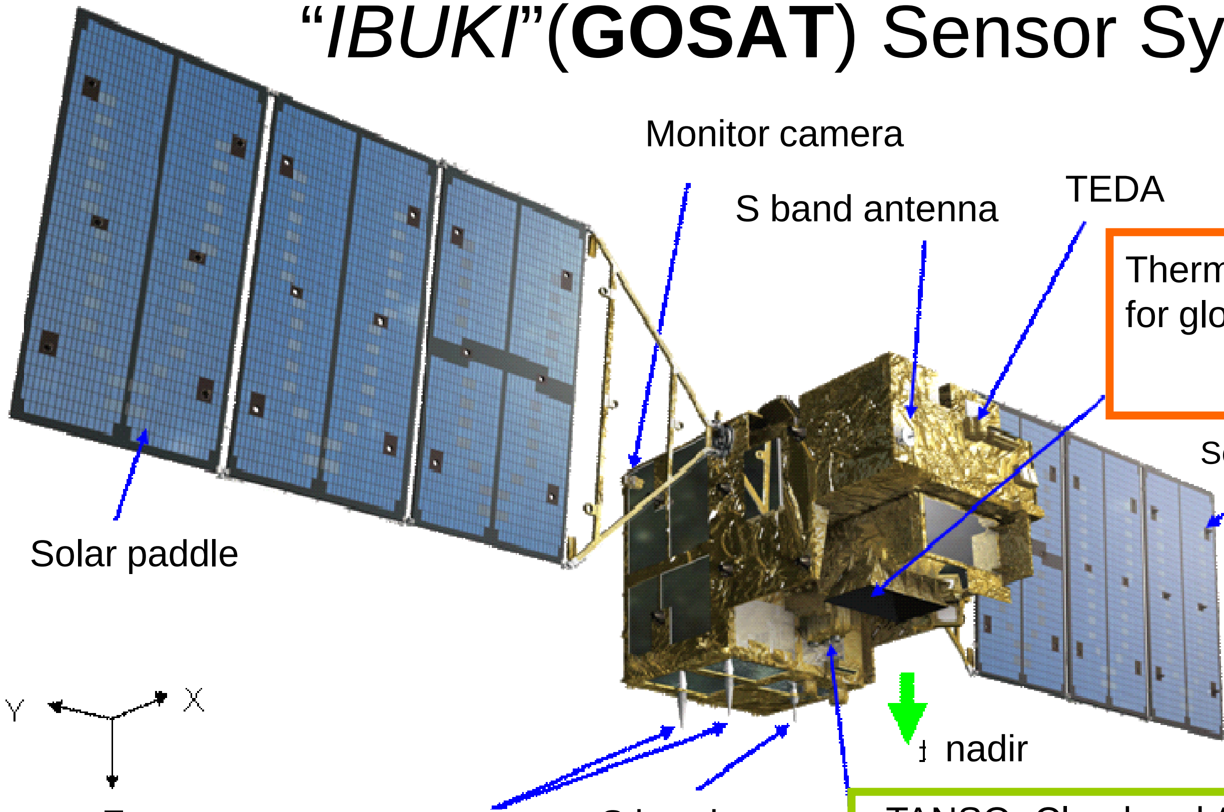
Contents

- **GOSAT: Greenhouse gases Observing SATellite**
- **GOSAT Overview**
- **GOSAT First Light Data (spectra) and Present Processed Results**
- **GOSAT Data Product Validation Status**
- **Line Parameters and forward calculations**
  - **Outline of the retrieval method**
- **Future Plan**



GOSAT launch on 23 January 2009 (photo by Mitsubishi)

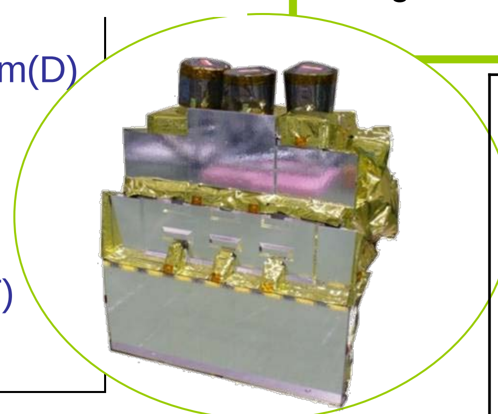
“*IBUKI*”(**GOSAT**) Sensor System



Thermal and Near-infrared Sensor for global Observation FTS

TANSO-FTS

TANSO- Cloud and Aerosol Imager **TANSO-CAI**



Size		
	Body	:3.7m(H)×1.8m(W)×2.0m(D)
	Paddle span	: 13.7 m
Mass		: 1750 kg
Power		: 3.8 kw（EOL)
Life Time		: 5 years
Launch		: 23 Jan 2009 12:54 (JST)
Launch Vehicle		: H-IIA Rocket F-15

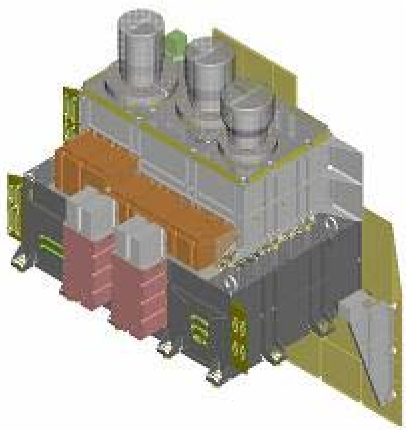
Orbit	Sun Synchronous	
	Local time	**13:00+/-0:15**
	Altitude	**666 km**
	Inclination	**98 deg.**
	Recurrent	**3 days**

TANSO-FTS

Ground Pointing Mechanism and Fore optics	Configuration	2-axes scanner (fully redundant) for ground pointing and calibration			
	Scanning	Cross Track (+/-35 deg) Along Track (+/-20 deg)			
	Field of view	IFOV <10.5 km 790 km (scan width) (latitude of 30 deg)			
Fourier Transform Spectrometer	Speed	0.25, 0.5, 1 (Interferogram)/sec			
	Spectral band	1P, 1S	2P, 2S	3P, 3S	4
	Coverage (micron)	0.75-0.78	1.56-1.72	1.92-2.08	5.5-14.3
	resolution (cm^{-1})	0.5	0.2	0.2	0.2
	Detector	Si	InGaAs	InGaAs	PC-MCT
	Calibration	Solar Irradiance, Deep Space, Moon, Diode Laser (1.55 micron, ILS)			Blackbody, Deep space

TANSO-CAI

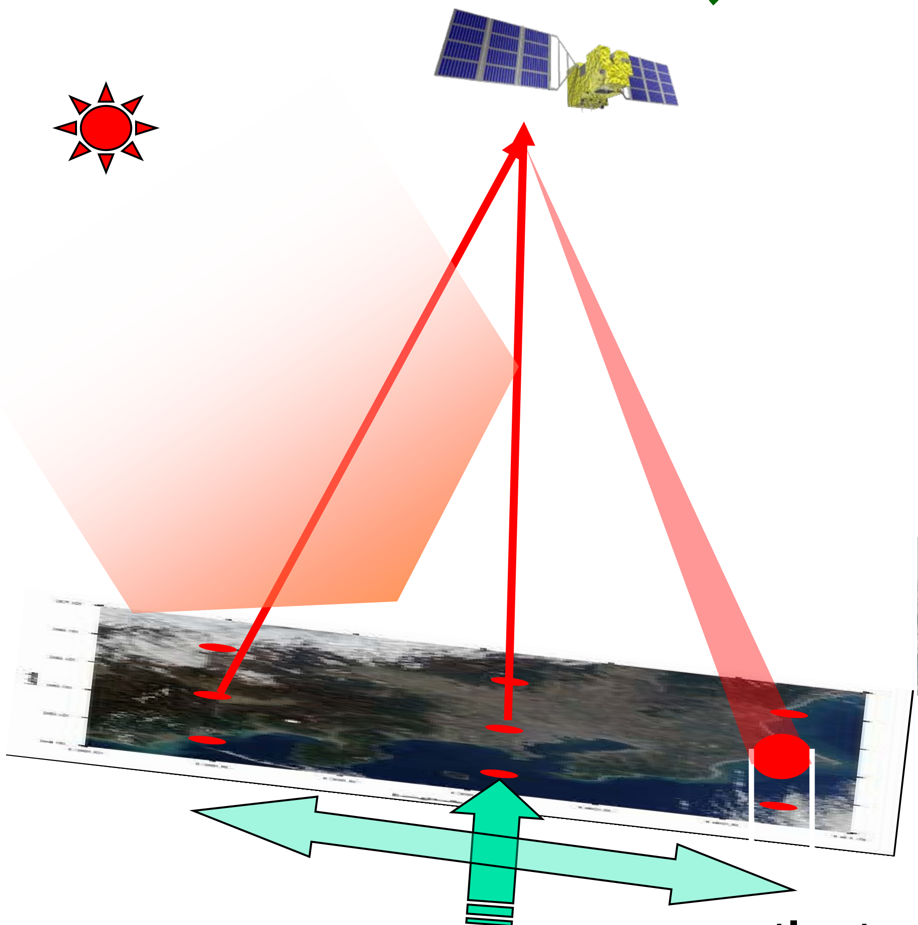
CAI is operated together with FTS to
- detect aerosol spatial distribution and cloud coverage
- retrieve scattering spectral characteristics of aerosol

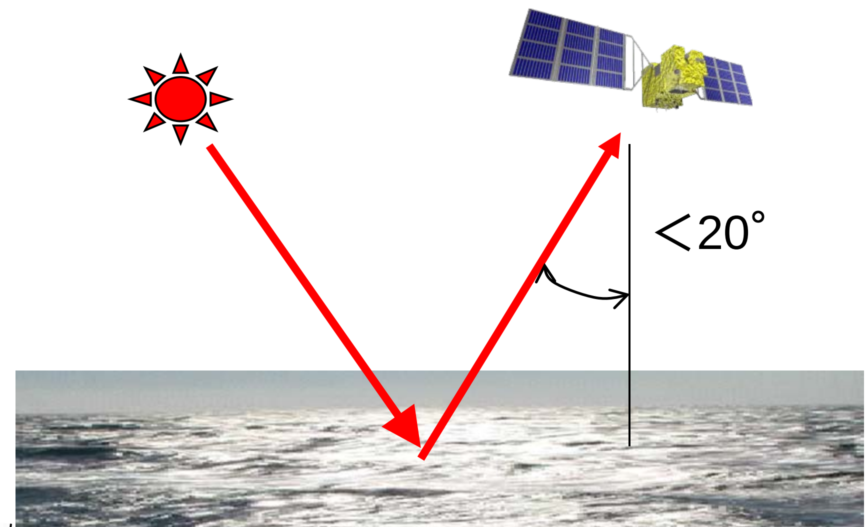


Band No.	Observation Band (nm)	Center Wavelength (nm)	Spatial Resolution (IFOV) (km)	FOV (km)	No. of Pixels (cross track)
1	372-387	380	0.5	1000	2000
2	667-680	678	0.5	1000	2000
3	866-877	870	0.5	1000	2000
4	1560-1640	1620	1.5	750	500

Observational Mode

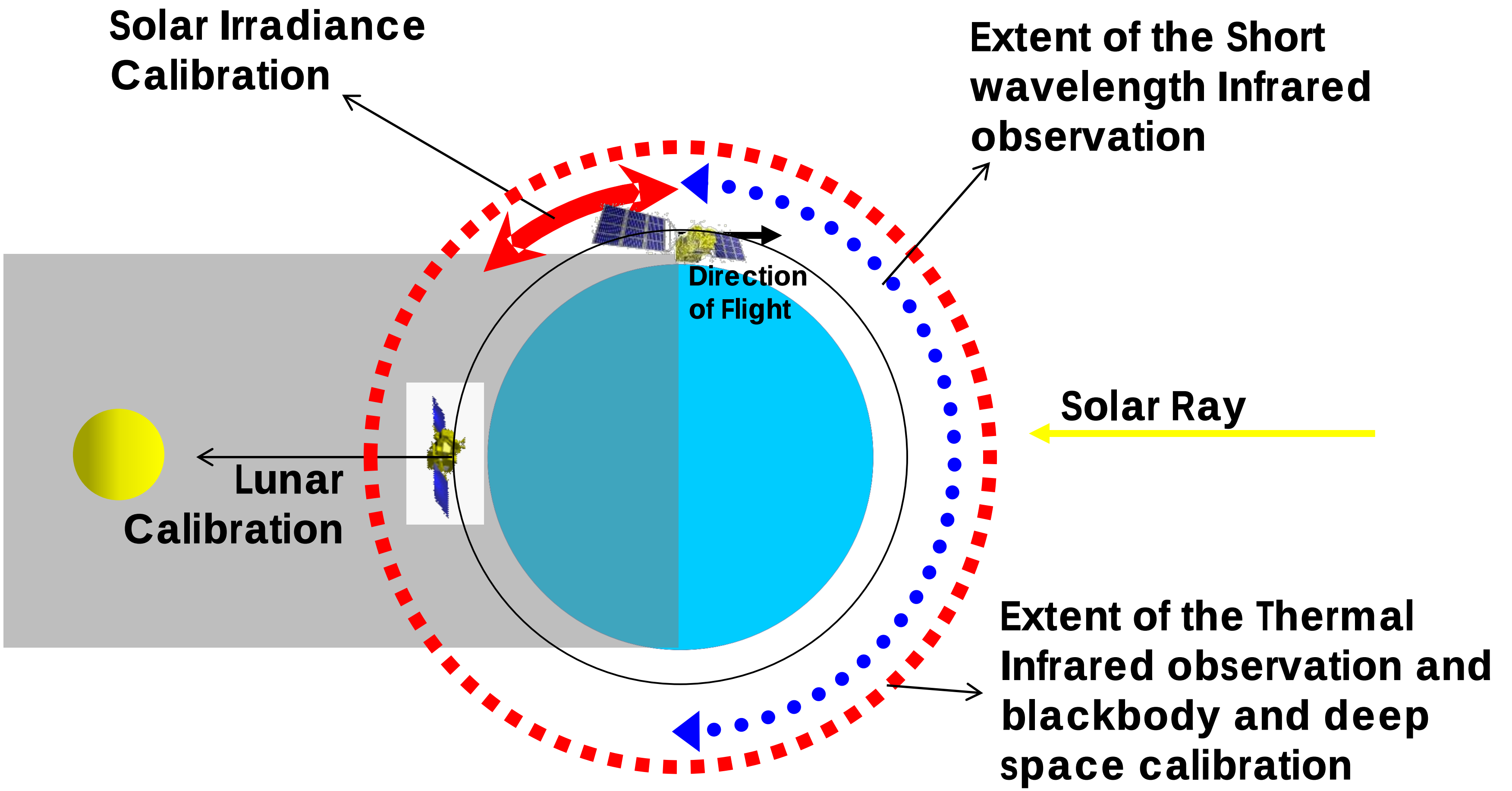
(TANSO-FTS)





