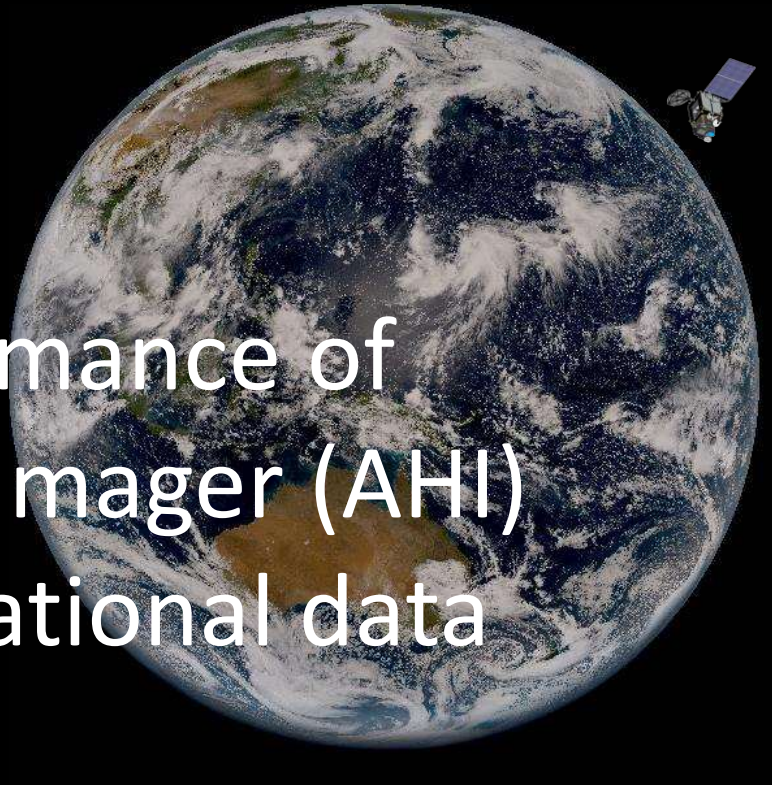


Calibration performance of Advanced Himawari Imager (AHI) from one-year operational data

Arata Okuyama
Meteorological Satellite Center / Japan Meteorological Agency

5st September 2016, Tokyo, Japan
CEOS WGCV Plenary # 41

2014 HIMAWARI-8
2016 HIMAWARI-9

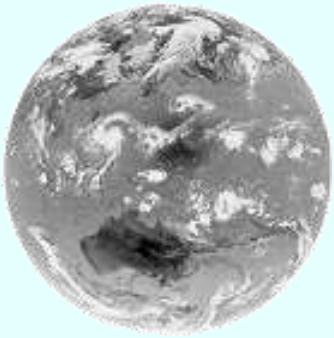
Himawari-9 launch planned date

- Planned date:
  - 1 November 2016
- Time:
  - 06:20 – 09:18 (UTC)
- Launch site:
  - Tanegashima Space Center, Japan
- Launch vehicle:
  - H-IIA #31

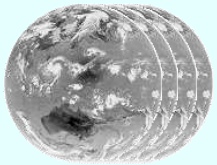
Improved resolutions

Spectral

VIS 1 band



IR 4 bands

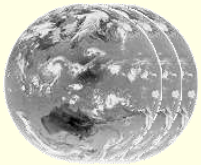


5 bands

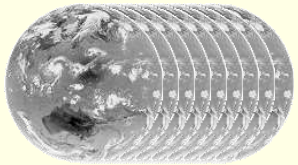
MTSAT-1R/2

VIS 3 bands

NIR 3 bands



IR 10 bands



16 bands

Himawari-8/9

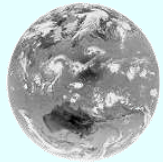
Spatial

MTSAT-1R/2	Himawari-8/9
VIS 1 km IR 4 km	VIS 0.5/1 km IR 2 km

at sub-satellite point

Temporal

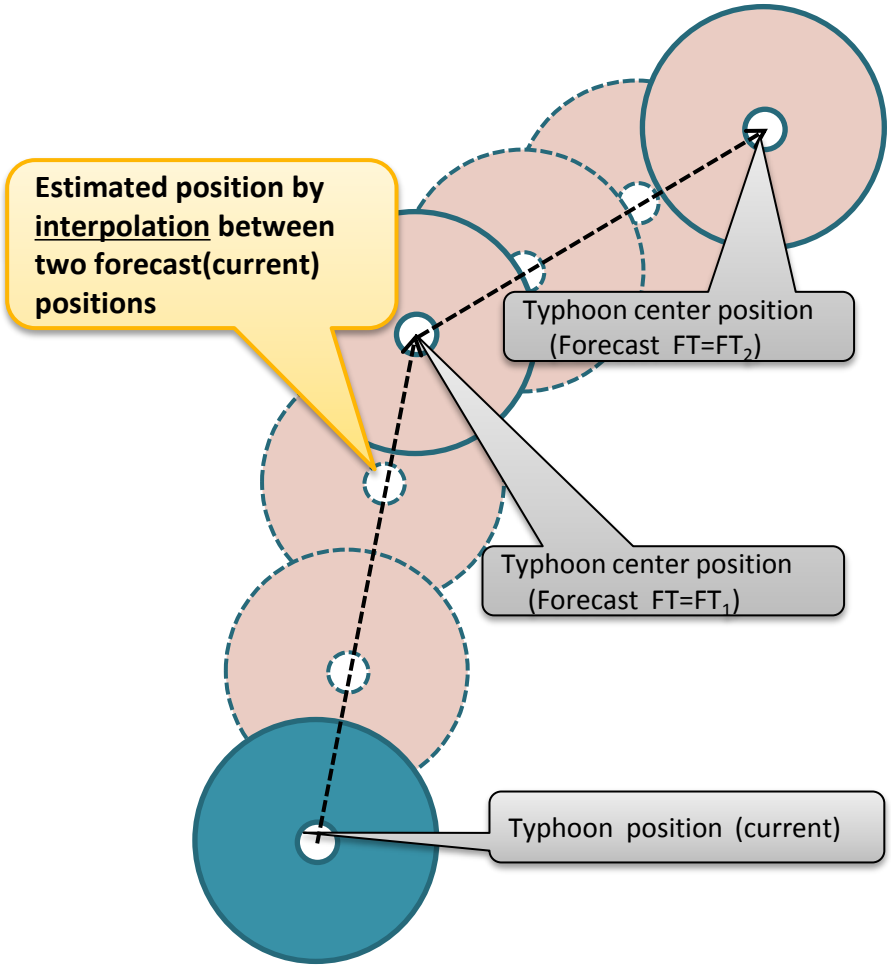
Observation Frequency



60min.
(full-disk obs.)

MTSAT-1R/2 **Himawari-8/9**

Target Area Observation (Typhoon)

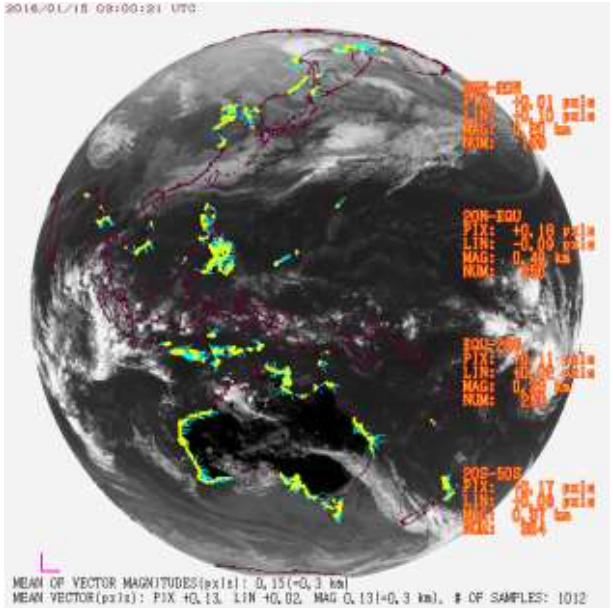


21 UTC on 9th – 10 UTC on 10th, May 2015
Typhoon Noul (2015) Band 03

Image Navigation and Registration (INR)

INR Approaches

- Orbit determination: based on ranging data
- Satellite attitude determination: based on star tracker and gyro data
  - It is refined using landmark analysis based on pattern matching for coastlines
- Based on the refined information, raw data is resampled and converted to Himawari Standard Data (HSD, L1B equiv. data) .