Sun Glint Pointing Mode

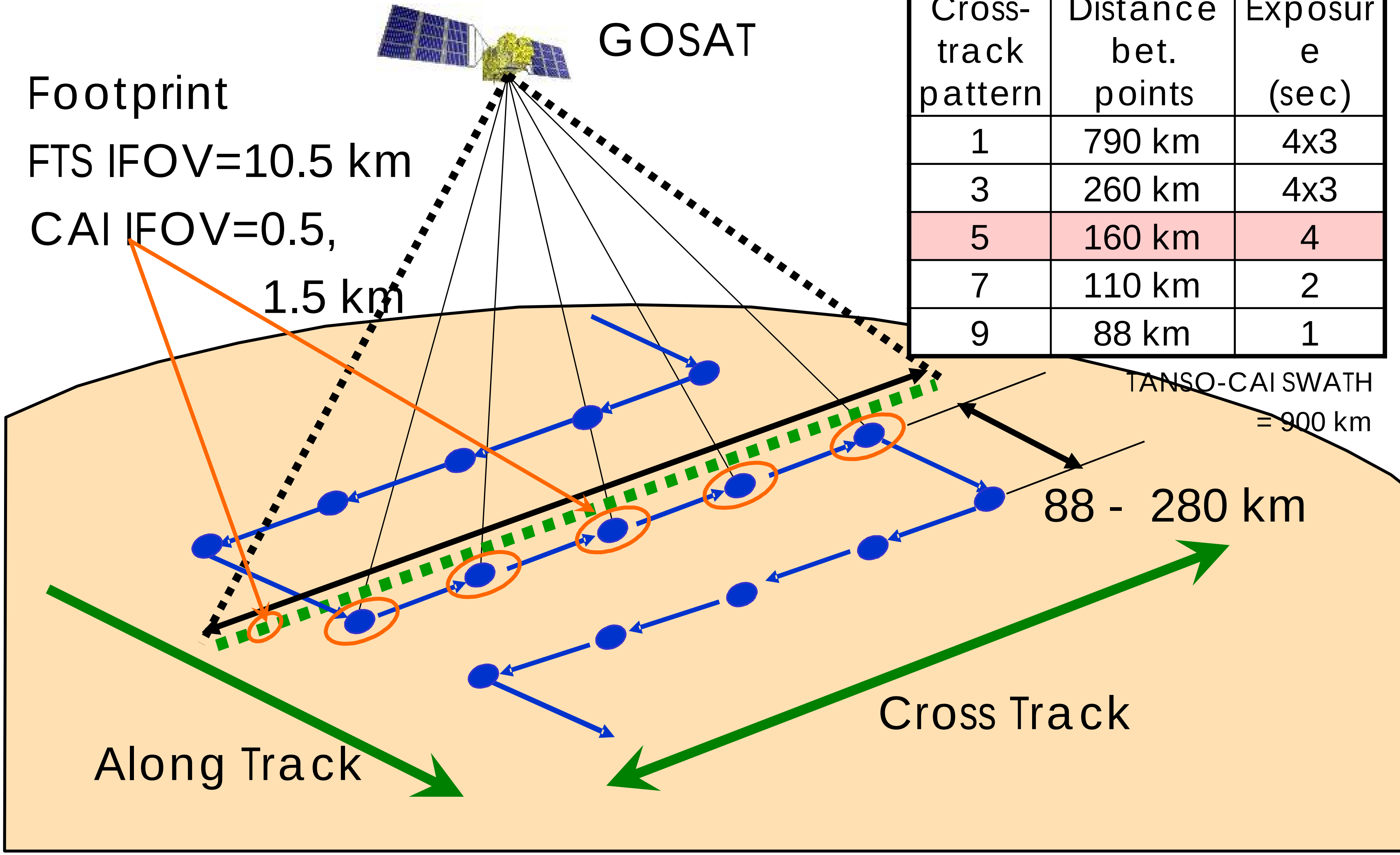
TANSO-FTS
In-Orbit Operation



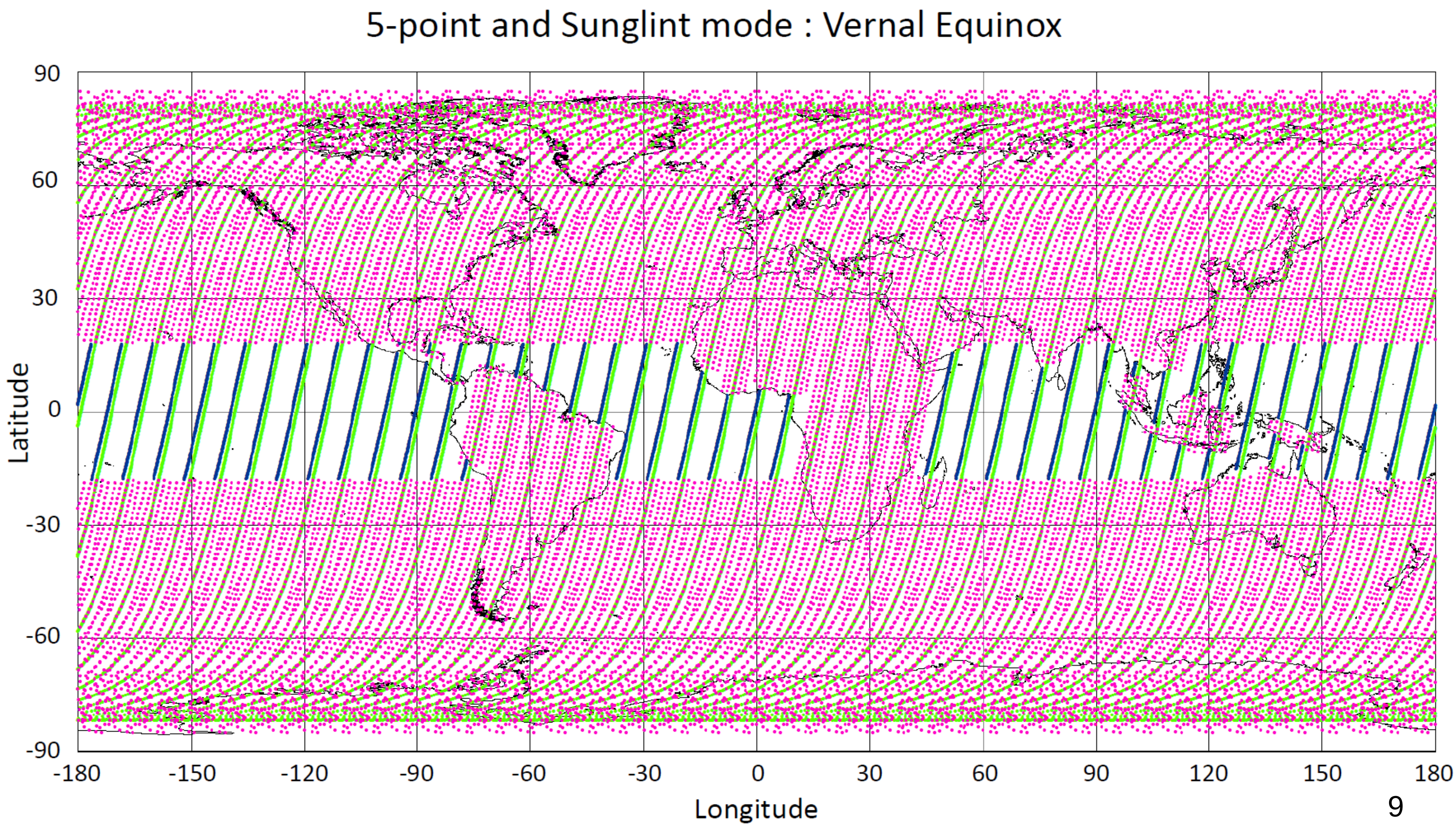
Blackbody and deep space calibration are performed at regular intervals.

TANSO-FTS
Observation Pattern

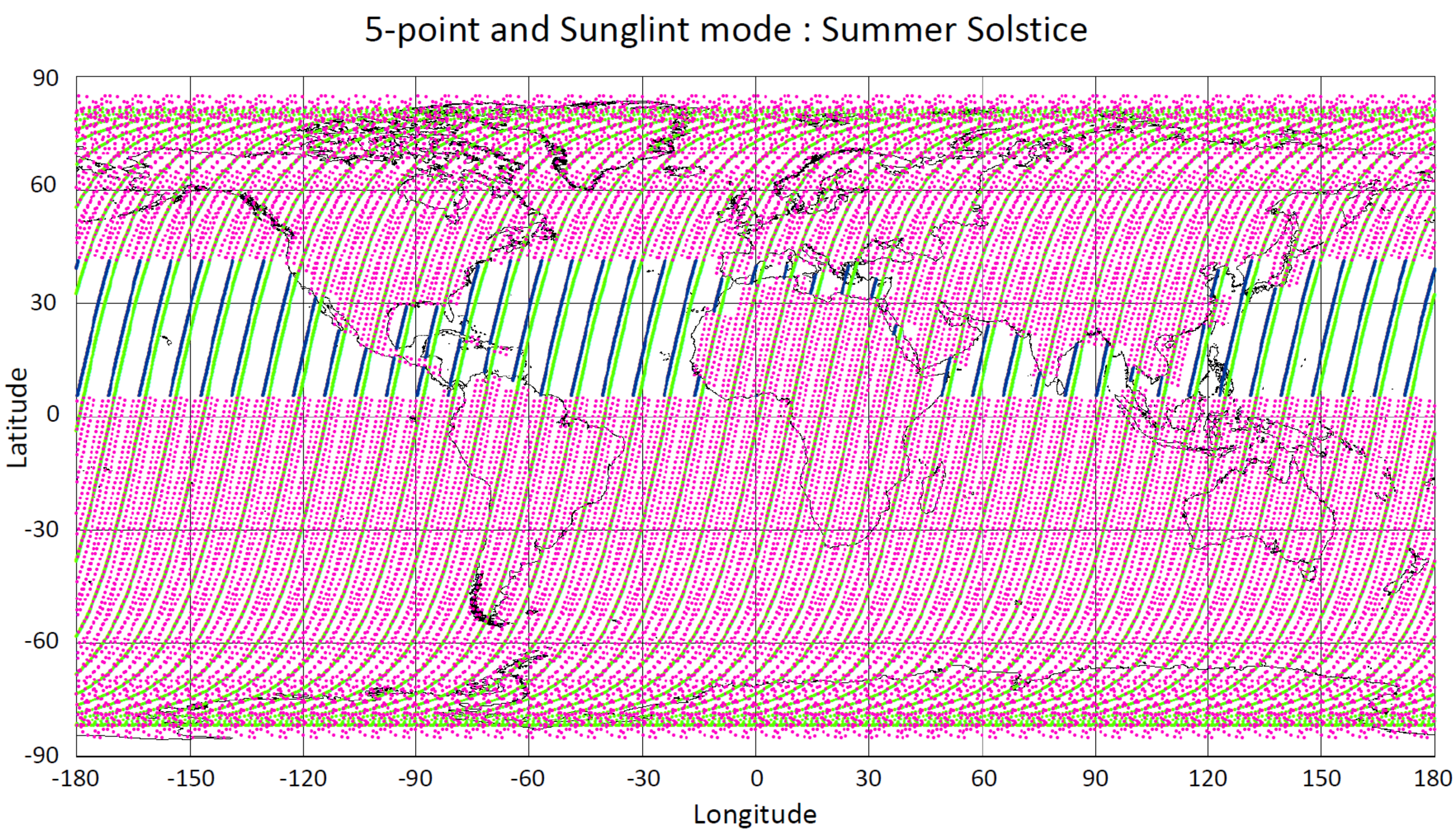
Cross-track pattern	Distance bet. points	Exposure (sec)
1	790 km	4x3
3	260 km	4x3
5	160 km	4
7	110 km	2
9	88 km	1



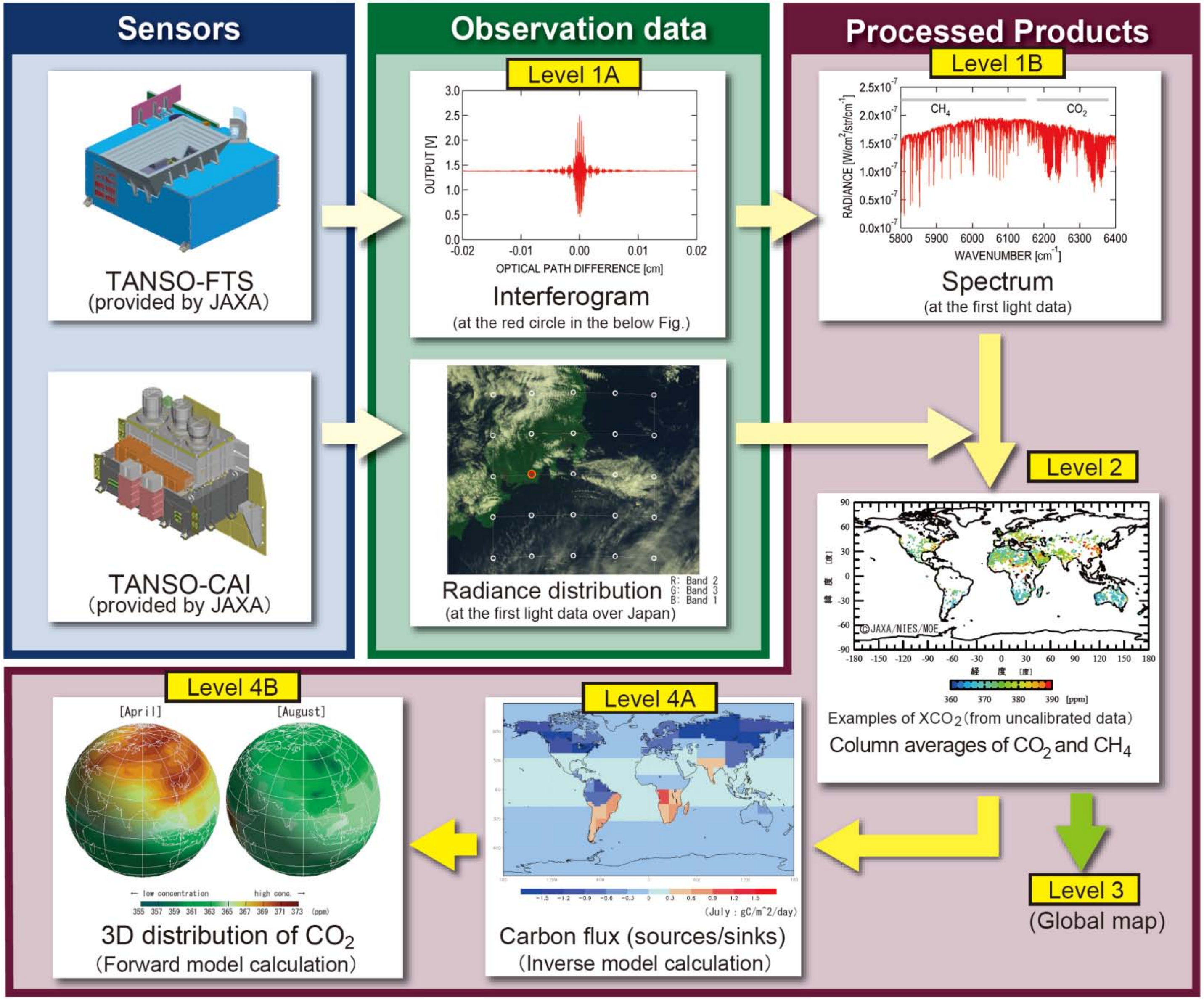
5 point mode + sunglint measurement over the sea (equinox)



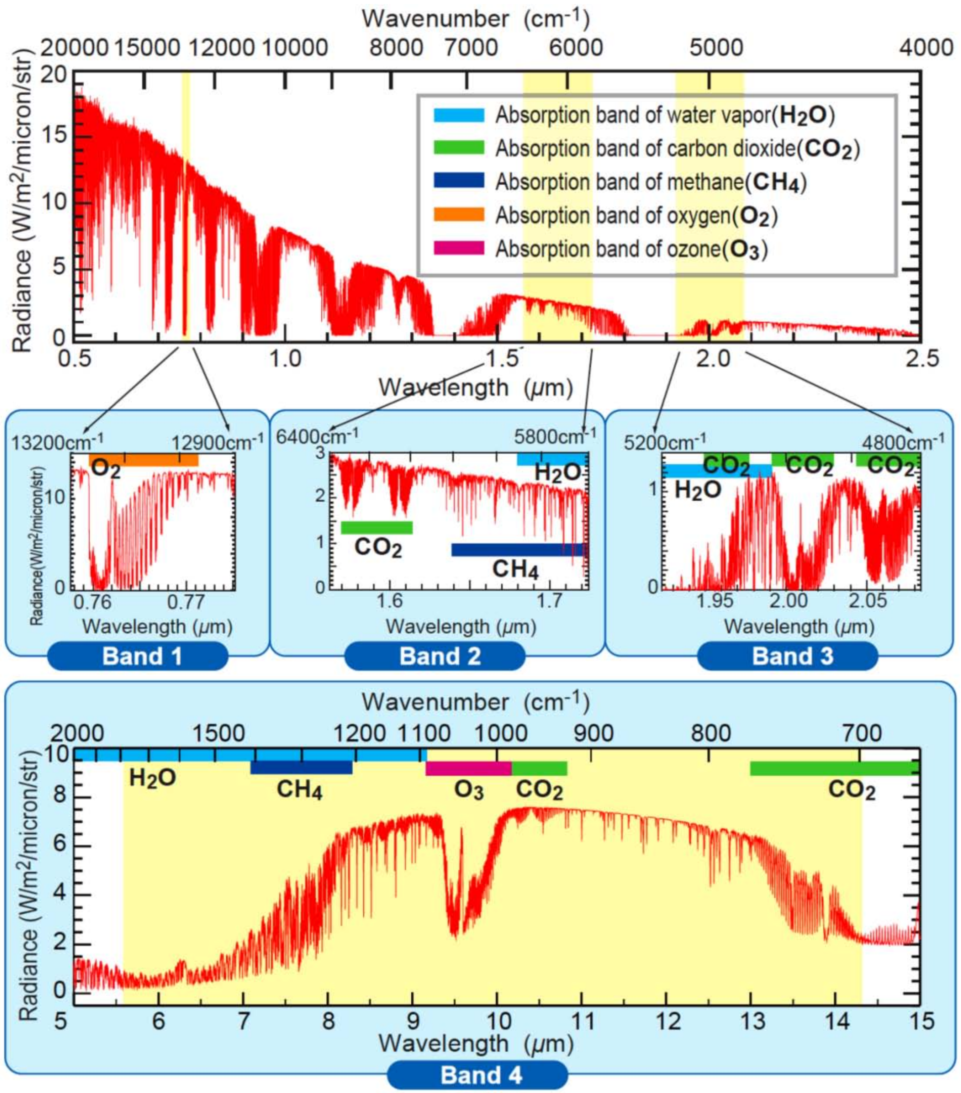
5 point mode + sunglint measurement over the sea (summer solstice)

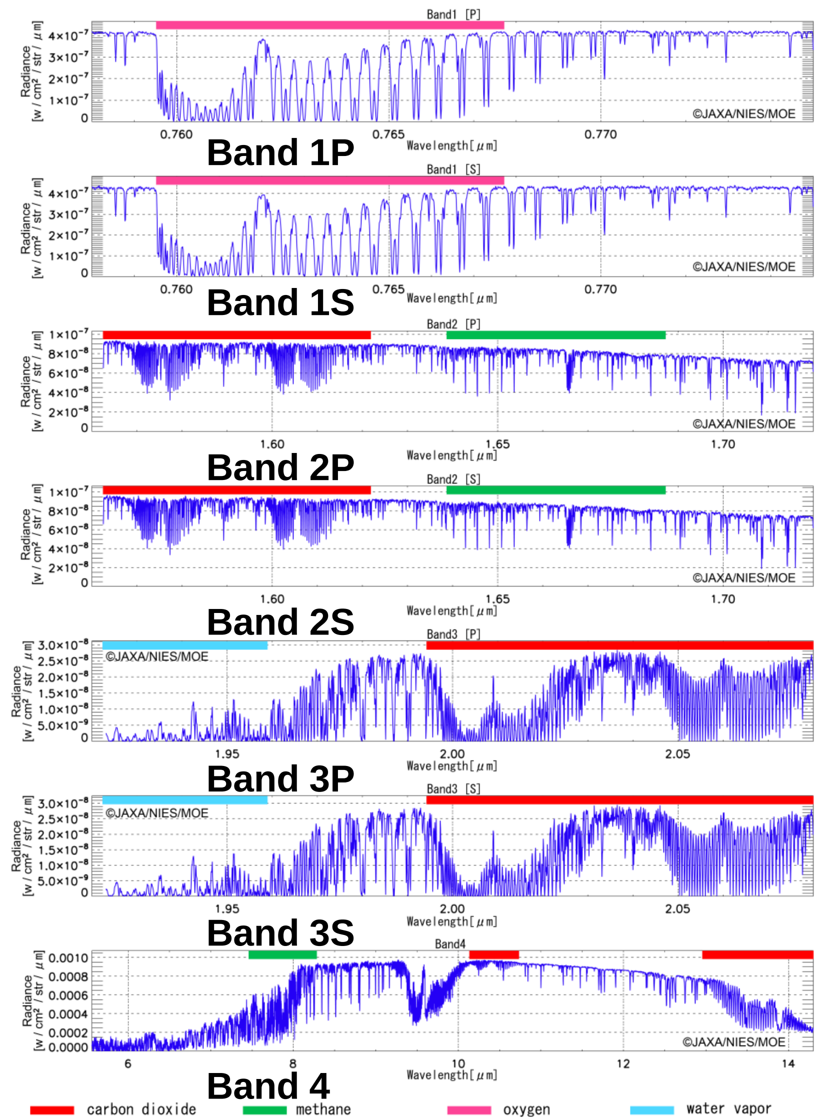


GOSAT Data Processing Flow



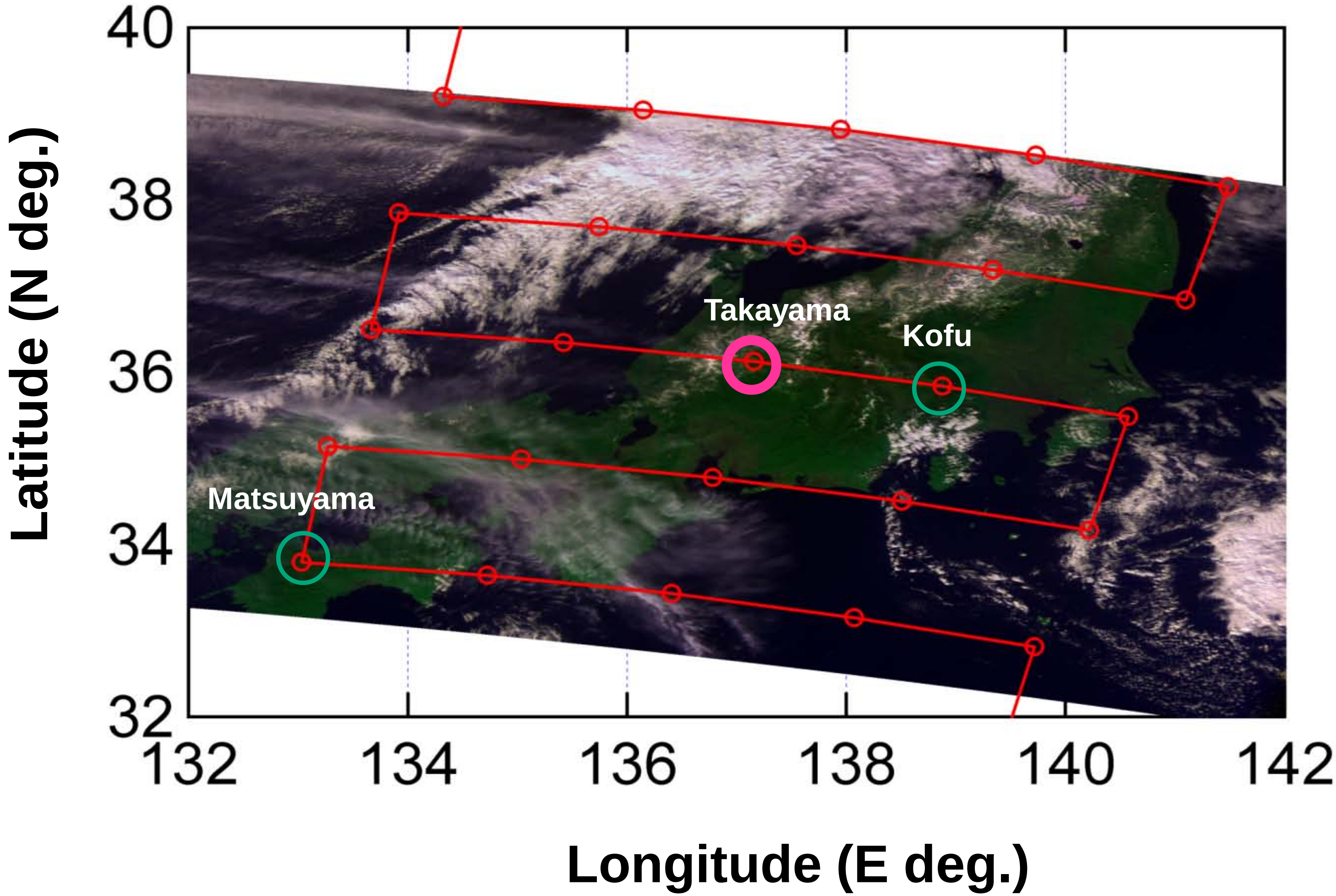
TANSO-FTS Level 1B





GOSAT First light spectra over Japan

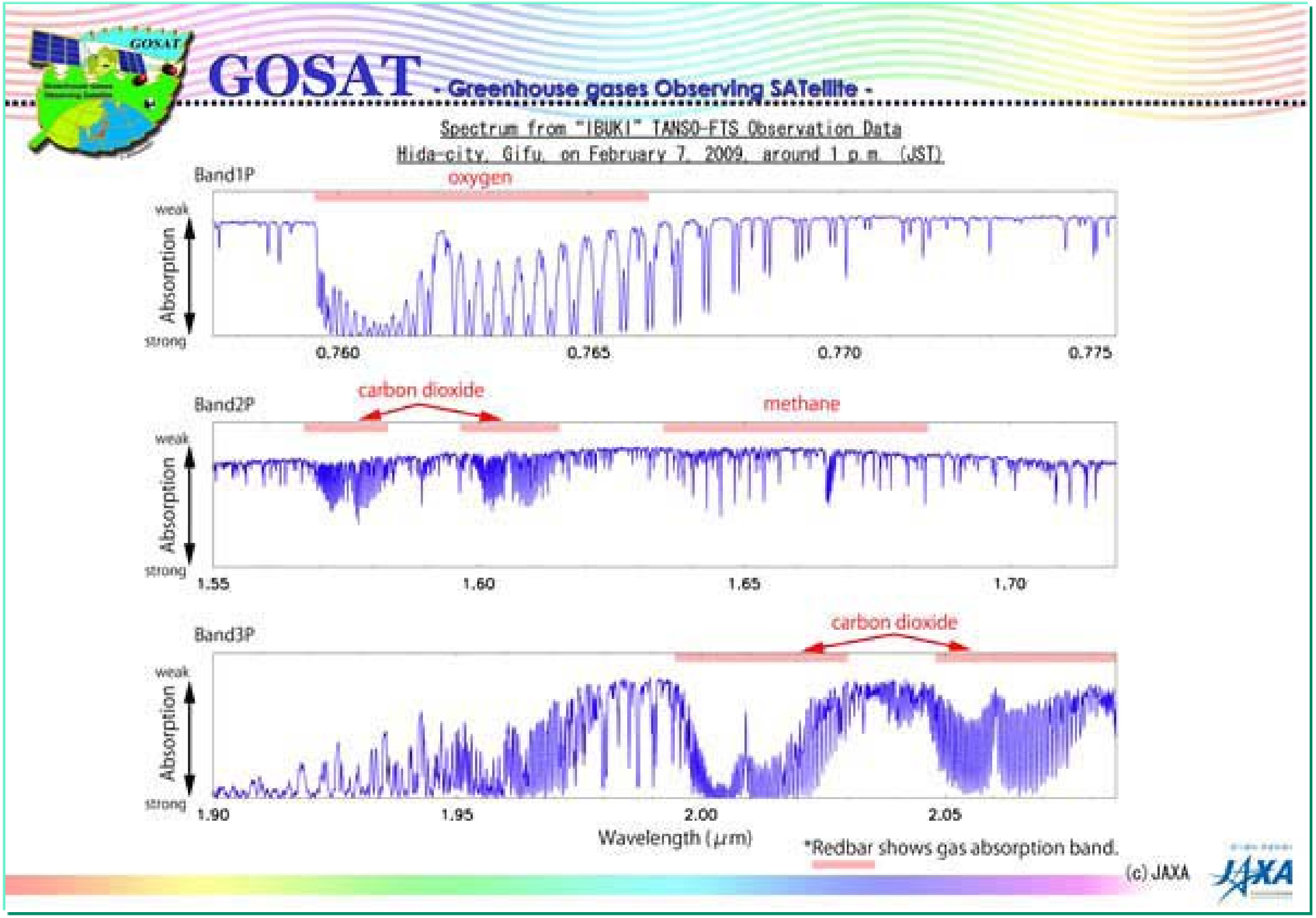
February 7, 2009 CAI L1B equivalent Image



GOSAT first Light Data

(February 7, 2009)

- The GOSAT first light data was press released by JAXA on February 9, 2009.