Validation approach

- Residual image navigation error in the HSD is validated using landmark analysis

Performance

- Usually less than 0.5 IR pixels (approx. 1 km at SSP)
- The error occasionally/provisionally becomes larger in the next full-disk observing cycle after station keeping maneuver and at the timing of satellite eclipse

Calibration

- On-board Calibration Target
  - VIS/NIR: solar diffuser (SD)
    - SD observation: twice a month
    - Deep space observation: every swath
    - Calibration slope is updated in June 2015 and the offset is updated every swath.

$$L_{obs} = \frac{q_n(C - C_{sp})^2 + m_n(C - C_{sp})}{\rho_{ns}(\theta)\rho_{ew}(\phi)}$$

  - IR: black body
    - Black body observation: every 10 mins
    - Deep space observation: every swath
    - Calibration coefficients are updated based on black body (every 10 mins.) and deep space (every swath).

$$L_{obs} = F(\theta,\phi)(q_n C^2 + m_n C + b_n) - G(\theta)R_{Mns} - H(\theta,\phi)R_{Mew}$$

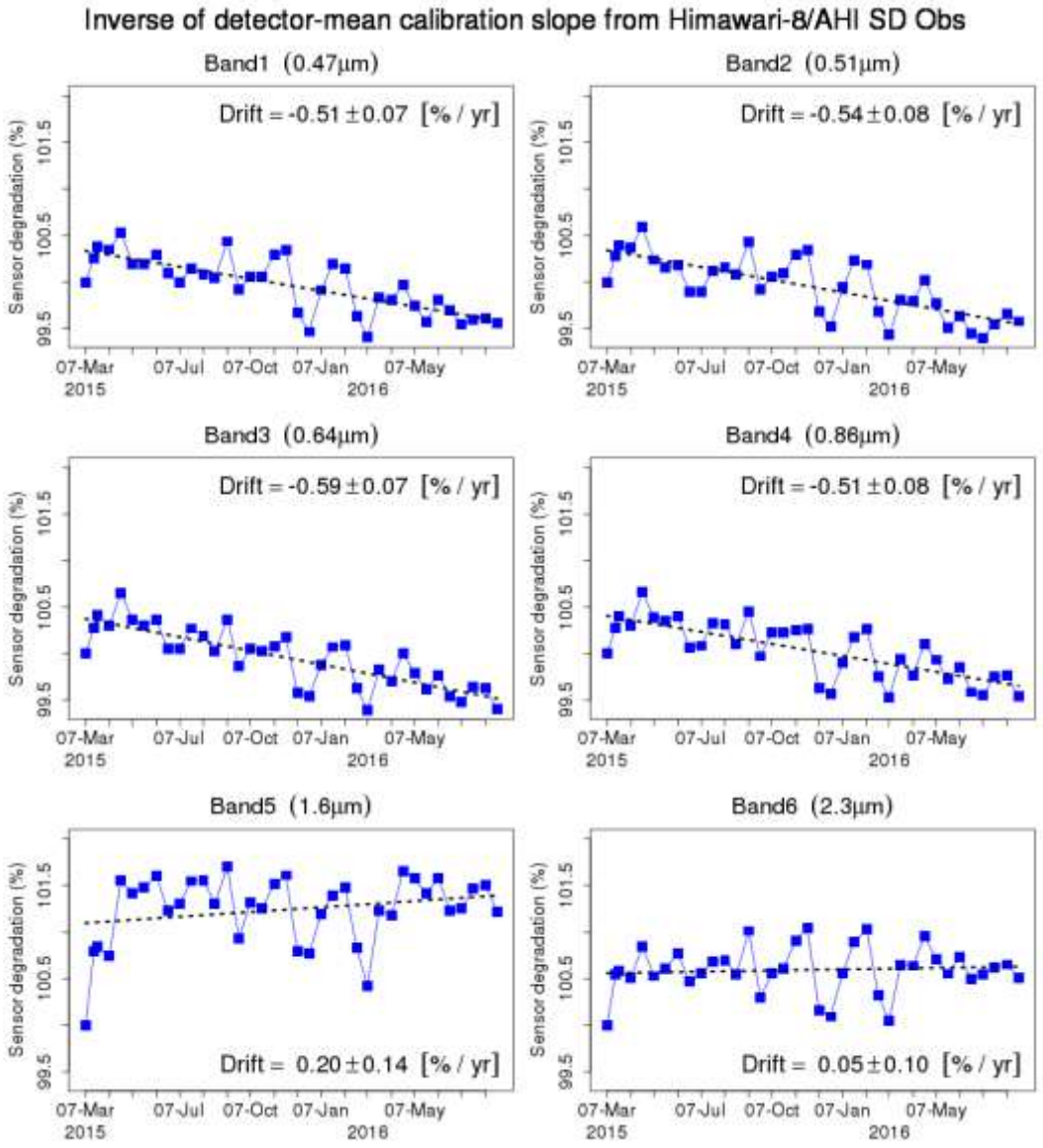
Radiometric Calibration Methods

Band [μm]	Solar Diffuser	Black Body	GSICS (IR)	GSICS (DCC)	GSICS (Moon)	RT simulation	Ray matching	GEO-GEO
Band1 [0.47]	Y			(Y)	(Y)	Y	Y	Y
Band2 [0.51]	Y			(Y)	(Y)	Y	Y	Y
Band3 [0.64]	Y			(Y)	(Y)	Y	Y	Y
Band4 [0.86]	Y			(Y)	(Y)	Y	Y	Y
Band5 [1.6]	Y			(Y)	(Y)	Y	Y	Y
Band6 [2.3]	Y			(Y)	(Y)	Y	Y	Y
Band7 [3.9]		Y	Y					Y
Band8 [6.2]		Y	Y					Y
Band9 [6.9]		Y	Y					Y
Band10 [7.3]		Y	Y					Y
Band11 [8.6]		Y	Y					Y
Band12 [9.6]		Y	Y					Y
Band13 [10.4]		Y	Y					Y
Band14 [11.2]		Y	Y					Y
Band15 [12.4]		Y	Y					Y
Band16 [13.3]		Y	Y					Y

(Y) : under implementation

Trend of SD observation

- Solar diffuser (SD) observation is performed twice a month
- Degradation: ~0.5%/yr in Bands 1-4, not clear in Bands 5 and 6
  - ✓ Generally consistent results with other calibration methods (will be shown later)

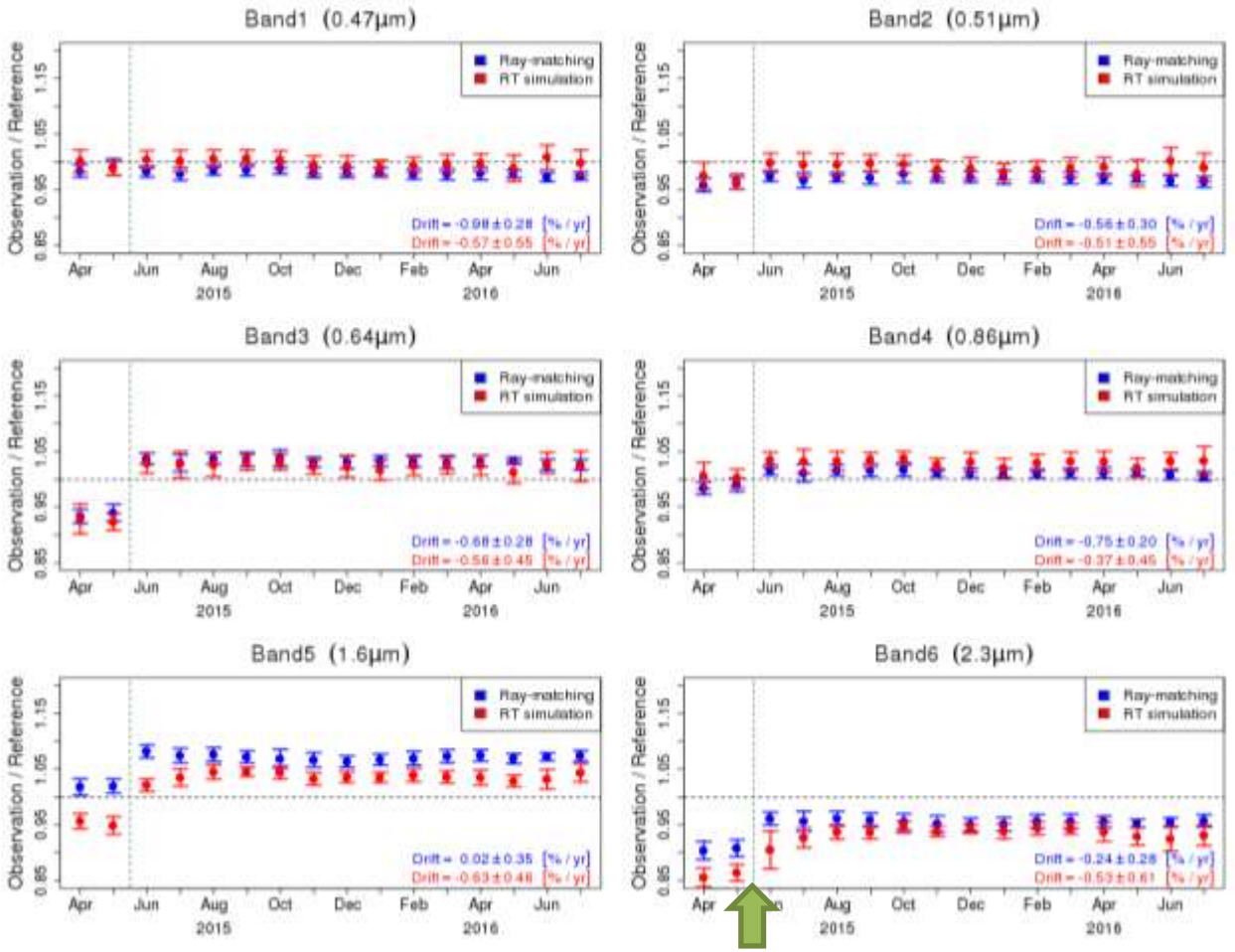


The values are averaged over all the detectors and are normalized at the first observation on 7 March 2015.