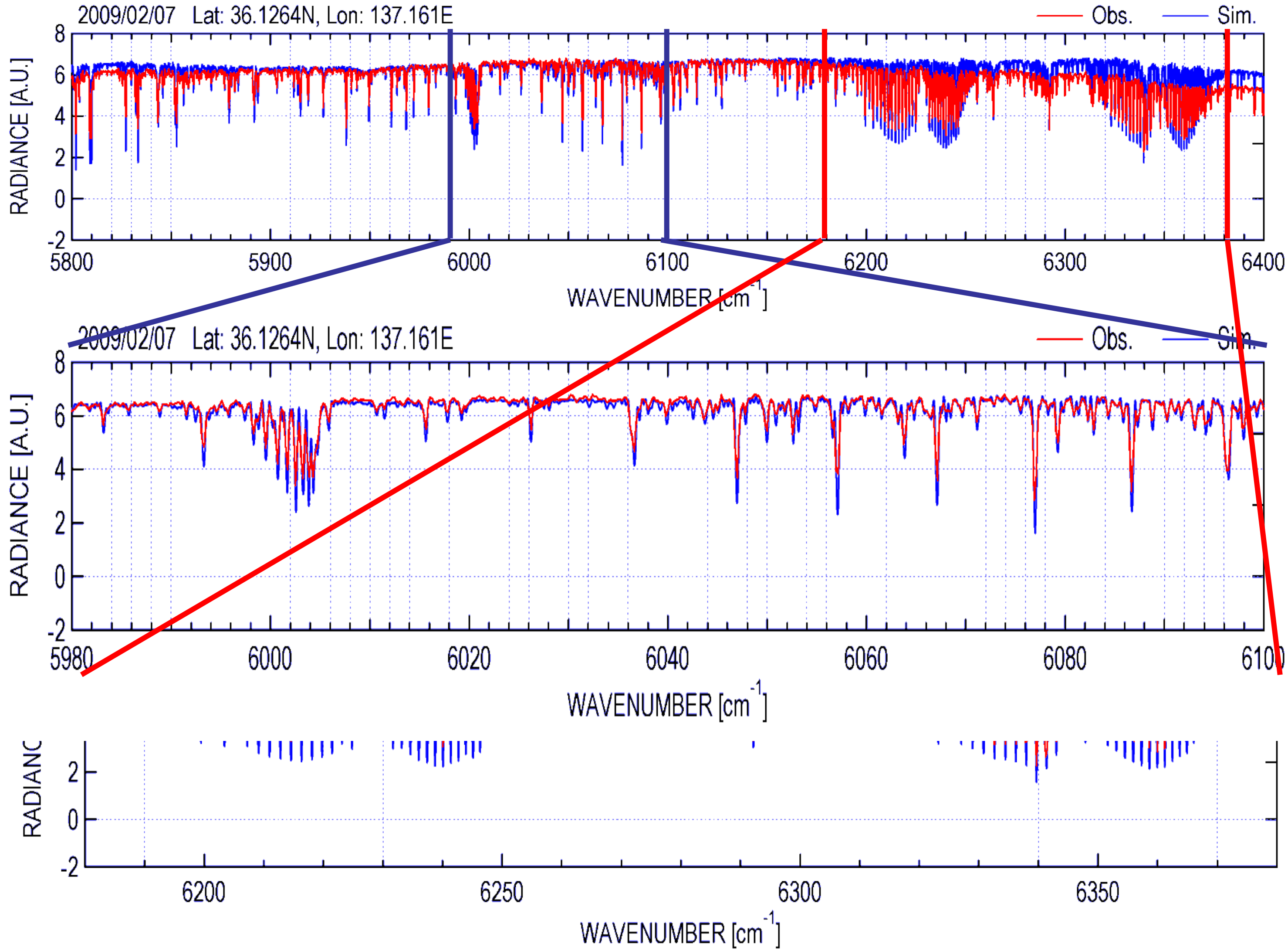
GOSAT first Light Data

(February 7, 2009)

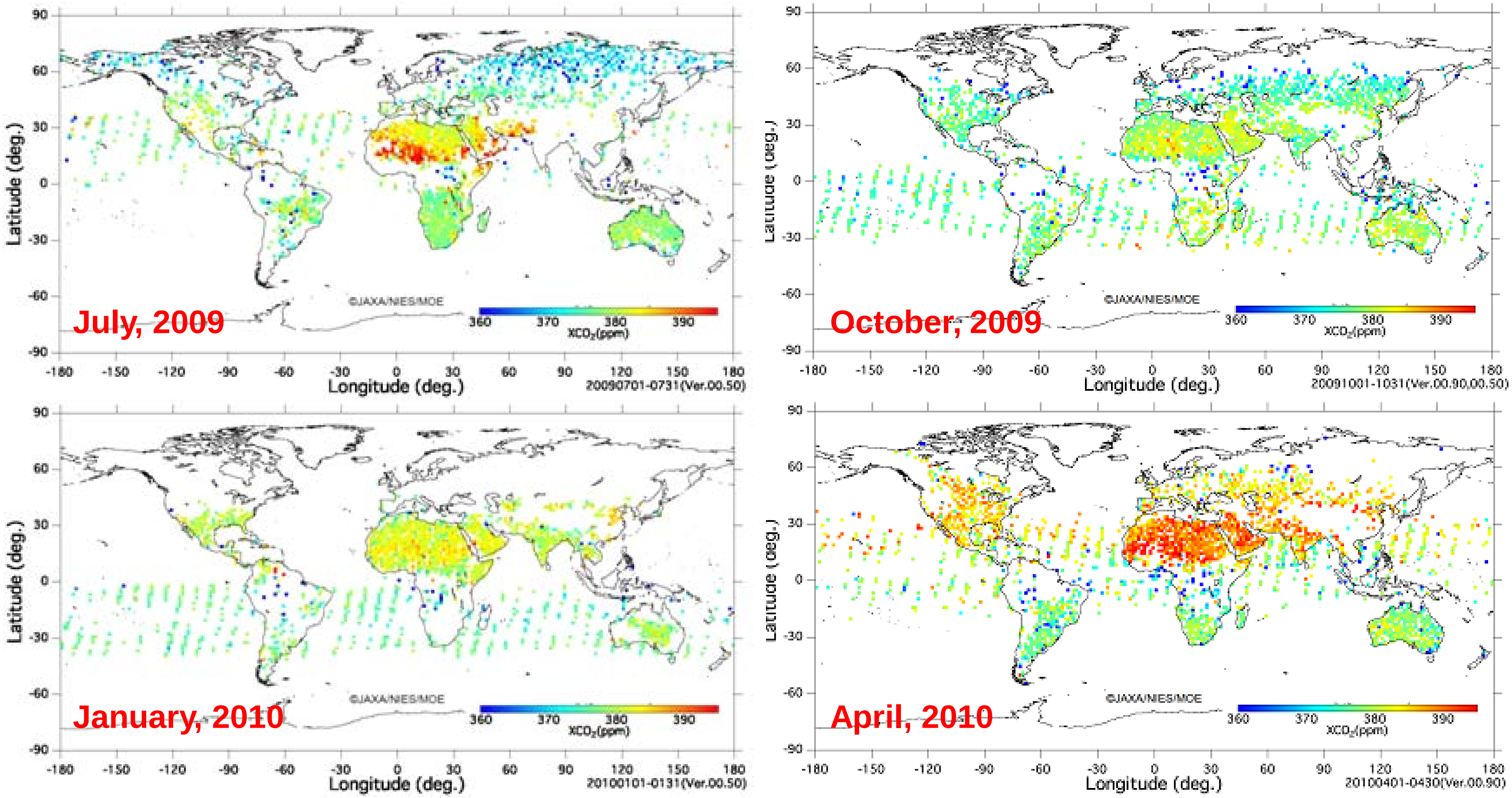
- NIES contributed to show the simulation spectra.

CH_4

CO_2

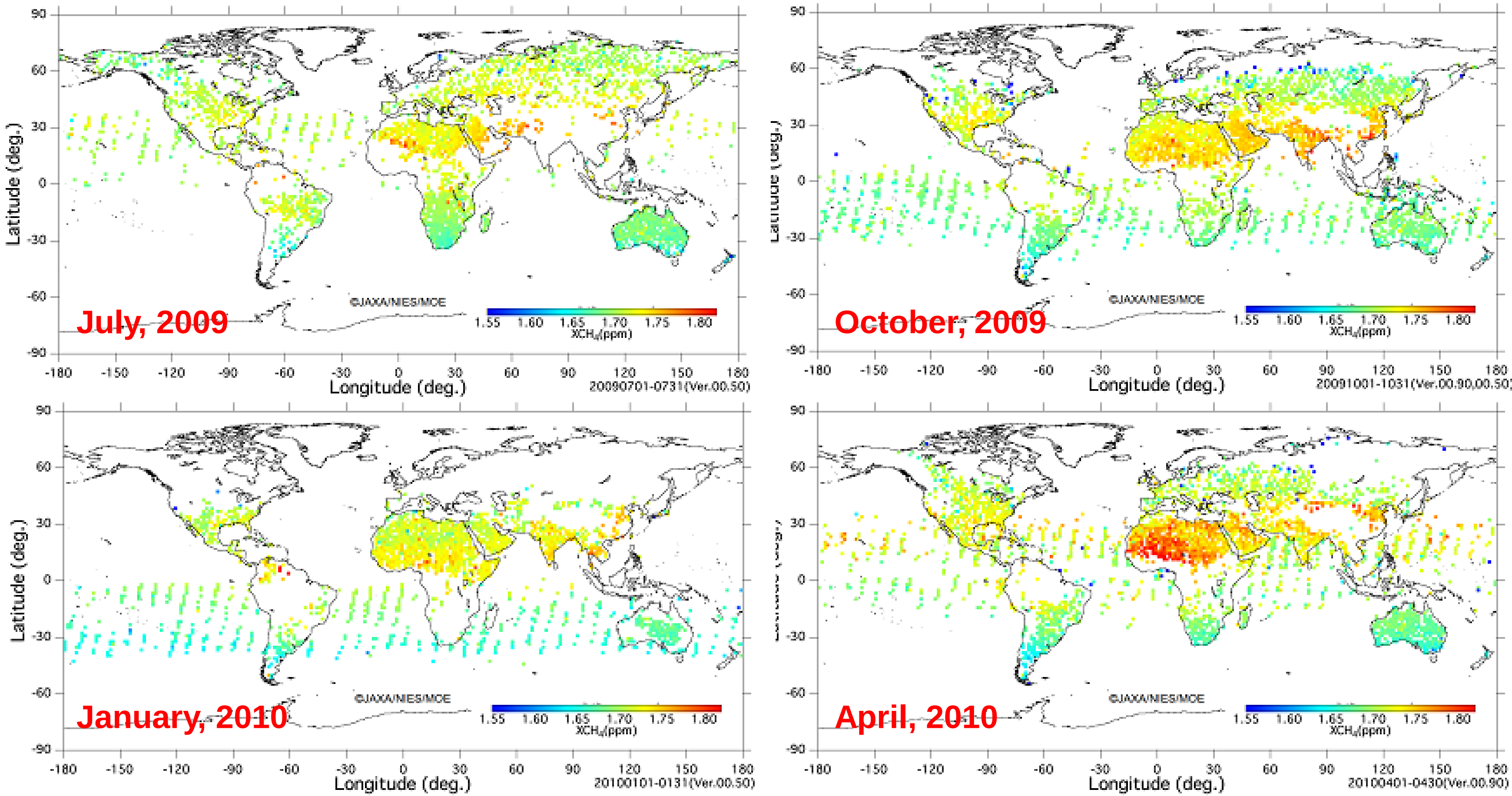


Seasonal variation of XCO_2



Areas of elevated concentrations are found in the desert areas of the Arabian Peninsula and northern Africa as well as their surroundings. The extent of the elevated concentration in these areas apperars to depend on the season. It is probable that these elevated concentrations were largely influenced by blown dusts of the deserts.

Seasonal variation of XCH_4



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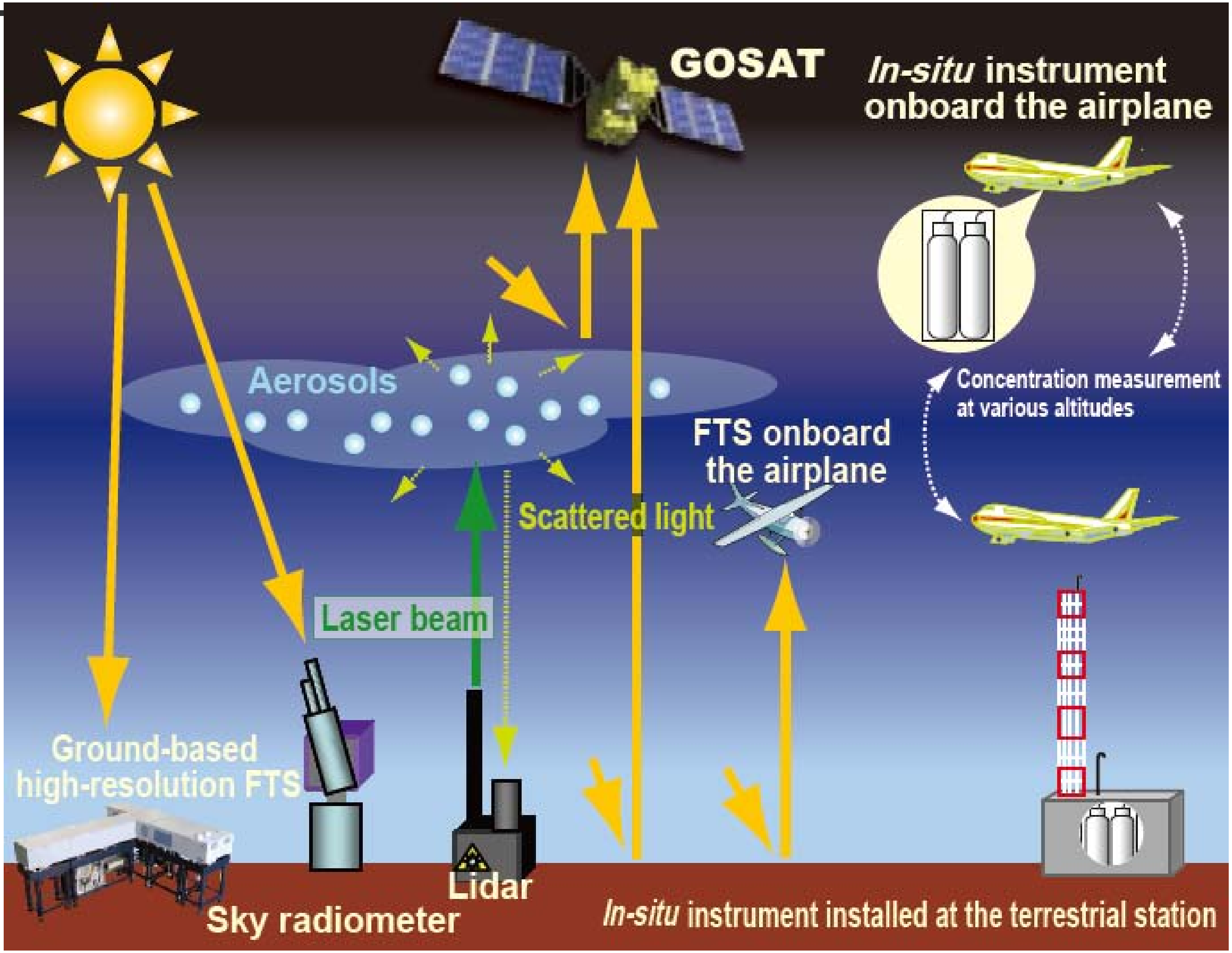
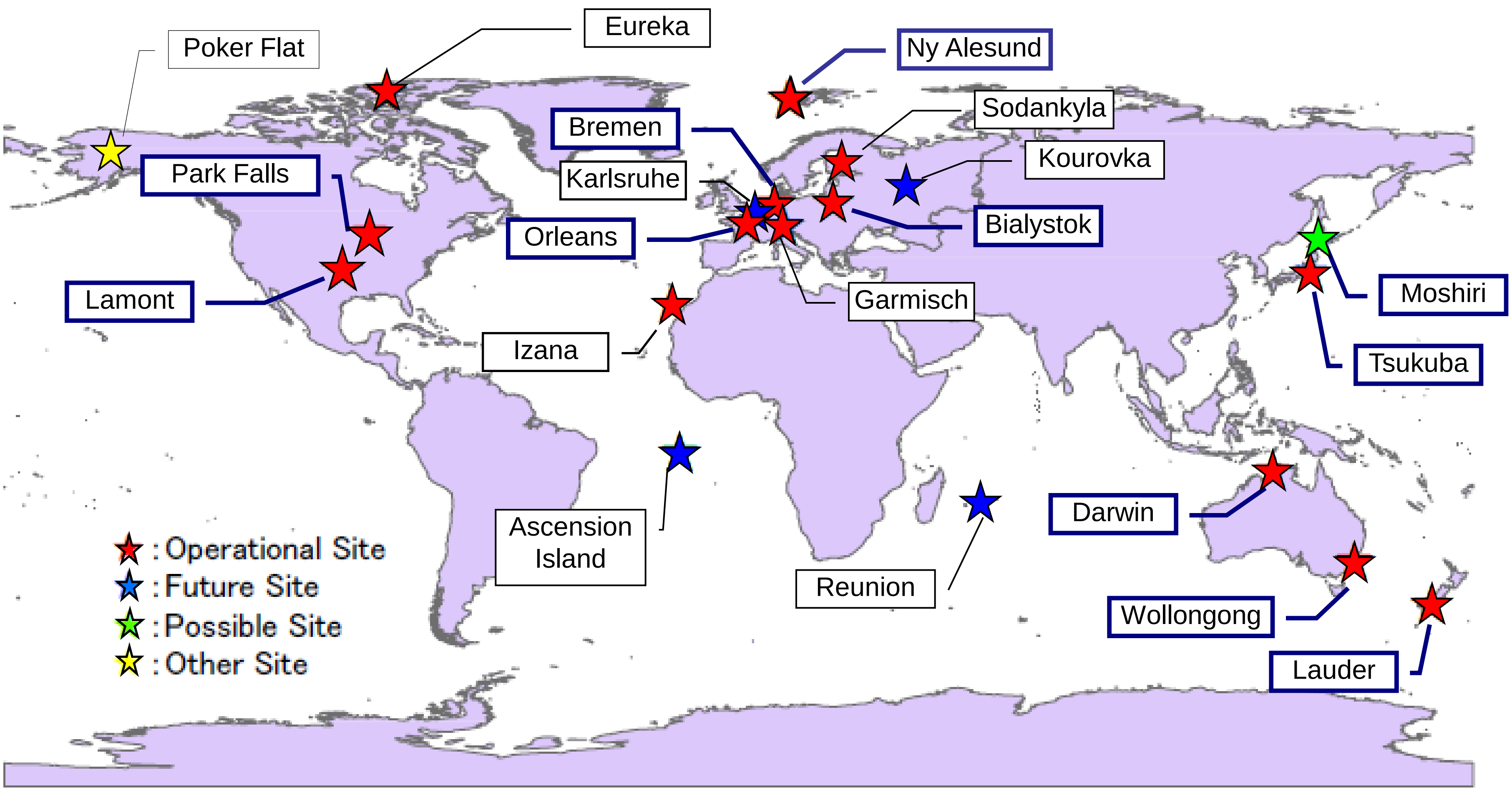
Schematic illustration of validation experiments



Source: GOSAT Project pamphlet

TCCON and other FTS sites for GOSAT validation

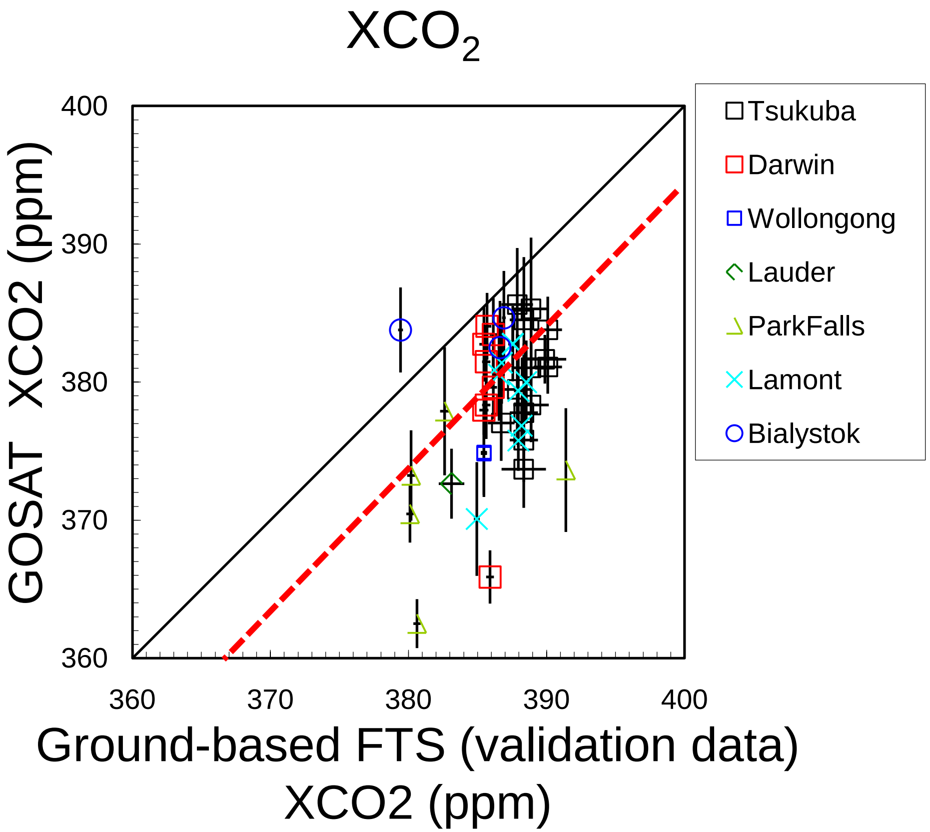
Ground-based high-resolution FTS network

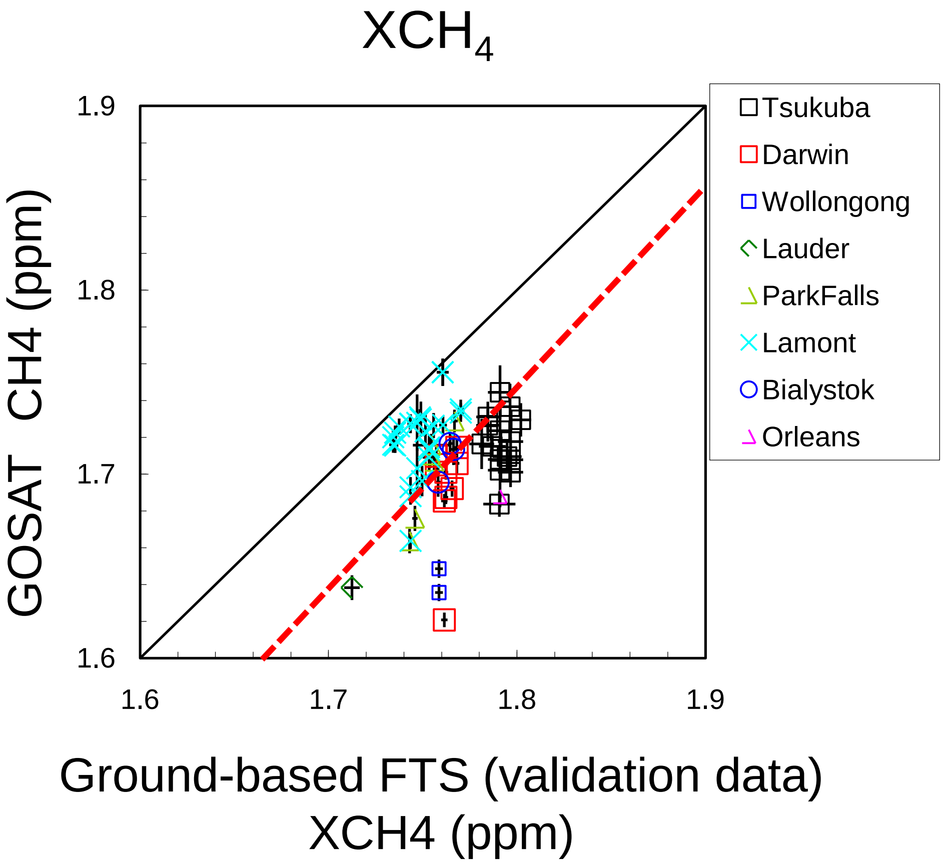


: will be used for the validation

TCCON :Total Carbon Column Observing Network (http://www.tccon.caltech.edu/index.html)

Comparison of GOSAT data with ground-based FTS data





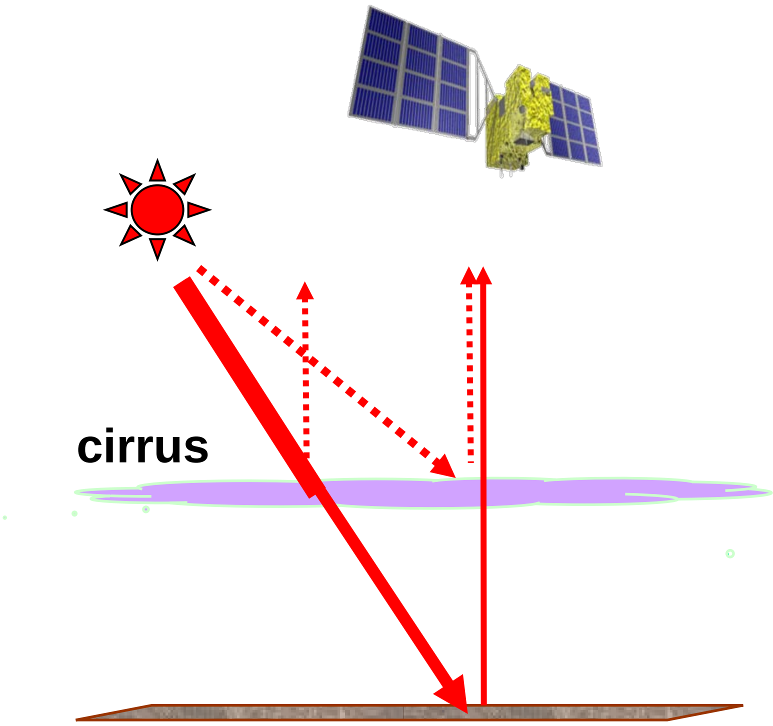
GOSAT product: V00.50 & V00.80

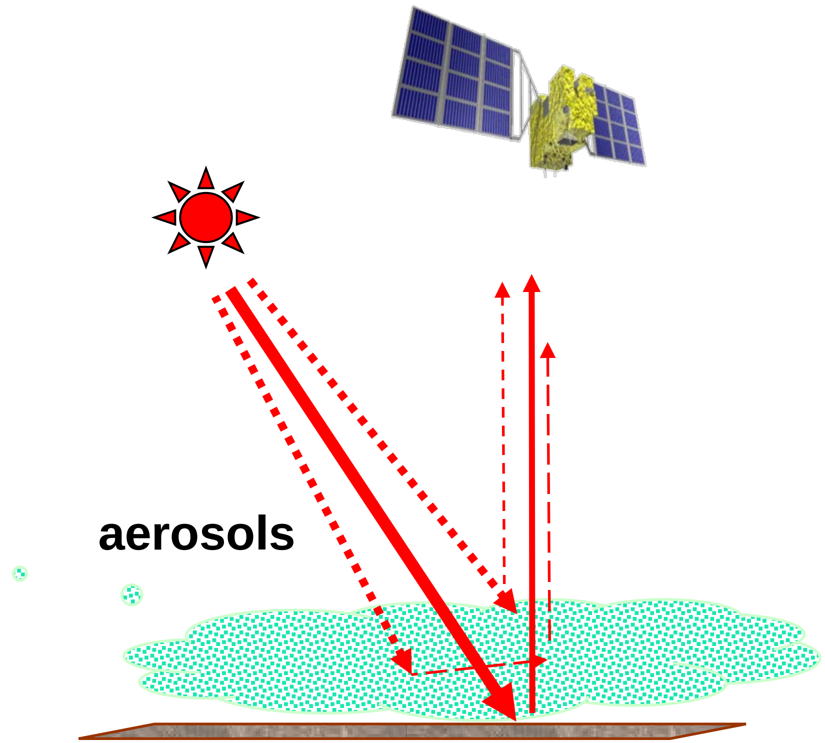
Validation data: TCCON and other FTSs data.

GOSAT Spectral Calculation (Forward Model for V00.xx)

- Assumption: Plane parallel atmosphere, Lambert surface over the land
- Discrete ordinate method, and a modified Duran's (2005) high-speed computation approach.
- HITRAN 2008 is used as a molecular spectroscopic database, except for H_2O and CH_4. Lyulin et al. (2009) is used for CH_4. HITRAN 2006 is used for water vapor.
- Gas absorption coefficient: cross section table is computed by LBLRTM (v11.3)
- Solar irradiance spectra: provided by R. L. Kurucz
- Rayleigh scattering, cirrus cloud, and aerosol scattering are computed.

Reflection from cirrus / aerosol



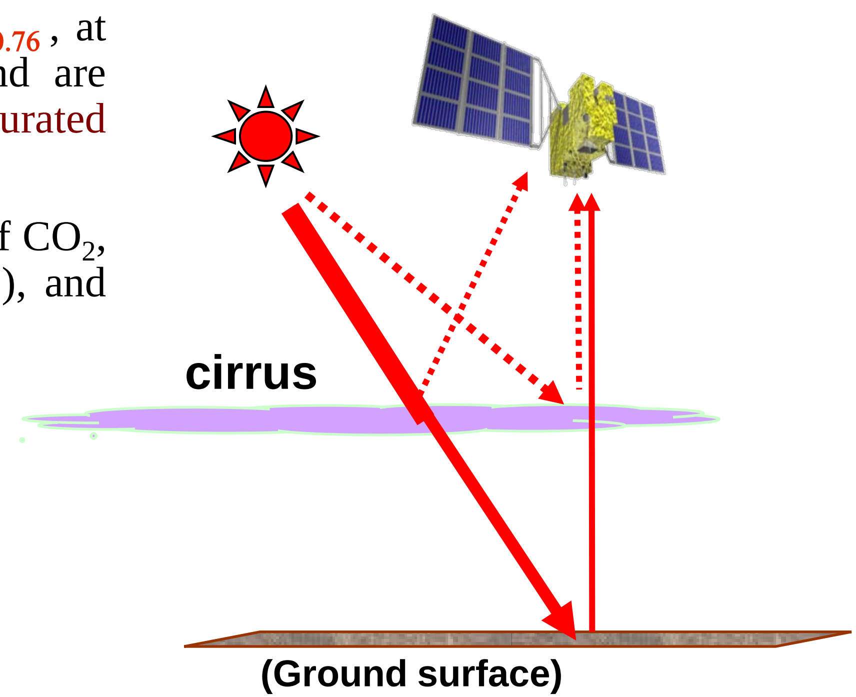


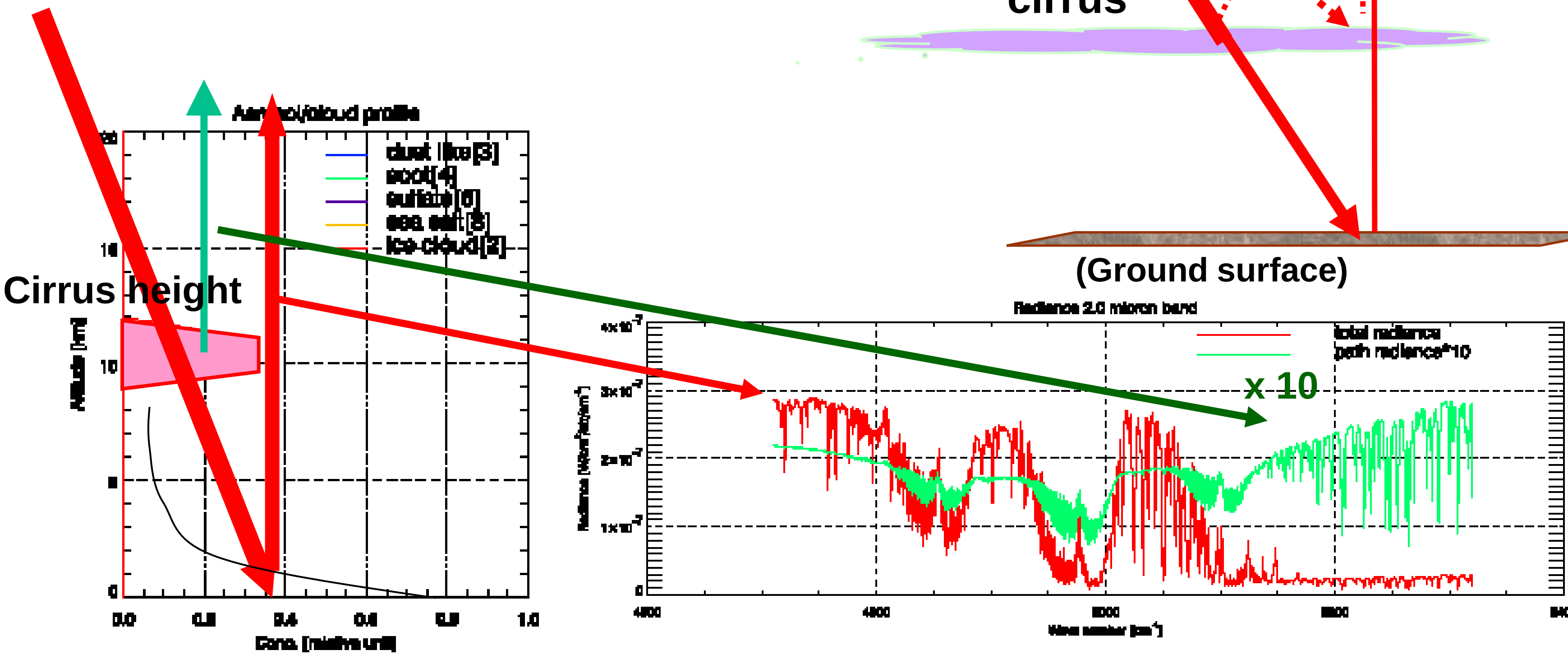
Cirrus effects will be cancelled with a two-step estimation method by using the H_2O saturated spectral region of the 2.0 μm band

Some types of the aerosols (e.g. Including black carbon) will affect serious error on the retrieval. We are now investigating a way to overcome the aerosol effects.