Calibration slopes
RT simulation and Ray-matching (VIIRS) approach

- Calibration coefficients are updated in June 2015 based on SD obs.
- Calibration bias was reduced after the updating .
- Band 1-4 observations are close to reference, band 5/6 show 4-7 % bias.

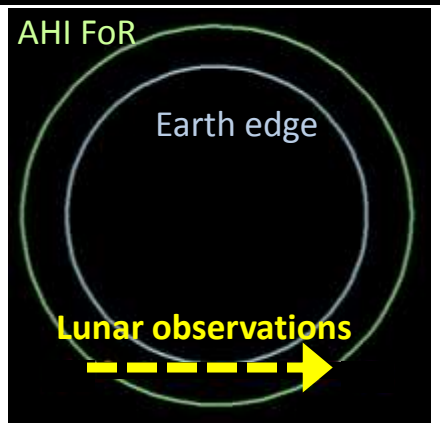
RT simulation: comparison with simulation
Ray-matching: comparison with VIIRS

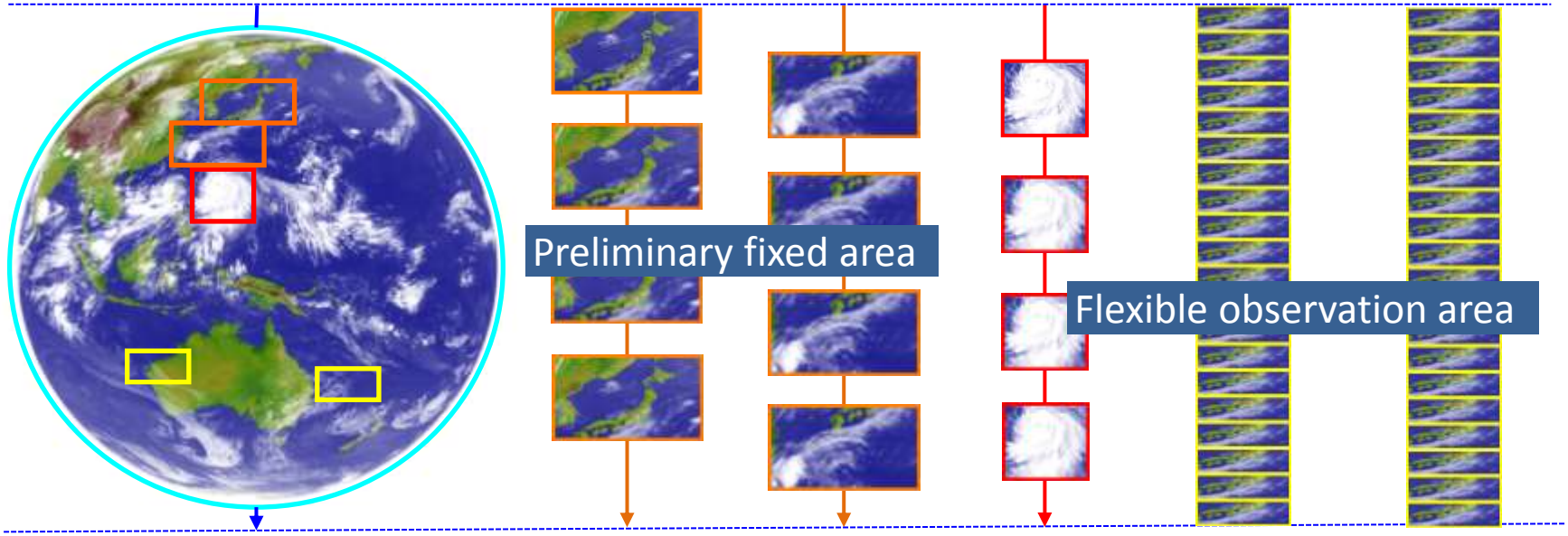


Update of calibration slopes

Moon observation

Region 4, 5: mainly used for landmark observation, but **region 5** is also used for lunar observation



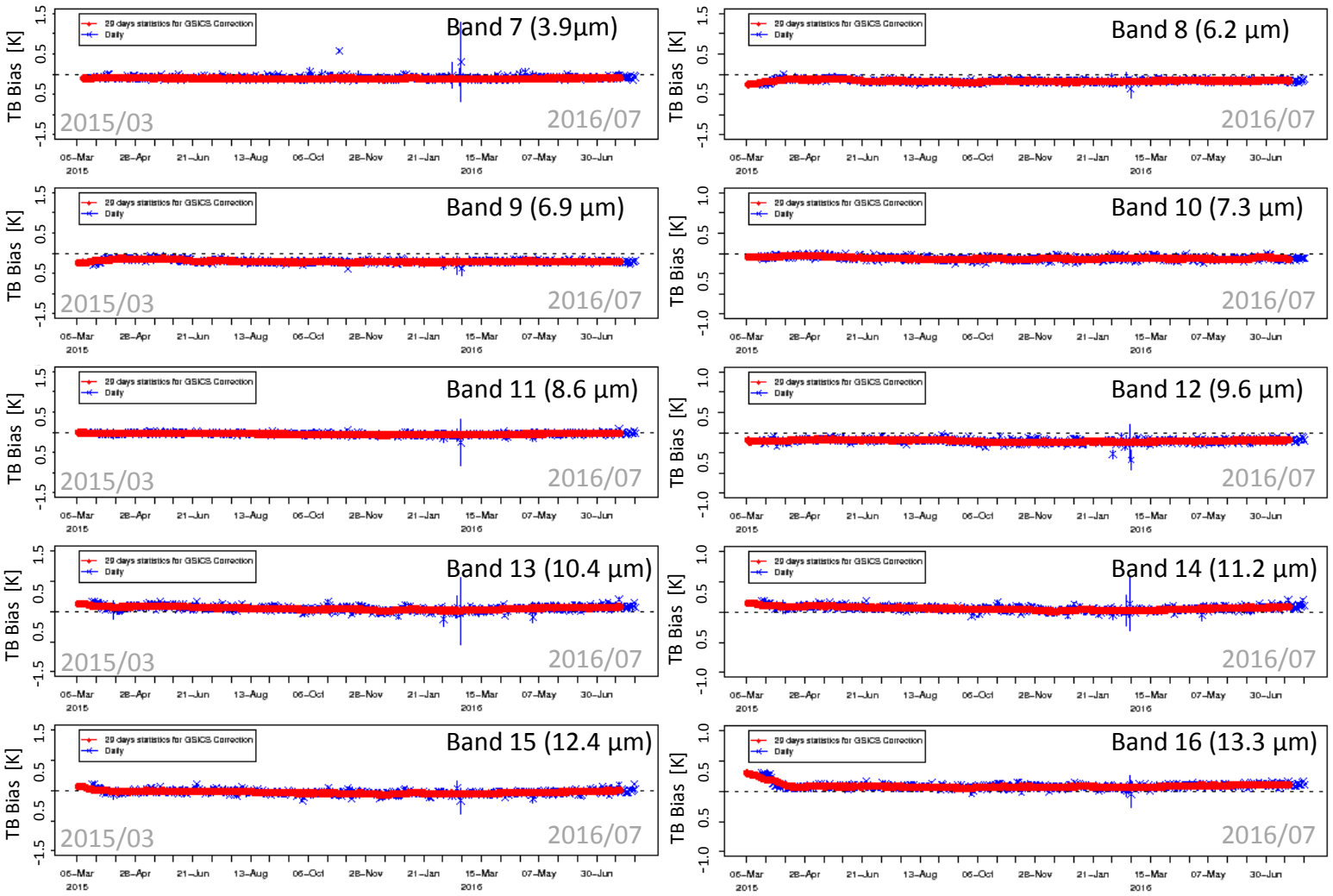


Full Disk Observation every 10 min.

Region 1	Region 2	Region 3	Region 4	Region 5
2000 x 1000km (NE Japan)	2000 x 1000km (SW Japan)	1000 x 1000 km (Target Area)	1000 x 500 km (Landmark Area)	1000 x 500 km (Landmark Area)
Every **2.5 min.**	Every **2.5 min.**	Every **2.5 min.**	Every **30 sec.**	Every **30 sec.**

TB bias trend is stable, less than 0.2K

Tb bias at standard scenes



Standard scene: typical brightness temperature defined as 1976 US Standard Atmosphere at nadir, at night, in clear sky, over the sea with SST=288.15K and a wind speed= 7m/s. It is computed by radiative transfer model, RTTOV.