Retrieval concept for cirrus screening (Two step method)

- Step #1: The cirrus optical depth (τ), the cirrus cloud center height (**h**), and ground surface albedo ($\alpha_{0.76}$, at 50 cm^{-1} intervals) at the 0.76 μm (O_2-*A*) band are estimated from the 0.76 μm band and the H_2O saturated spectral region of the 2.0 μm band
- Step #2: Simultaneous retrieval of column density of CO_2, ground surface albedo ($\alpha_{1.6}$ at 25 cm^{-1} intervals), and re-estimation of τ from the 1.6 μm band





TANSO-FTS SWIR Level 2 Data Processing (up to Versions 00.90)

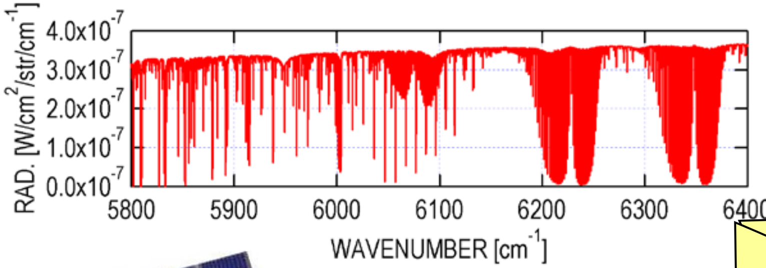
Three steps for data processing

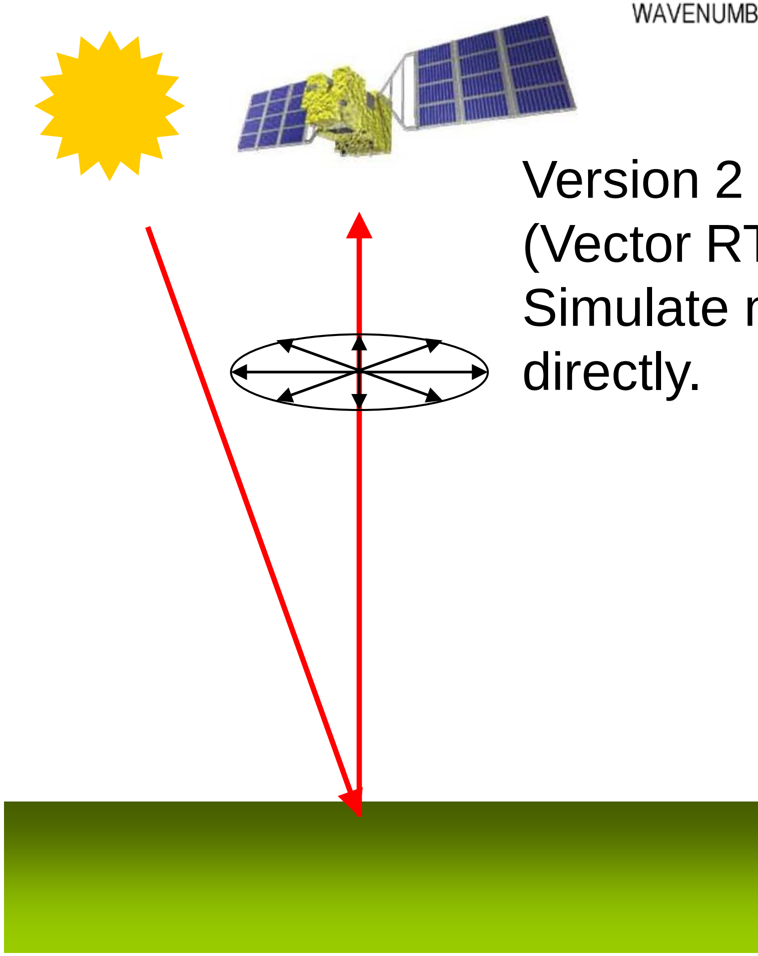
1) Data Screening (filtering)

2) Optimal Estimation (retrieval)

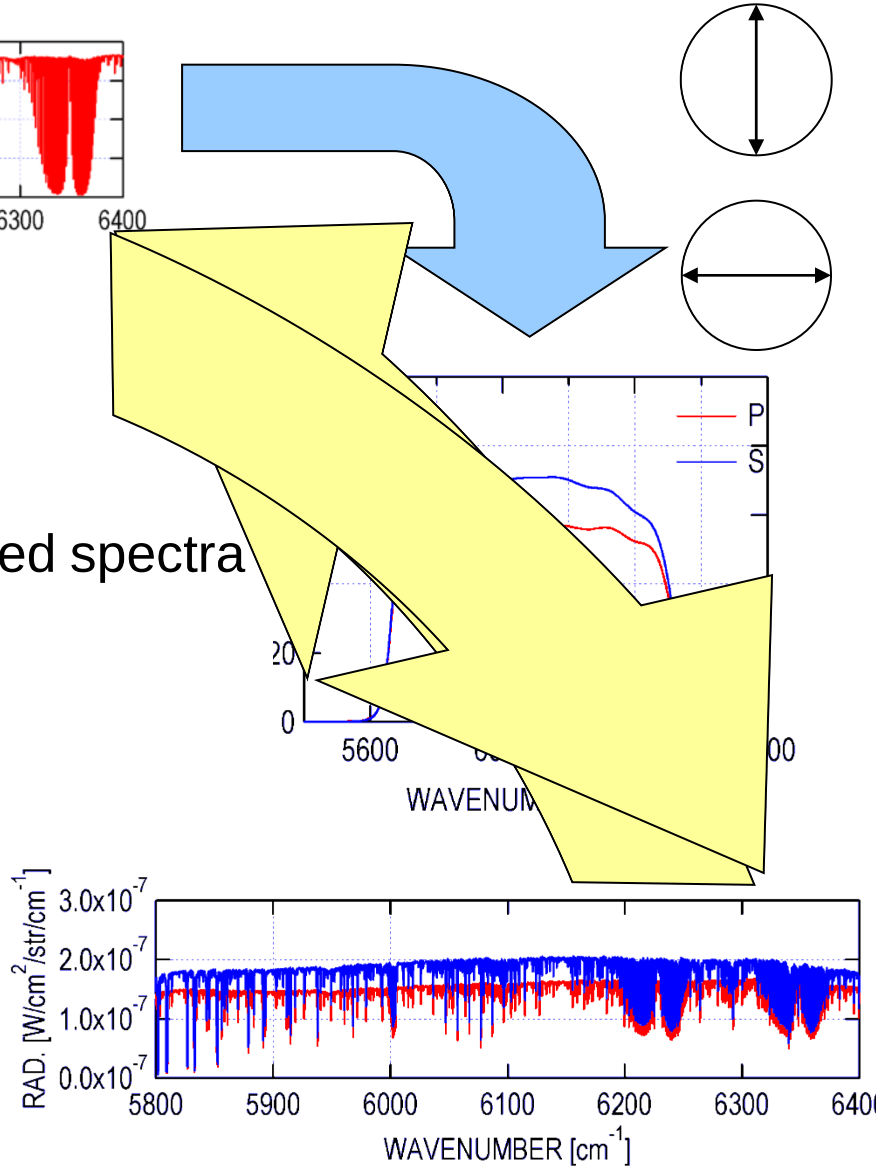
3) Quality Check (screening)

Incident light is devided by two polarized component by PBS.





Version 2
(Vector RT code)
Simulate measured spectra directly.



MEASURED SPECTRA

Radiative transfer model: Hstar and Pstar2.

- **High spectral resolution version of the System for Transfer of Atmospheric Radiation (Hstar);** [Nakajima et al.]
  - Scalar radiative transfer (radiance calculation only).
  - **Hybrid model: Discrete-ordinate / matrix-operator (adding) method** (Nakajima and Tanaka, 1986).
  - Multilayer multiple scattering media.
  - The delta-M truncation method.
  - Exact single scattering correction; TMS- and IMS-method (Nakajima and Tanaka, 1988).
  - Rough ocean surface model (Nakajima and Tanaka, 1983) / Lambert surface.
  - Direct multi-solar beam (for LUT calculation).
  - Arbitrary viewing geometry (Source function integration).

- **Vector radiative transfer model (Pstar2).**
  - Same as the above radiative transfer scheme.
  - Coupled atmosphere-ocean system including polarization effect.

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   Cited by Scopus (5)
2. **Aerosol light absorption and its measurement: A review** • Review article
   Journal of Quantitative Spectroscopy and Radiative Transfer, Volume 110, Issue 11, July 2009, Pages 844-878
   Moosmuller, H.; Chakrabarty, R.K.; Arnott, W.P.
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3. **The effect of line-broadening on the overall width of transition arrays in dense plasmas**
   Journal of Quantitative Spectroscopy and Radiative Transfer, Volume 99, Issue 1-3, May 2006, Pages 283-294
   Hoarty, D.J.; Bentley, C.D.; Crowley, B.J.B.; Davidson, S.J.; Gales, S.G.; Graham, P.; Harris, J.W.O.; Iglesias, C.A.; James, S.F.; Smith, C.C.
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4. **Radiation characteristics of Botryococcus braunii, Chlorococcum littorale, and Chlorella sp. used for CO"2 fixation and biofuel production**
   Journal of Quantitative Spectroscopy and Radiative Transfer, Volume 110, Issue 17, November 2009, Pages 1879-1893
   Berberoglu, H.; Gomez, P.S.; Pilon, L.
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   Journal of Quantitative Spectroscopy and Radiative Transfer, Volume 110, Issue 11, July 2009, Pages 833-843
   Wriedt, T.
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6. **Spectra of dense pure hydrogen plasma in Balmer area**
   Journal of Quantitative Spectroscopy and Radiative Transfer, Volume 83, Issue 3-4, February 2004, Pages 387-405
   Vitel, Y.; Gavrilova, T.V.; D'yachkov, L.G.; Kurilenkov, Y.K.
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7. **The HITRAN 2004 molecular spectroscopic database**
   Journal of Quantitative Spectroscopy and Radiative Transfer, Volume 96, Issue 2, December 2005, Pages 139-204
   Rothman, L.S.; Jacquemart, D.; Barbe, A.; Chris Benner, D.; Birk, M.; Brown, L.R.; Carleer, M.R.; Chackerian, C.; Chance, K.; Coudert, L.H.; Dana, V.; Devi, V.M.; Flaud, J.M.; Gamache, R.R.; Goldman, A.; Hartmann, J.M.; Jucks, K.W.; Maki, A.G.; Mandin, J.
   Cited by Scopus (1141)

25. **Matrix formulations of radiative transfer including the polarization effect in a coupled atmosphereocean system**
    Journal of Quantitative Spectroscopy and Radiative Transfer, Volume 111, Issue 6, April 2010, Pages 878-894
    Ota, Y.; Higurashi, A.; Nakajima, T.; Yokota, T.
    Cited by Scopus (1)

Retrieval: Optimal Estimation

Measurement | Prior constraint

Cost Function: $J(\mathbf{x}) = [\mathbf{y} - \mathbf{F}(\mathbf{x})]^T \mathbf{S}_\varepsilon^{-1} [\mathbf{y} - \mathbf{F}(\mathbf{x})] + (\mathbf{x} - \mathbf{x}_a)^T \mathbf{S}_a^{-1} (\mathbf{x} - \mathbf{x}_a)$

$$\mathbf{x}_{i+1} = \mathbf{x}_i + \left(\mathbf{K}_i^T \mathbf{S}_\varepsilon^{-1} \mathbf{K}_i + \mathbf{S}_a^{-1} + \lambda_i \mathbf{D}^2\right)^{-1} \left\{\mathbf{K}_i^T \mathbf{S}_\varepsilon^{-1} [\mathbf{y} - \mathbf{F}(\mathbf{x}_i)] + \mathbf{S}_a^{-1} (\mathbf{x}_i - \mathbf{x}_a)\right\}$$

$\mathbf{x}_i$	State vector
$\mathbf{x}_a$	A priori values for state vector
$\mathbf{y}$	Observed spectrum
$\mathbf{S}_a$	Covariance matrix for a priori values for state vector
$\mathbf{S}_\varepsilon$	Covariance matrix for observed spectrum
$\mathbf{F}(\mathbf{x}_i)$	Forward model
$\mathbf{K} = \frac{\partial \mathbf{F}(\mathbf{x})}{\partial \mathbf{x}}$	Jacobian

Optimal Estimation

CO_2 and CH_4 are retrieved under the assumption of cloud-free condition.

CO_2 retrieval: 6180 ~ 6380 cm^{-1} (TANSO-FTS Band 2)

- ~~CO_2 profile~~
- aerosol optical thickness
- surface albedo (land) / surface wind speed (ocean)
- adjustment factor for relative radiometric calibration
- solar Fraunhofer lines, H_2O absorption lines are masked

HITRAN 2008

CH_4 retrieval: 5900 ~ 6150 cm^{-1} (TANSO-FTS Band 2)

- ~~CH_4 profile~~
- H_2O profile (HITRAN 2006)
- aerosol optical thickness
- surface albedo (land) / surface wind speed (ocean)
- adjustment factor for relative radiometric calibration
- solar Fraunhofer lines are masked.

Lyulin et al. (2009)

Dry air column is calculated from the meteorological data.

➔ converted to XCO_2 and XCH_4

Next Improvement of Forward Calculation

- Changing Line Parameter Database
  - CH_4: Lyulin et al. (2009) ➔ HITRAN 2008
  - H_2O: HITRAN 2006 ➔ HITRAN 2008
- Line mixing considerations for all bands

⬇

- Retrieval Improvements
  - Simultaneous retrieval form Band 1 (O_2-*A* band) and Band 2 (CO_2 1.6 micron)
  - Parameters: CO_2 profile, CH_4 profile, H_2O profile, aerosol optical thickness (AOT), surface albedo/wind speed, temperature shift, surface pressure, wavenumber correction coefficient

Incorporation of LM + CIA for the O_2 *A*-band

- Three types of the forward calculation were tested

1) LM+ CIA : Ps = 989 hPa (a priori: 981 hPa), $\chi^2 = 1.5038$

Residuals (obs. – calc.) of spectra are sufficiently small.

2) Speed dependence are also included → show very small effect :

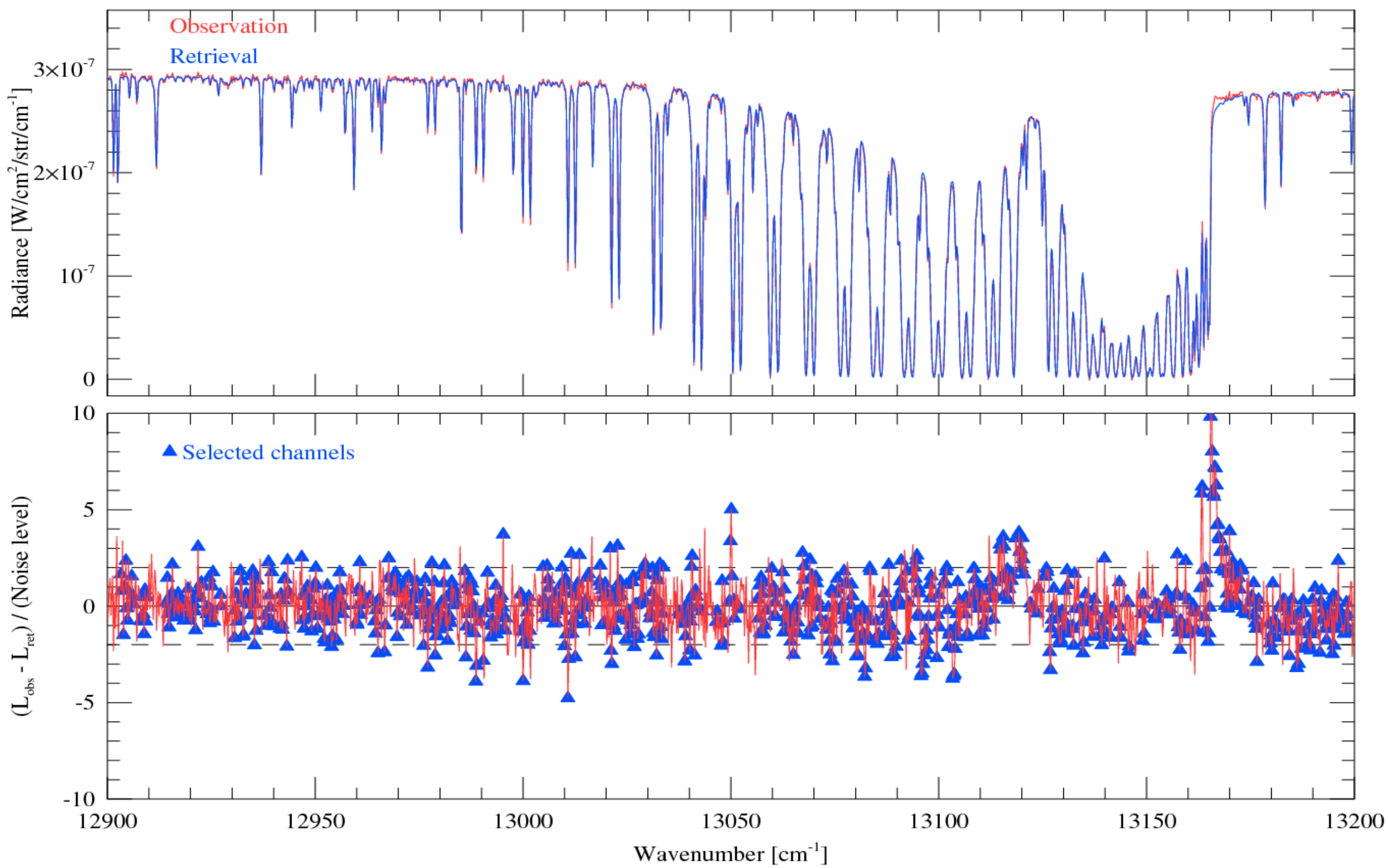
Ps = 989.05 hPa and $\chi^2 = 1.5073$.

3) Voigt (without CIA and LM) :

Ps = 1018 hPa and $\chi^2 = 2.5647$.

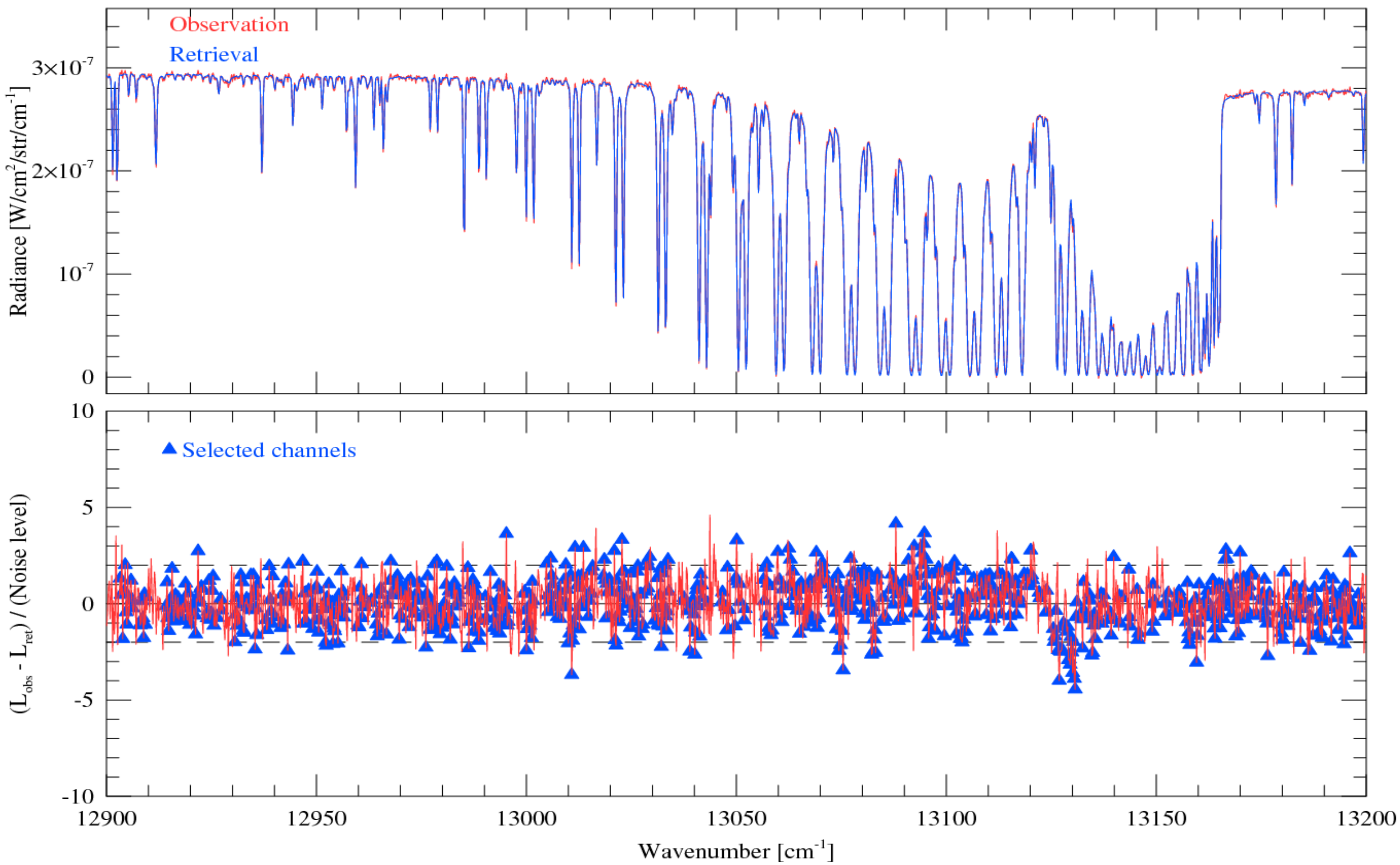
O_2 A-band: Result with Voigt profiles

Ps = 1018 hPa, χ^2 = 2.5647



O_2 A-band: Result with LM+CIA codes

Ps = 989 hPa, χ^2 = 1.5038



Line Mixing conbinationTests for Retrievals

- H_2O: HITRAN2008（2009 update）
- CH_4: Lyulin et al.（2009）
- Comparison among the following three cases

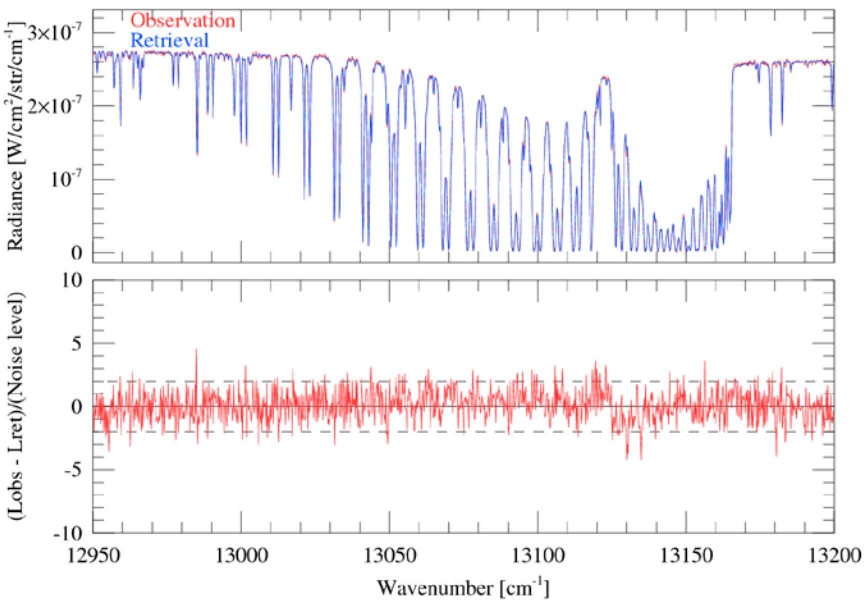
	O2 – *A* Band	Weak CO2	Note
Case 0	Tran LM+CIA	Hartmann	
Case 1	HITRAN2008	Hartmann	Without CIA
Case 2	Tran LM+CIA	HITRAN2008	

Retrieval conditions

- TANSO-FTS Band 1 & 2
- Simultaneous retrieval of H_2O, CO_2, CH_4, aerosol optical thickness (AOT), ground surface albedo, and irradiance correction coefficient
- Assumed cloud free and no cirrus contaminated
- 2009/04/26 – 28, over the land, (346 scans)

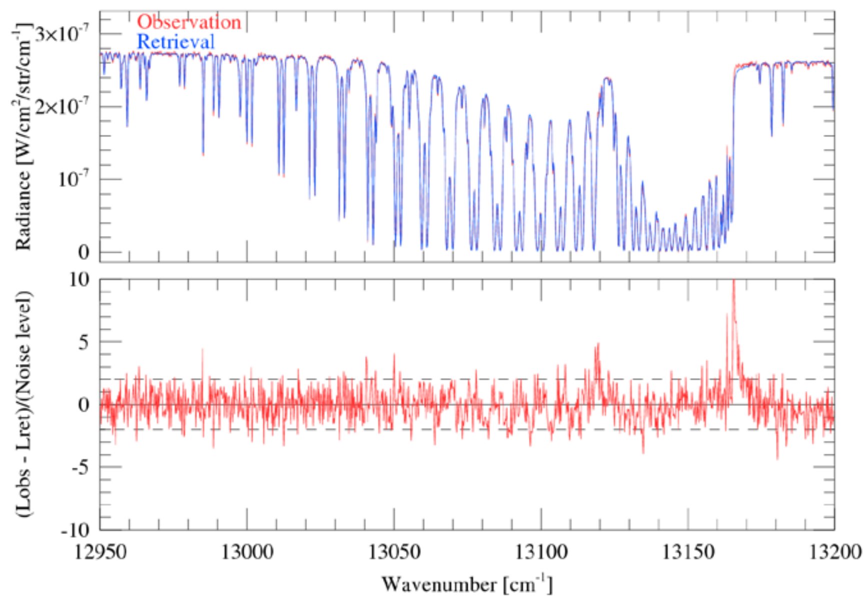
Spectral residuals after retrievals

Case 0



With Line Mixing

Case 1

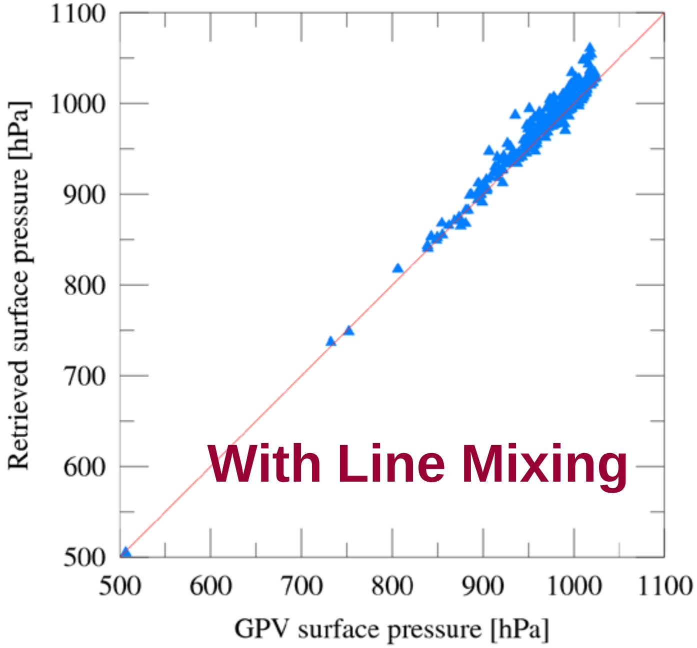


Without Line Mixing

Surface pressure (Meteor. vs Retrievd)

Case 0

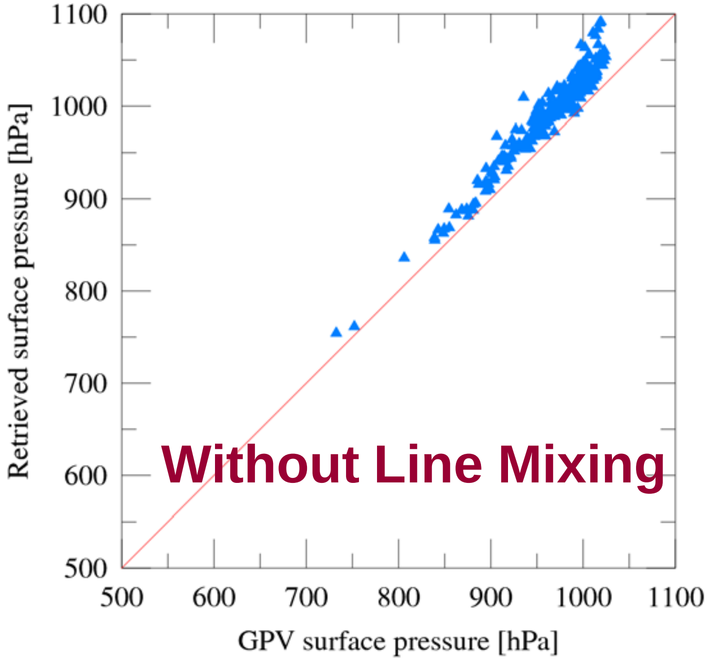
GOSAT Data



Meteorological Data (GPV)