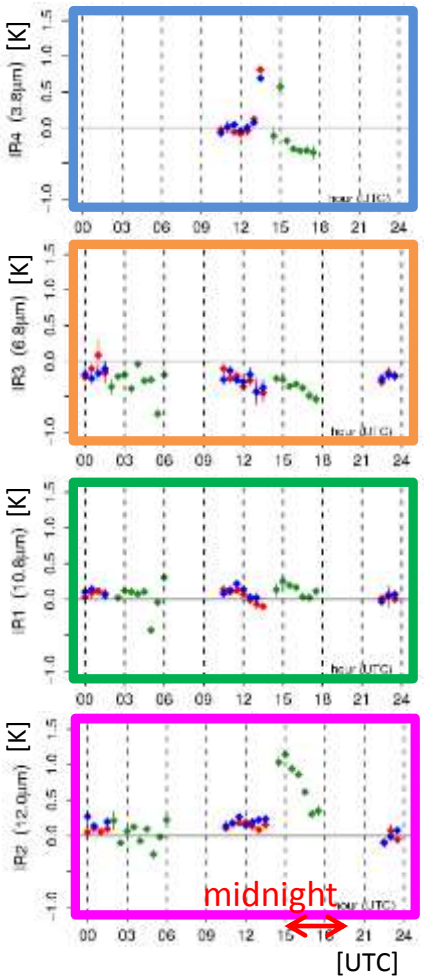
Time dependence of TB biases

Monthly statistics in February 2016

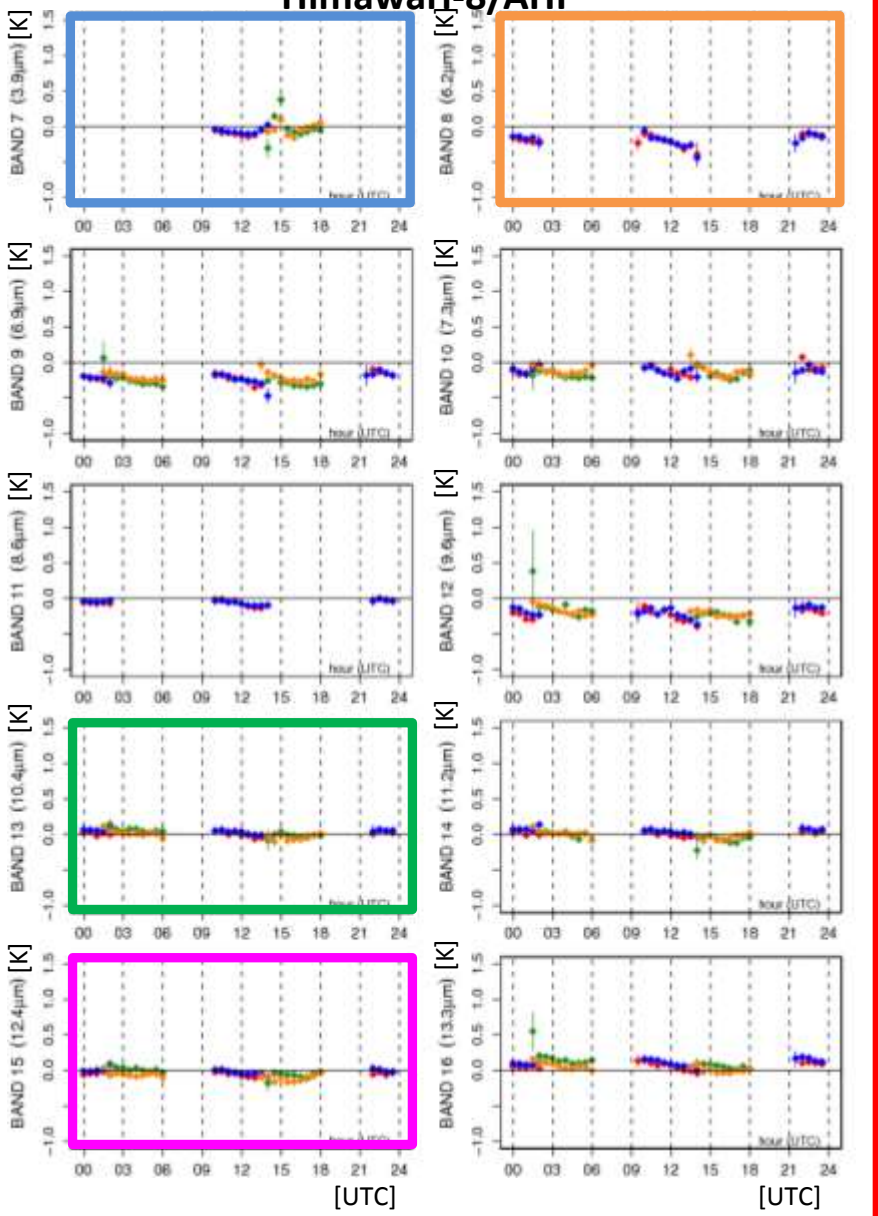
- No significant diurnal variation in Himawari-8

Reference sensors:
- Metop-A/IASI
- Metop-B/IASI
- Aqua/AIRS
- S-NPP/CrIS

MTSAT-2/Imager



Himawari-8/AHI



Updates of Himawari-8 Ground Processing System

Ground processing module was updated in March 2016.

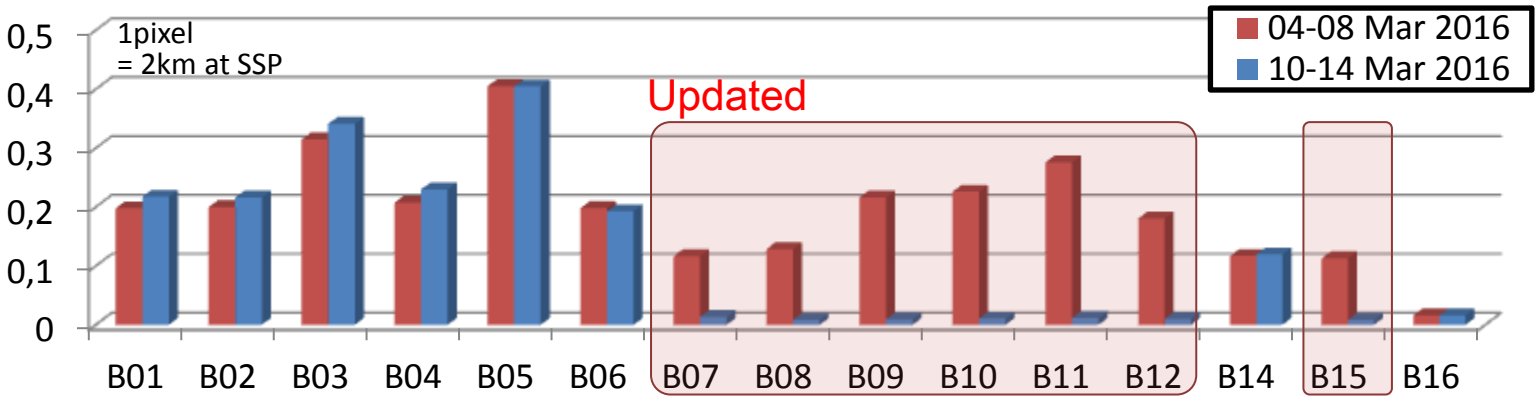
1. Improvement of the band-to-band co-registration process for IR bands
2. Improvement of the resampling process
3. Implementation of a coherent noise reduction process
4. Bug fix for HSD header information

The updates improved Himawari-8 image quality.

Ground Processing System Update – Band-to-band Co-registration Process for IR Bands

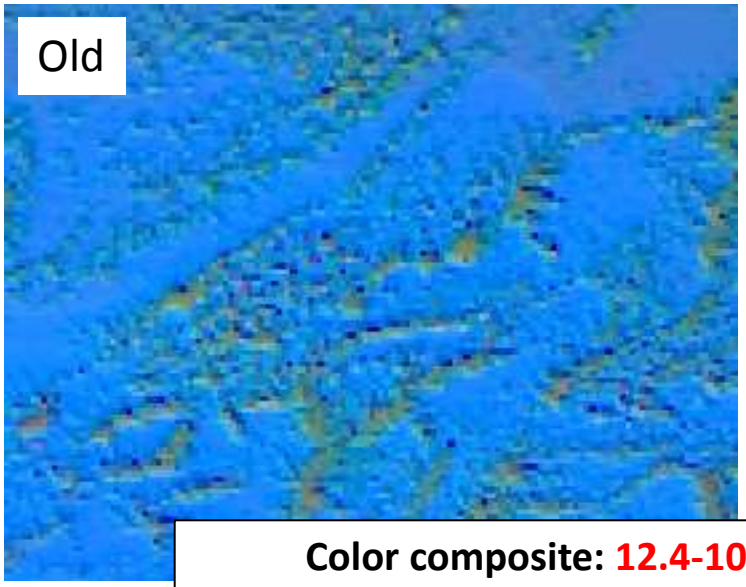
- **Applied bands: IR bands 7, 8, 9, 10, 11, 12 and 15**
- **In the old process, co-registration correction was estimated:**
  - ✓ Based on co-registration errors from pattern matching during **in-orbit testing**
  - ✓ VNIR and Band 7 (3.9μm): optimized using AHI's temperature
  - ✓ IR except Band 7: constant
- **In the new process: (applied in March 2016)**
  - ✓ Based on the co-registration errors of previous full-disk observing cycle w/o optimization
  - ✓ Change of pattern matching method and a bug fix to determine its domain is also included
  - ✓ Significant error reduction (e.g. ~0.2km -> ~0.02km in band 15)
    - New process would also be applied to remaining bands in future
- **The new process will be applied to VIS/NIR , IR bands 14 and 16: (Planned Shortly)**

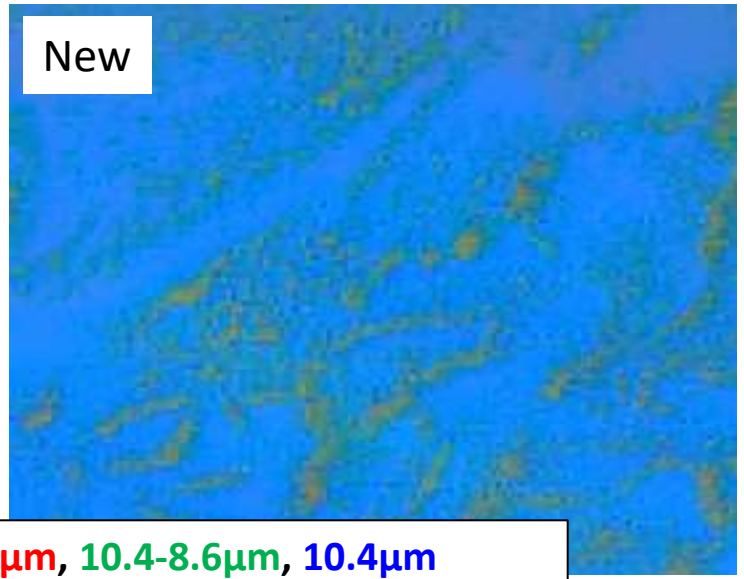
Band-to-band co-registration errors w.r.t. **band 13 (10.4 μm)** observation



Ground Processing System Update – Resampling Process

- **Applied bands: All bands**
- **In the old process:**
  - ✓ Unnatural spotted pixels in band-to-band differential imagery at the edge of clouds
  - ✓ Due to unoptimized resampling and large band-to-band co-registration errors
- **In the new process (refined resampling parameters)**
  - ✓ Band-to-band radiance inconsistency is significantly reduced
  - ✓ New band-to-band co-registration process also contributed to this improvement



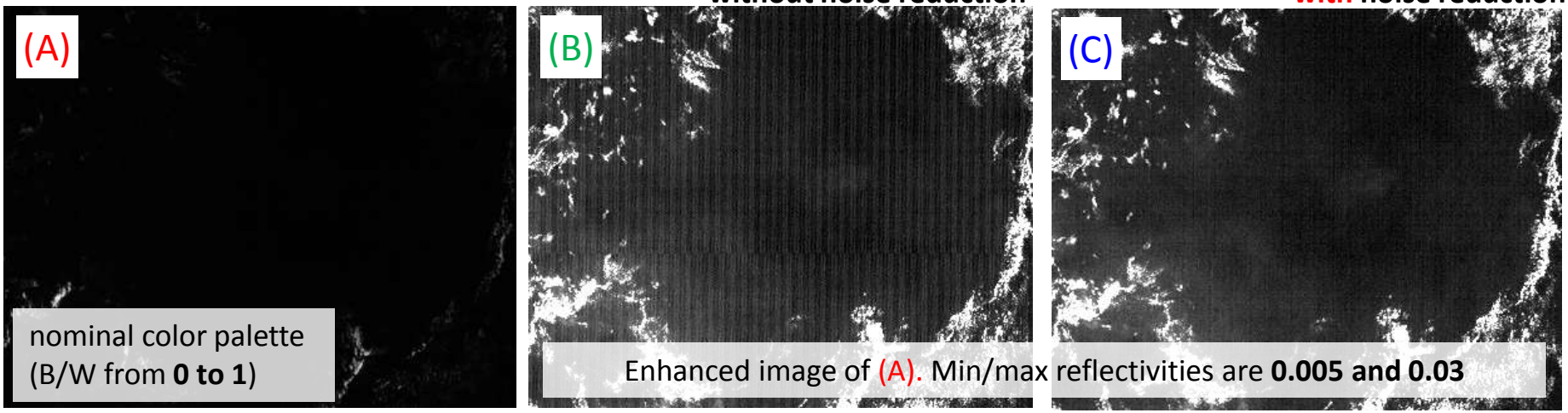


Color composite: 12.4-10.4µm, 10.4-8.6µm, 10.4µm
Dust RGB image at 00:10 UTC on 9 December 2015

Ground Processing System Update – Coherent Noise Reduction Process

- **Applied bands:** 1, 2, 4, 5, 6, 10, 11, 12, 13, 14, 15. Band 7 had been applied already.
- **What is the "coherent noise" and its reduction process?**
  - ✓ Stripes perpendicular to the scan direction over low-radiance areas
  - ✓ E.g. cloud-free ocean in VIS/NIR, deep convective cloud in IR and deep space in all bands
  - ✓ Noise reduction parameters: based on deep-space observation and the Fourier transform

Images with/without the noise reduction process



Band 4 (0.86 μm) 00:20 UTC on 25 November 2015

Summary

- Image navigation
  - Residual error in the HSD is less than ~1km
- Calibration
  - IR: very stable TB biases - less than 0.2K for standard scenes, no significant diurnal variation
  - VIS/NIR (reflectivity/radiance): less than +/- 3% for band 1-4 (0.46–0.86 μm) since June 2015, but +/- 4-6% biases still remain in band 5/6 (1.6 and 2.3 μm)
- Updates of ground processing system in March 2016
  - Band-to-band co-registration, resampling process, coherent noise reduction: significant improvement in image quality
  - The update will be applied to other bands shortly.

Acknowledgement

JMA is grateful to JAXA, NOAA, EUMETSAT, GSICS and researchers in Japanese universities for our collaboration on Cal/Val and products development.

- Back up

Overview – Planning of JMA satellite systems (Himawari-series)

GMS (Geostationary Meteorological Satellite)

GMS (Himawari)

Launched in Jul 1977

GMS-2 (Himawari-2)

Aug 1981

GMS-3 (Himawari-3)

Aug 1984

GMS-4 (Himawari-4)

Sep 1989

GMS-5 (Himawari-5)

Mar 1995

(GOES-9)

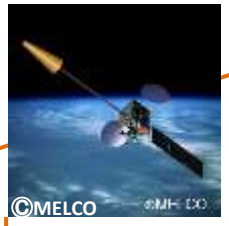
Back-up operation of GMS-5 with GOES-9 by NOAA/NESDIS from May 22, 2003 to June 28, 2005

MTSAT (Multi-functional Transport SATellite)

MTSAT-1R (Himawari-6)

Launched in Feb 2005

MTSAT-2 (Himawari-7)



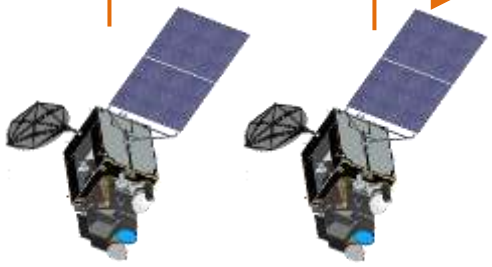
Feb 2006

Himawari-8 **Himawari-9**

Himawari

Oct 2014

2016



Satellite	Observation period
GMS	1978 – 1981
GMS-2	1981 – 1984
GMS-3	1984 – 1989
GMS-4	1989 – 1995
GMS-5	1995 – 2003
GOES-9	2003 – 2005
MTSAT-1R	2005 – 2010
MTSAT-2	2010 – 2015
Himawari-8	2015 – 2022
Himawari-9	2022 – 2029

Advanced Himawari Imager (AHI) on Himawari-8 Satellite

- Himawari-8 started operation on 7 July 2015
- AHI : new generation GEO imager
  - ✓ 3 VIS, 3 NIR and 10 IR bands
  - ✓ Full disk observing cycle: 10 min., rapid scanning within 2.5 min. / 30 sec. intervals