Case 1

GOSAT Data



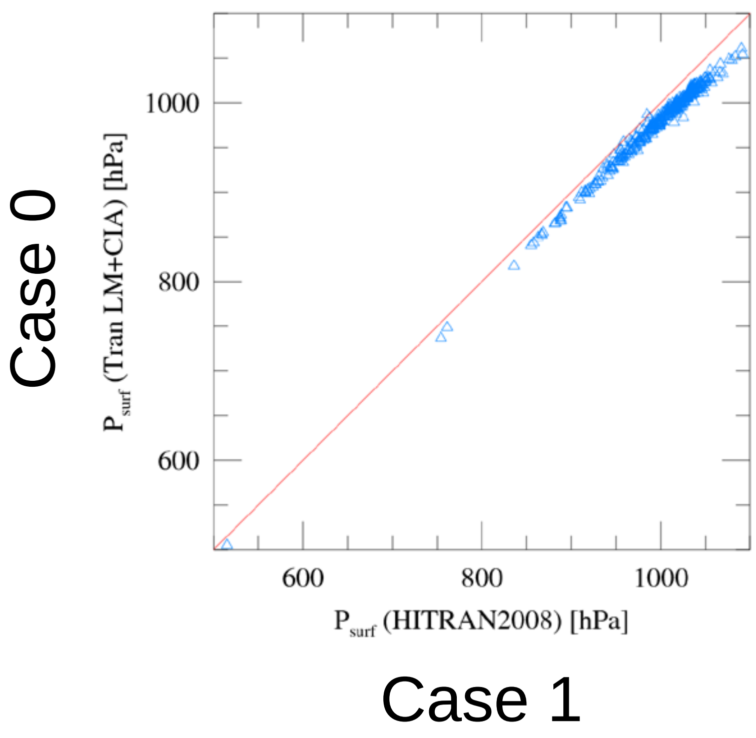
Meteorological Data (GPV)

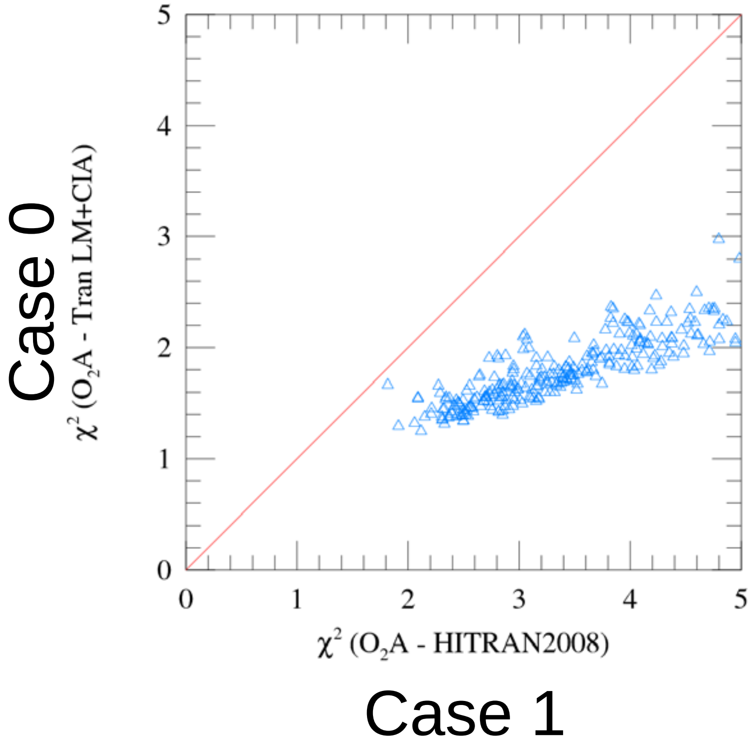
Case 0 vs. Case 1

Surface pressure

Residuals

With Line Mixing in O2 A-band





Without Line Mixing in O2 A-band

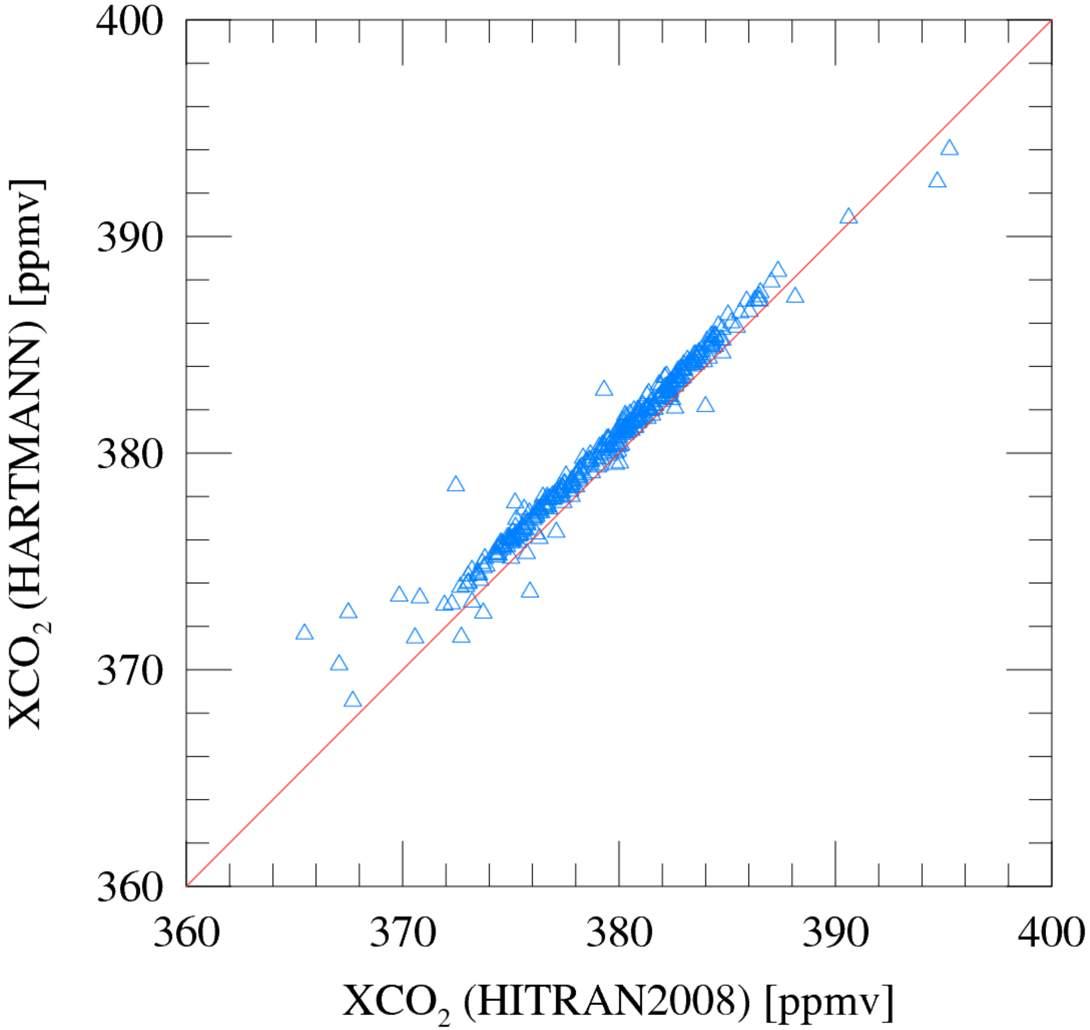
Line Mixing conbinationTests for Retrievals

- H_2O: HITRAN2008（2009 update）
- CH_4: Lyulin et al.（2009）
- Comparison among the following three cases

	O2 – *A* Band	Weak CO2	Note
Case 0	Tran LM+CIA	Hartmann	
Case 1	HITRAN2008	Hartmann	Without CIA
Case 2	Tran LM+CIA	HITRAN2008	

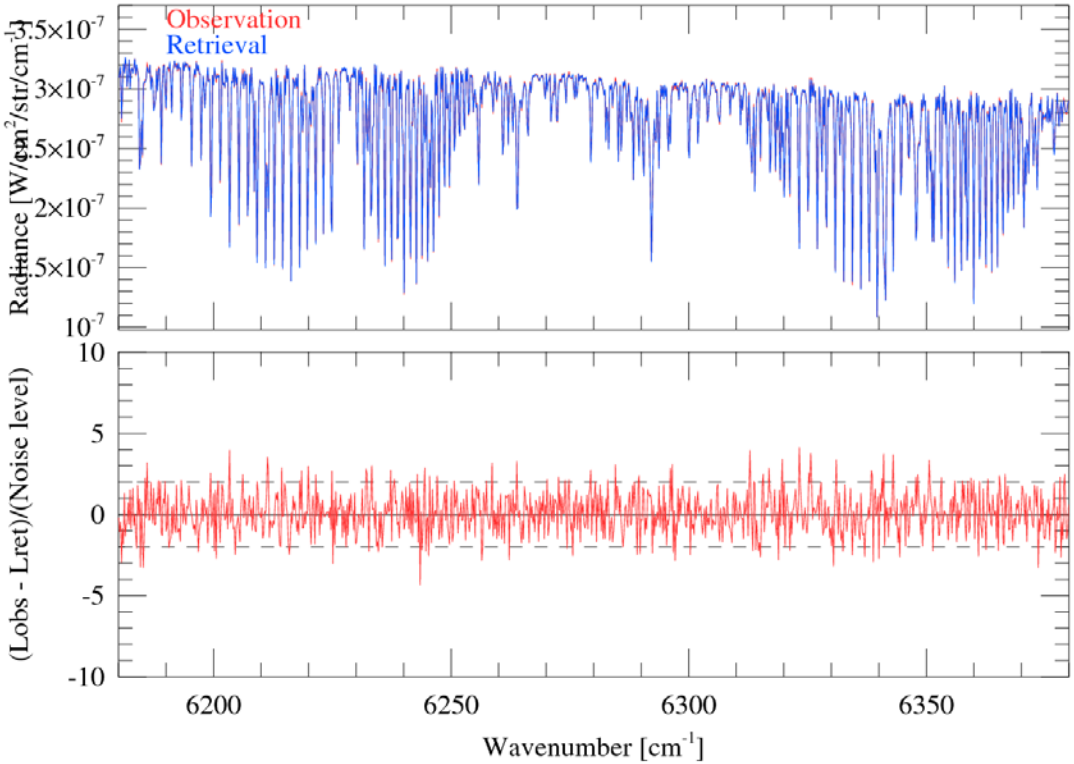
XCO_2 : Case 0 vs. Case 2

With Line Mixing in weak CO2 band

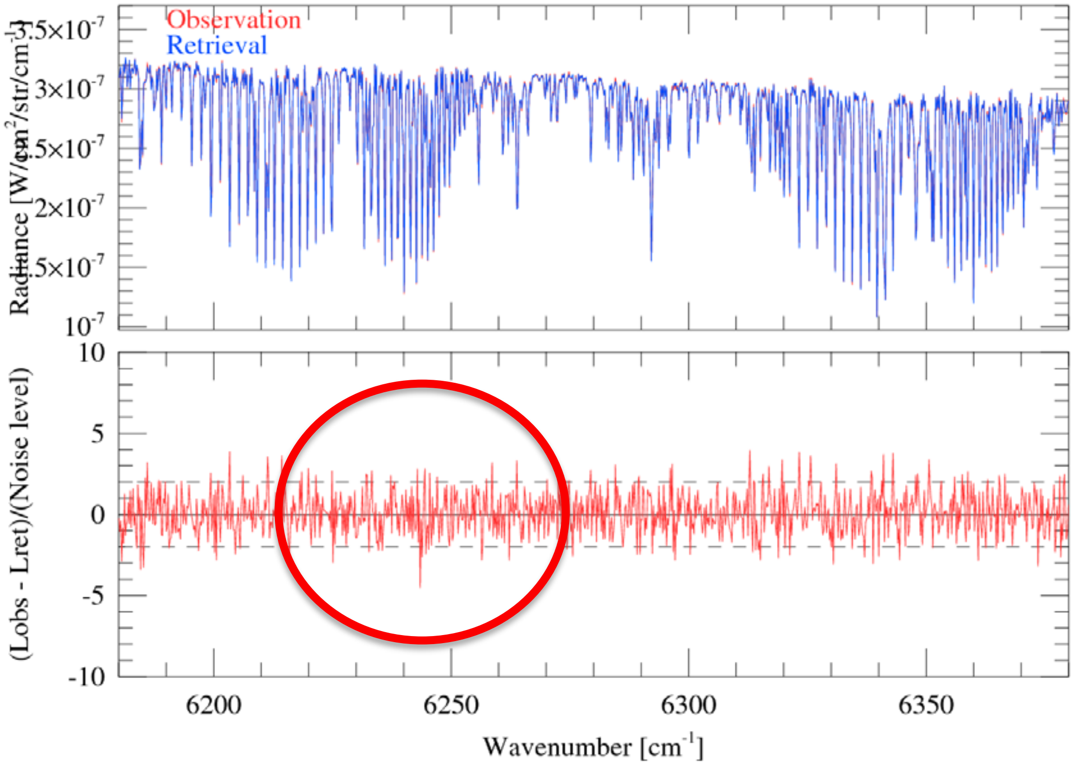


Without Line Mixing in weak CO2 band

Case 0: spectral residuals



Case 2: spectral residuals



Announcement

GOSAT Research Activities

- **Research Announcement**
  - **Research Topics**
    1) Calibration
    2) Data Processing Algorithm
    3) Validation
    4) Carbon Balance Estimation and Atmospheric Transport Models
    5) Data application
  - **The 1st GOSAT RA in 2008**

    52 research themes were selected.
  - **The 2nd GOSAT RA in 2009**

    36 research themes were selected.
  - **The 3rd GOSAT RA in August 2010 (Planned)**
- **Data Release**
  - CAI & FTS-L1B data product: October 30, 2009
  - CAI & FTS-L2 data product: February 18, 2010
  - Improved FTS-L2 data product: August, 2010 (Planned)

Japan Aerospace Exploration Agency (JAXA)

National Institute for Environmental Studies (NIES)

Ministry of the Environment (MOE)

NIES GOSAT Project Web site

Greenhouse gases GOSAT PROJECT Observing SATellite

Japanese

GOSAT Project

Contact FAQ Site Map

Top | News | About GOSAT | Research Announcement | Technical Information | Project Results | Glossaries | Links

Observation data distribution and Observation request service are here

GOSAT User Interface Gateway

News

- (April 14,2009) "GOSAT Project" pamphlet was revised.
- (April 7,2009) We have just launched the 2nd Research Announcement on GOSAT.
- (April 1,2009) We made the "News" page.
- (Febrary 13,2009) The first data of GOSAT were acquired. The results are shown on following JAXA's home page.
- (Febrary 9,2009) GOSAT path calendar has been disclosed.
- (Febrary 6,2009) GOSAT Data Policy has been disclosed.

Global Greenhouse Gas Observation by Satellite

GOSAT Project

http://www.gosat.nies.go.jp/index_e.html

NIES organized the research team dedicated to the GOSAT project within its organization in April 2004, and since then has been working for the research and development with respect to GOSAT "IBUKI".

(If you click the above image, and it opens in another window.)

What's New

Last Update: April 14, 2009

Concluding Remarks

- GOSAT Level 2 data products (Vers. 00.xx) of CO_2 and CH_4 have negative biases of 2 – 3%, however the overall tendency of global seasonal variations seems good.
- Some part of the retrieval results are affected by dust aerosols.
- Precise line parameters and line shape calculation are quite important to retrieve XCO2 and XCH4 correctly.
- Some line parameters will be changed, and line mixing for O_2-*A* band in forward calculation will be included in the next version of the algorithm.