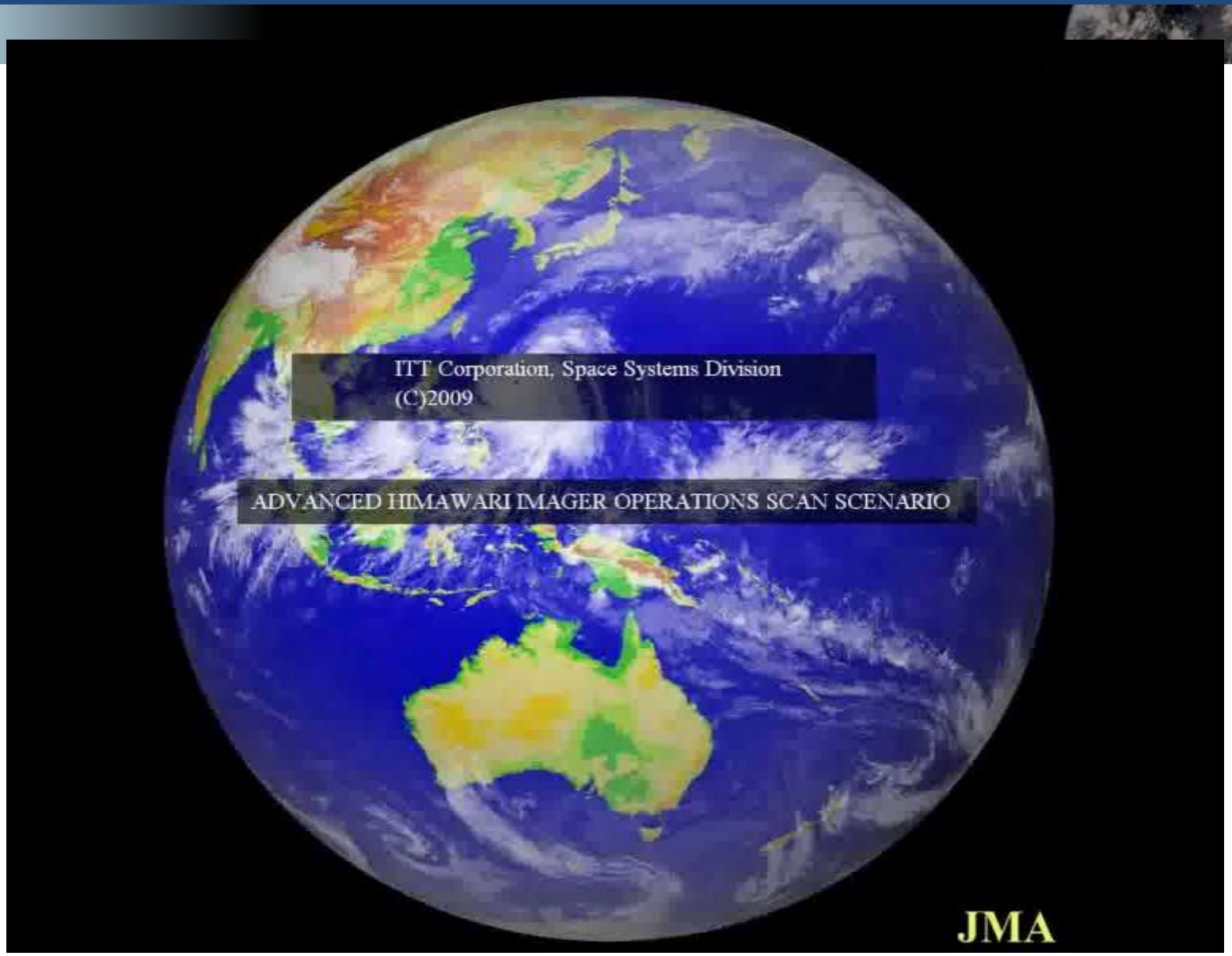
Band	Himawari-8/AHI			GOES-R/ABI		MTSAT-2/IMAGER	
	Wave length	Spatial resolution	Bit depth	Wave length	Spatial resolution	Wave length	Spatial resolution
1	0.47 μm	1km	11	0.47 μm	1km		
2	0.51 μm	1km	11				
3	0.64 μm	0.5km	11	0.64 μm	0.5km	0.68 μm	1km
4	0.86 μm	1km	11	0.86 μm	1km		
				1.38 μm	2km		
5	1.6 μm	2km	11	1.61 μm	1km		
6	2.3 μm	2km	11	2.26 μm	2km		
7	3.9 μm	2km	14	3.90 μm	2km	3.7 μm	4km
8	6.2 μm	2km	11	6.15 μm	2km	6.8 μm	4km
9	6.9 μm	2km	11	7.00 μm	2km		
10	7.3 μm	2km	12	7.40 μm	2km		
11	8.6 μm	2km	12	8.50 μm	2km		
12	9.6 μm	2km	12	9.70 μm	2km		
13	10.4 μm	2km	12	10.3 μm	2km	10.8 μm	4km
14	11.2 μm	2km	12	11.2 μm	2km		
15	12.4 μm	2km	12	12.3 μm	2km	12.0 μm	4km
16	13.3 μm	2km	11	13.3 μm	2km		

Spectral Bands

#	Himawari -8/ AHI	GOES-R/ ABI	GK-2A/ AMI	MTG/ FCI	FY-4/ AGRI	MTSAT-2/ IMAGER	GOES-15	GOES-11	MSG/ SEVIRI	SNPP,JPSS/ VIIRS	Terra, Aqua/ MODIS	NOAA/ AVHRR
1	0.47	0.47	0.455	0.444	0.47					0.488 (M03)	0.488	
2	0.51		0.511	0.510						0.555 (M04)	0.531	
3	0.64	0.64	0.642	0.640	0.65	0.68	0.65	0.65	0.635	0.672 (M05) 0.64 (I01)	0.667	0.630
4	0.86	0.86	0.860	0.865	0.825				0.81	0.865 (M07) 0.865 (I02)	0.870	0.862
				0.914							0.905	
		1.38	1.38	1.380	1.375					1.378 (M09)	1.375	
5	1.6	1.61	1.61	1.610	1.61				1.64	1.610 (M10) 1.61 (I03)	1.640	1.61
6	2.3	2.26		2.250	2.25					2.250 (M11)	2.130	
7	3.9	3.90	3.85	3.80	3.75	3.7	3.90	3.90	3.92	3.70 (M12) 3.74 (I04)	3.750	3.74
8	6.2	6.15	6.24	6.30	6.25	6.8	6.55	6.75	6.25		6.715	
9	6.9	7.00	6.95		7.1							
10	7.3	7.40	7.34	7.35					7.35		7.325	
11	8.6	8.50	8.60	8.70	8.5				8.70	8.55 (M14)	8.550	
12	9.6	9.70	9.63	9.66					9.66		9.730	
13	10.4	10.3	10.43	10.50	10.7	10.8	10.70	10.70	10.8	10.763 (M15)		10.80
14	11.2	11.2	11.20		11.0					11.45 (I05)	11.030	
15	12.4	12.3	12.30	12.30		12.0		11.95	12.0	12.013 (M16)	12.020	12.00
16	13.3	13.3	13.30	13.30	13.5		13.35		13.4		13.335	

* Some picked up bands are shown for MODIS, VIIRS

AHI Scan Scenario



Ground Processing System Update – Band-to-band Co-registration Process for IR Bands

- **Old process to estimate co-registration correction:**
  - ✓ Based on co-registration errors from pattern matching during **in-orbit testing**
  - ✓ VNIR and Band 7 (3.9μm): optimized using AHI's temperature
  - ✓ IR except Band 7: constant
- **New process applied to IR bands 7, 8, 9, 10, 11, 12 and 15: (on March 2016)**
  - ✓ Based on the co-registration errors of previous full-disk observing cycle w/o optimization
  - ✓ Change of pattern matching method and a bug fix to determine its domain is also included
  - ✓ Significant error reduction (e.g. ~0.2km -> ~0.02km in band 15)
    - New process would also be applied to remaining bands in future
- **New process applied to VIS/NIR , IR bands 14 and 16: (Planned Shortly)**

Band-to-band co-registration errors w.r.t. band 13 (10.4 μm) observation

BAND	01	02	03	04	05	06
BEFORE	0.1977	0.1996	0.3144	0.2074	0.4048	0.1979
AFTER	Expected to be less than half roughly					

Units in IR pixel size
(1pixel = 2km at SSP)

BAND	07	08	09	10	11	12	13	14	15	16
BEFORE	0.1162	0.1284	0.2159	0.2256	0.2756	0.1803	-	0.1168	0.1130	0.0159
AFTER	0.0134	0.0084	0.0091	0.0104	0.0115	0.0098	-	similar order of other bands	0.0081	in the same order

- "BEFORE" and "AFTER": averages of all full-disk data 4-8 and 10-14 March 2016
- VIS/NIR bands: daytime averages (21:00-08:50 UTC)

Data dissemination/distribution methods

Two Ways of Himawari-8/9 Imagery Dissemination/Distribution

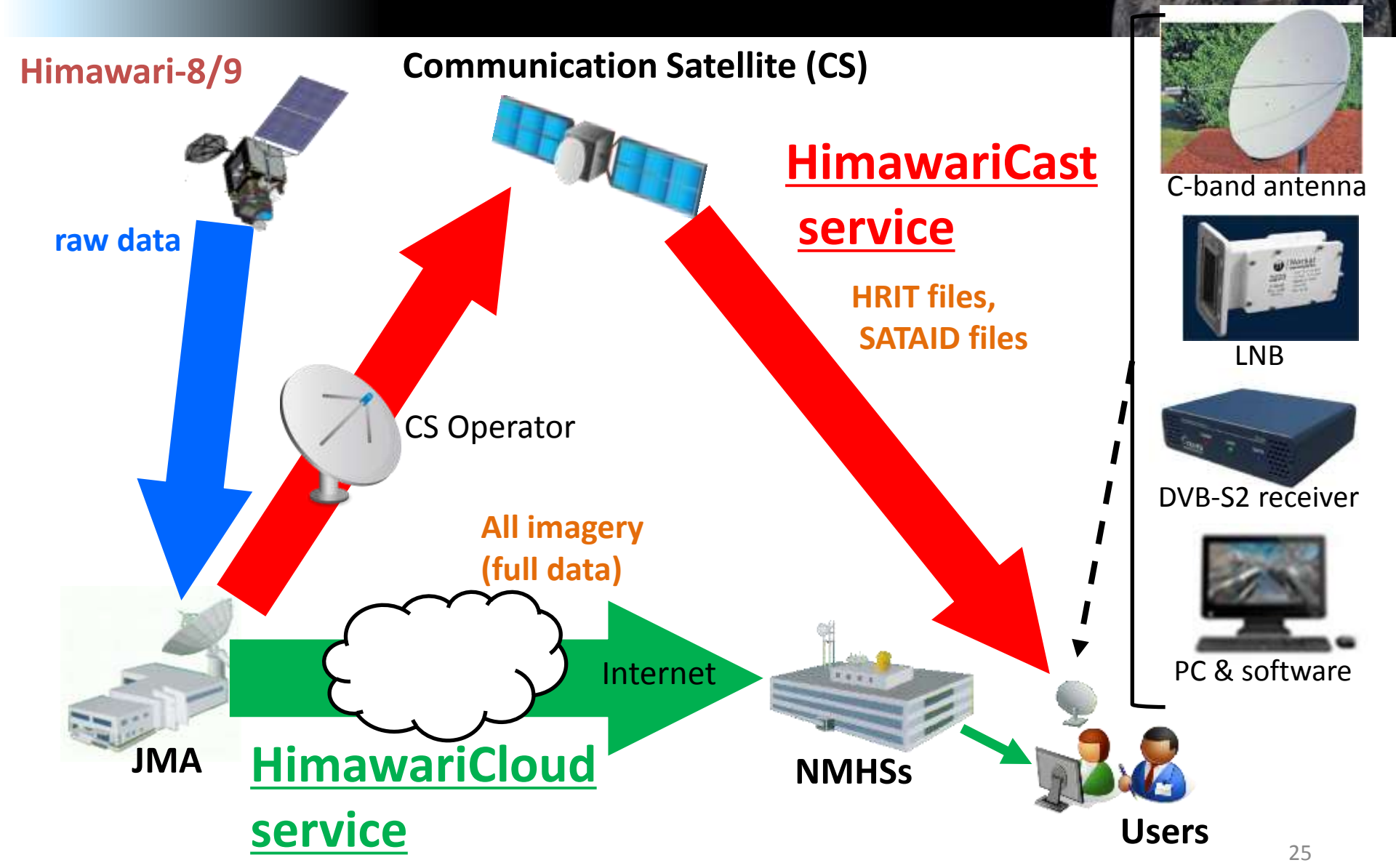
HimawariCast via Communication Satellite

- **14 bands** (1 Vis. And 13 IR) every **10 minutes** for Full Disk
- Coarse Spatial Resolution as of MTSAT **HRIT compatible**
- Meteorological data and products in **SATAID format**
- **No Pass Code** for Receiving

HimawariCloud via Internet Cloud

- **Full Specification** (temporal and spatial) of Imagery
- Himawari Standard Format
- HRIT files(same as the ones disseminated via HimawariCast)

Data dissemination/distribution methods



AHI navigation process

- Orbit/Attitude determination
  - Himawari-8's orbit determination is based on ranging data.
  - The satellite attitude determination involves the use of star trackers and gyros.
  - The attitude of the imager is not necessarily the same as that of the satellite itself due to the effects of misalignment and/or thermal distortion.

- Refinement of the attitude
  - Absolute error:
    - The attitude is refined using landmark analysis based on pattern matching for coastlines. This process is applied a reference band.
  - Relative (band-to-band) error:
    - Band to band co-registration error is estimated by a pattern matching between the reference band image and a target band image.
  - The estimated error is reflected into satellite attitude.

- In ABI...
  - These process is similar to ABI. ABI use star sensing to refine the imager's attitude, but we use landmark analysis instead of the star sensing.

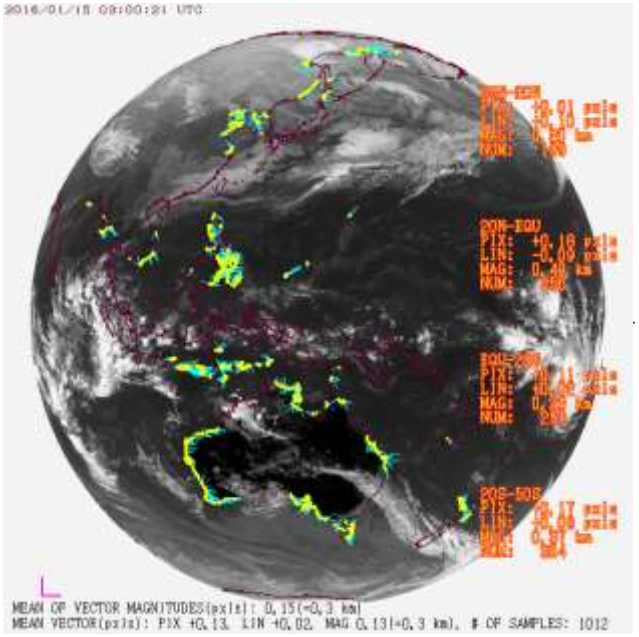
Based on "Himawari-8/AHI latest performance of navigation and calibration", Tasuku Tabata, et. al., Meteorological Satellite Ctr., Japan Meteorological Agency, 9881-94, SPIE Asia Pacific remote sensing, 2016

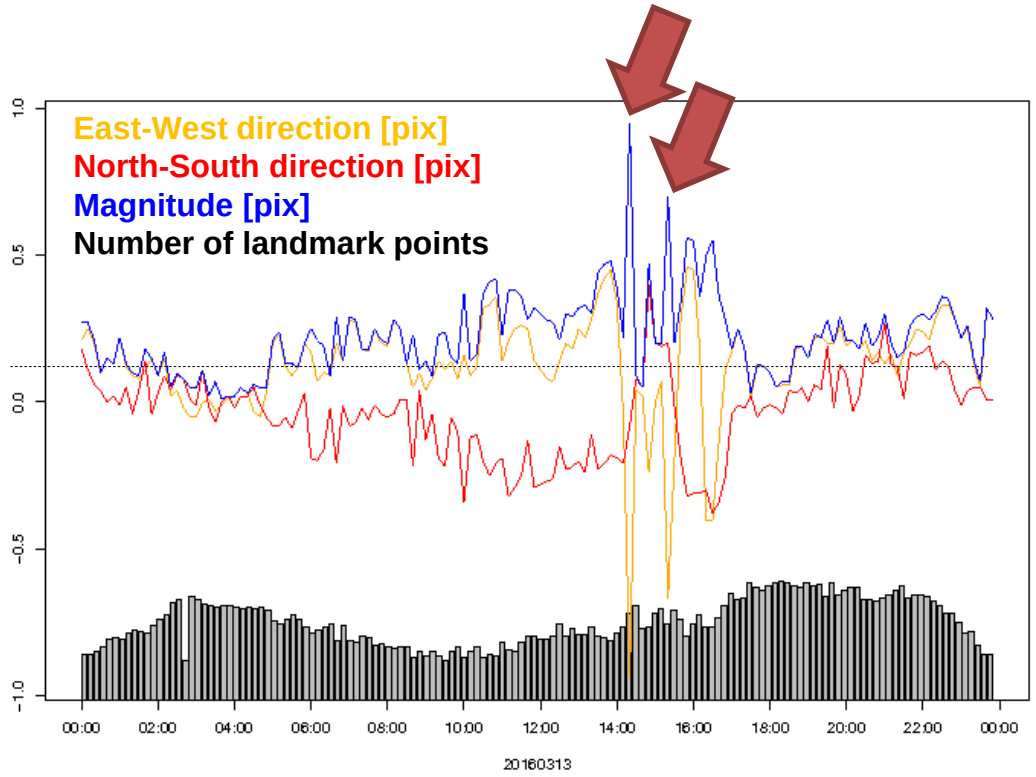
Validation of registration

- Approach
  - The residual image navigation error in Himawari Standard Data (HSD) is evaluated via landmark analysis.
- Error amount
  - The error is monitored and is usually less than 0.5 pixels (~ 1 km at SSP).
  - However, image navigation error occasionally and provisionally becomes larger in the next timeline of orbit determination after station keeping maneuver and the timing of satellite eclipse.

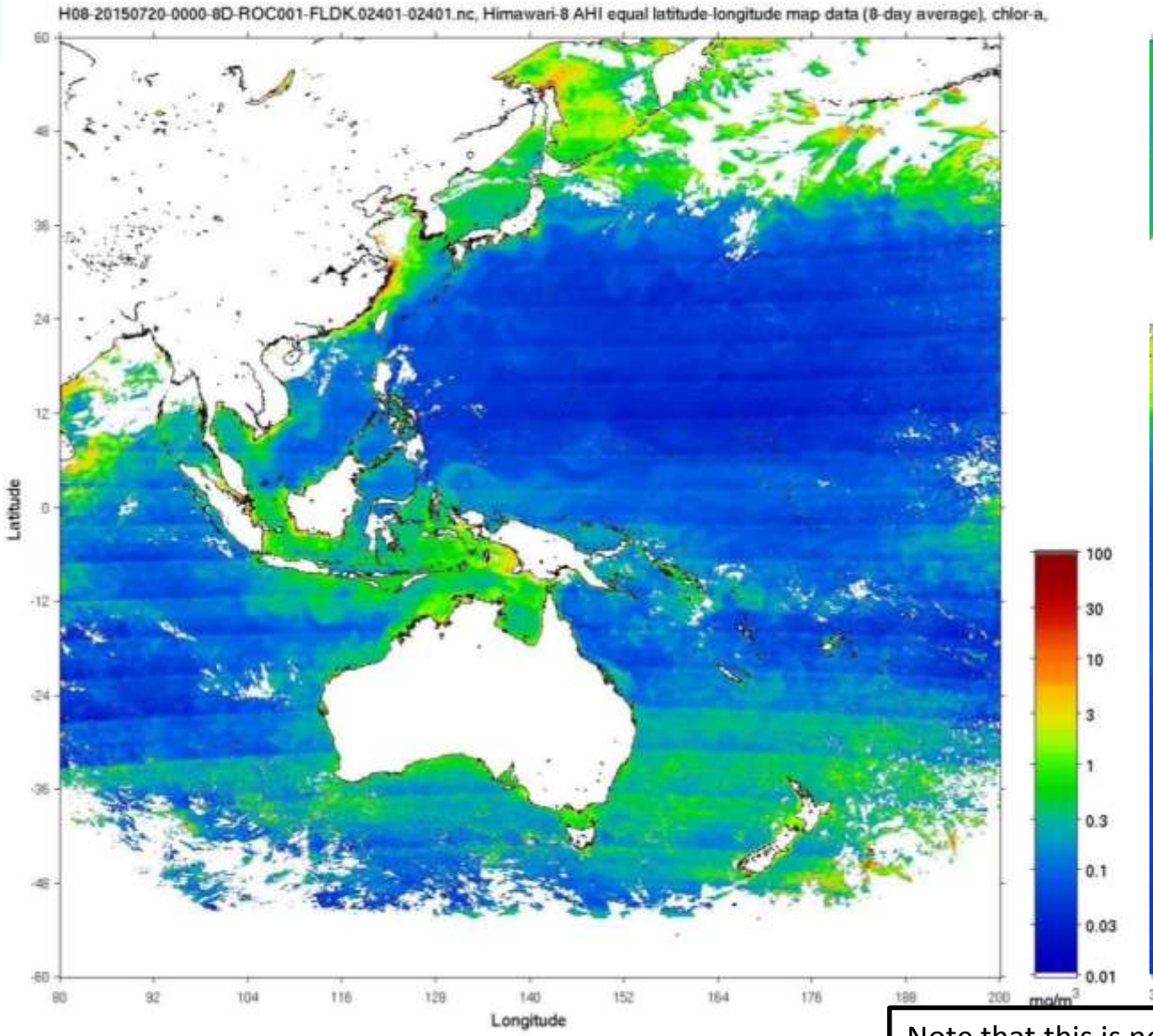
Validation of registration

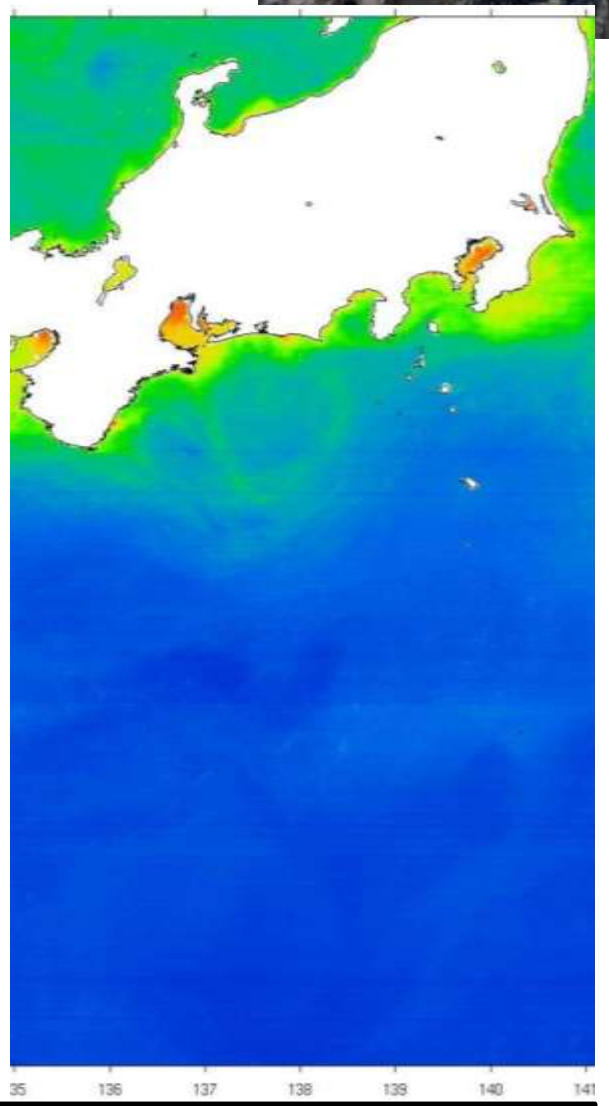
- Example: The exceptional large error
  - There are two spikes in the Figure.
  - The first: the timing of the sun disappearing behind the earth at 14:20 UTC
  - And the other: its re-emergence at 15:20 UTC.





3. Ocean color: Chl-a 2015/07/20-27 00:00-05:50 (AHI)





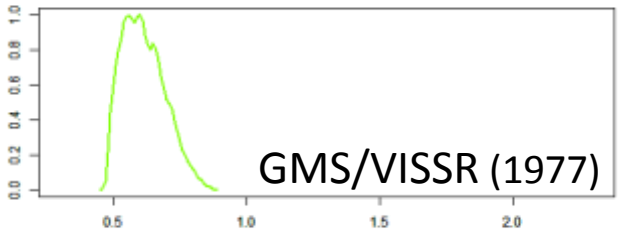
Hiroshi Murakami, "JAXA Himawari-8 Ocean Color and Aerosol", 2016 GSICS Data & Research Working Groups Meeting Mini Conference, 29 Feb.,2016

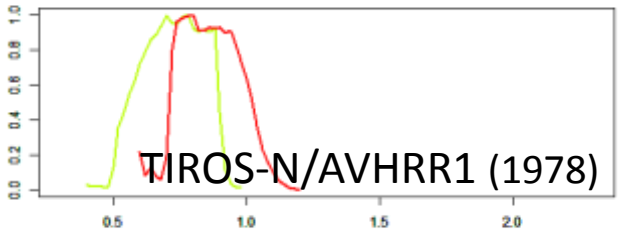
Note that this is not retrieved from one image but based on images in 1 week.

History of imagers' spectral response (VIS/SWIR)

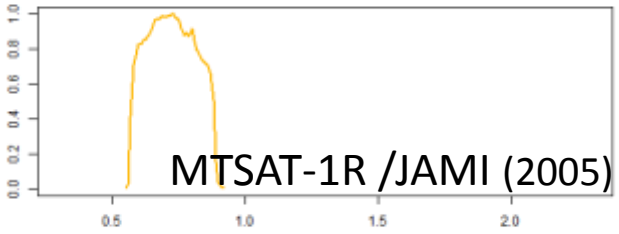
- GEO imagers' spectral resolution have gotten closer to the LEO imagers', in the new generation meteorological satellites.
- Now is a good time to use GEO imager in combination with LEO imager.

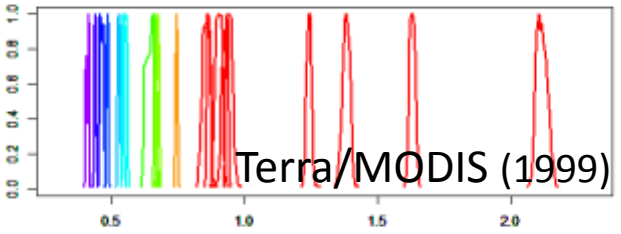
1980s



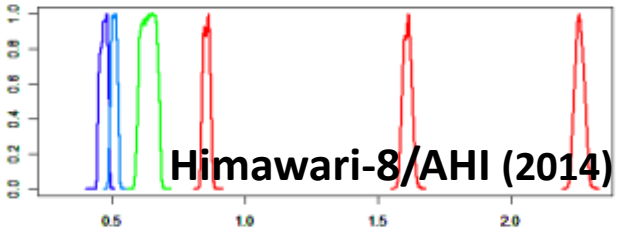


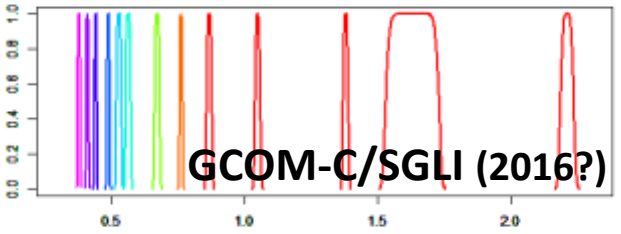
2000s





2010s+





AVHRR1: http://www.star.nesdis.noaa.gov/smcd/spb/fwu/homepage/AVHRR/spec_resp_func/index.html
MODIS: ftp://mcst.ssaihq.com/pub/permanent/MCST/PFM_L1B_LUT_4-30-99/L1B_RSR_LUT/
SGLI: http://suzaku.eorc.jaxa.jp/GCOM_C/w_sgli/c_sgli_prod_01.html